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The Conference Board and Growth and Development Center of the University of Groningen

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International Comparisons of R&D Expenditure: Does an R&D PPP make a difference?[1]

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Abstract

Estimates of purchasing power parities (PPPs) relative to the United States for R&D expenditure in 19 manufacturing industries are developed for France, Germany, Japan, the Netherlands and the United Kingdom in 1997 and 1987. These PPPs are used to estimate differences in international R&D costs and intensity. Current practice of comparing R&D expenditure across countries uses GDP deflators and PPPs. Compared to current practice the results differ substantially, but the results using our preferred R&D PPP are similar to those estimated using a Jaffe-Griliches type R&D PPP.

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1. Introduction

Concerns with science and technology (S&T) capabilities are widespread in the U.S. 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. In particular, the ratio of R&D expenditure to GDP or national income is often interpreted as a measure of innovativeness since it measures a nation's sacrifice of resources to achieve future technological change. Despite interpretation issues, trends and levels of R&D spending and R&D intensity measures are a key focus of policy discussions across the world. [2] In Europe, for example, governments at the Lisbon European Council, noted that European R&D expenditures are well below those of the U.S. and set a target to dramatically increase R&D spending from 1.9% of GDP to 3.0% by 2010.

The preferred measure for international comparisons of national effort devoted to R&D is a *real* R&D intensity measure, where R&D input is converted using input-specific PPPs and output is converted using an appropriate industry PPP. This is because the relative prices of R&D inputs and industry outputs vary across countries. The R&D PPP, which is a weighted average of various input PPPs, is the cost of a unit of R&D in a given currency.[3] It measures how much expenditure is necessary to acquire one U.S. dollar's worth of R&D inputs. Dividing R&D nominal expenditures for a country or industry by its R&D PPP produces comparable values across countries. In this sense, PPPs are comparable to price deflators that adjust nominal values for price changes to arrive at real, or volume, measures.

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

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[2] Policy discussions must also include consideration of the productivity and composition of these efforts, which differ across countries (and industries), as well as the magnitudes of the spillovers generated. These issues are not dealt with in this study.

[3] As rates of equivalence for comparable goods in local currency prices, PPPs have the same units as exchange rates. 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—e.g., 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 (NSF, 2002).

the early 1990s for the year 1985. Typically, the issue is either ignored because detailed price data is not available or a GDP PPP is used in cost comparisons. For comparisons of R&D intensity, nominal values are 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 on the lack of good information on the "price" of R&D in his remarks 20 years ago, on the occasion of the 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).

Ideally, R&D PPPs should correspond to actual differences in prices for the goods and services that are used in R&D, not an aggregate proxy such as GDP. While GDP PPPs at some level include prices of primary inputs to R&D – labor services, materials and capital goods – 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 and these prices often diverge because downstream prices include tax and distribution margins. Finally, use of GDP PPPs does not capture differences in the industrial composition of R&D across countries. And while use of industry-level ratios of R&D and gross output can partially address the composition issue, remaining distortions in prices can be a serious problem.

While the seriousness of the price measurement biases is not known, recent experience with industry-level PPPs from the ICOP project offers caution even for economies at similar levels of development. For many countries, industry output price levels are significantly different from overall GDP price levels (Van Ark and Timmer, 2001). Thus PPP adjustments – taking account of differences in the structure of relative prices across economies – may be worth the considerable effort required for their measurement. [4]

This paper brings together a wide range of statistical data to develop measures of the relative price of R&D for 19 manufacturing industries for six OECD countries – France, Germany, Japan, the Netherlands, the United Kingdom and the United States – where the U.S. is the base country. This exercise is undertaken for two benchmark years, 1997 and 1987. The data come from a variety of primary sources, principally national R&D surveys of business enterprises and collections of international prices. Interpretation of the data is guided by information collected in over 25 interviews of R&D executives at international affiliates of multinational companies in four of the most R&D-intensive industries. The interviews were invaluable in understanding issues of comparability of different countries' data, due to differences in reporting practices, tax regulations, and interpretations of R&D definitions, among other issues. Moreover, we gleaned important qualitative information that was useful in interpreting the implications of the results.

In the sections that follow, we first examine previous research on R&D PPPs and its limitations. Next we describe our development of estimates for 1997 and 1987. These PPPs are used to estimate differences in international R&D cost levels and intensity. We then assess differences with current practices. We find that our preferred estimate for the R&D PPP is similar to the Jaffe-Griliches alternative, which is far easier to estimate. Both measures differ substantially from the GDP PPP.

2. Previous research on R&D PPPs

This study is certainly not the first that attempts to tackle the problem of estimating PPPs for R&D. But, there has been relatively little effort, particularly compared to the volume of work carried out by official statistical agencies in the price index area, to create R&D PPPs. 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.

A key factor is that the output of R&D is not well defined. If R&D were a typical economic activity, like steel or cotton, then standard practices could be applied. However, the

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[4] The Frascati Manual (OECD, 1994) 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 since 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.

results of R&D often are ideas and other intangibles in the “hard-to-measure” area.[5] 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 indices, which can be used to assess differences in costs, assuming a unit of R&D generates comparable output of new technology and knowledge. This approach characterizes all the major studies from the 1960s onwards. [6]

2.1 Overview of earlier studies

Most of the literature approaches measuring the cost of R&D across countries by estimating prices for a basket of “standard” R&D inputs at the economy-wide level. Freeman and Young (1962) performed the first of these studies. Their work was undertaken before the first edition of the Frascati Manual in 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 today.

They 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 (1962) study, since the Department of Defense imposes similar budget

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[5] In related work, we are developing economic definitions of R&D and relating current changes in the patterns of R&D activity within the firm and across national boundaries to differences in research and development. We find that although research is for the most part intangible, development is quite different and has physical dimensions that are much more likely to be susceptible to more direct measurement.

[6] 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 et al., 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.

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 U.K.[7] He distinguishes between labor cost, other current cost and capital expenditure. For the countries 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 price relatives from trade statistics, with weights the aggregate quantities of these products. For other current expenditure, he assumes the exchange rate is applicable. Based on these figures, he finds the U.S. is around 40% more expensive and Japan 70% cheaper than the U.K.

In 1979 the OECD published a study, which showed calculations for R&D deflators for the period 1966-1976 and an R&D PPPs for 1970. They distinguish four cost categories: labor, other current costs, land and buildings and instruments and equipment. The labor PPP was calculated as the average labor cost per R&D worker. A PPP for other current expenditure was proxied as current government expenditure other than salaries, from International Comparisons Project (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 is Kiba, Sakum and Kikuchi (1994). The countries they cover are France, Germany, Japan and South Korea, with the U.S. as the base country. Their breakdown of cost categories is more refined than previous studies': they distinguish materials spending from other current expenditure and they break down capital expenditure into machinery & equipment, land & building and other assets. Since this fine a breakdown is not available for all countries, they use the data from countries that were available for those with no data.

Kiba et al.'s (1994) basic approach is to select prices parities from GDP final expenditures (ICP studies) to proxy each of the R&D input cost categories.[8] They select their

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[7] In Table 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 U.K. weights, in effect creating a Laspeyres-type index. Although the Laspeyres index has weaknesses, it is transitive.
[8] For other costs, multiple price parities are selected and the prices of inputs within each cost category are combined using the inputs GDP share to form an overall PPP.

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 input structure for the (market) R&D industry information could be very useful. However, our research indicates that this frequently is not the case for the R&D industry. 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 what facilities are deemed 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. 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.

2.2 Drawing lessons

The methodology for calculating these PPPs shows some common features. As 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 prevents this method from being implemented broadly. While Kiba *et al.* (1994) use ICP government and educational labor PPPs as a proxy for an R&D labor PPP, this is likely to be inferior to 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.

Calculating a PPP for the other current expenditure category is a problem because it is difficult to decide exactly what inputs are in this category. In general, there are two major groups, 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, frequently referred to as overhead costs, can include anything from building rent to scientific journals.

The procedure used by MacDonald (1973), assign 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. 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.

MacDonald (1973), OECD (1979) and Kiba *et al.* (1994) come up with capital PPPs using import and export prices. Unfortunately, these prices are not likely to 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, as is done by the OECD (1979) and Kiba *et al.* (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 economy-wide 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. Moreover, none of the studies calculates a Fisher-type index, which is the preferred method (Van Ark and Timmer, 2001).

Despite the various shortcomings of each study, the studies provide a similar bottom line. Table 1, which shows that the relative price of R&D compared to the United States had a strong upward trend between 1962 and 1985.[9] In the Table we focus on those countries that are included in this study. While R&D was less expensive outside the U.S. in every country, the gap narrowed substantially in the 20 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 U.S. 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.

[9] Some studies originally used a different base country, but all have been recast to use the U.S. as the base country to facilitate the comparison.

3. R&D PPP Estimation

This work is motivated by our 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 International Comparisons of Output and Productivity (ICOP) group has created databases of industry-level PPPs that are available for broad use, supplementing the ICP programs of the World Bank, the OECD and Eurostat (see Van Ark and Timmer, 2001 and OECD, 2003). 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, 1980, 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 is reported as a capital expenditure. 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 1 show that similar results are found despite large differences in data availability and methodology.

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. These industry R&D PPPs are then aggregated to the manufacturing level. In undertaking this work we follow the industry-of-origin approach.[10] The principal result of these calculations is two measures that we later use in assessing the cross-country differences. First, an R&D PPP, which measures the price of an R&D unit in a particular country relative to the price in the U.S. 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 U.S.

The R&D PPPs are 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,

$$PPP_L^{x,u} = \sum_i w_i^u PPP_i \tag{1}$$

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):

$$w_i^u = C_i^u \Big/ \sum_j C_j^u \tag{2}$$

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,

$$PPP_P^{x,u} = \sum_i w_i^x PPP_i \tag{3}$$

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

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 (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

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[10] The industry-of-origin approach is described in Gilbert and Kravis (1954), Van Ark (1993), Van Ark and Timmer (2001) and OECD (2003).

costs compared to the U.S., which is the base country in all the calculations. Thus, all of the comparisons are made on a bilateral basis. [11]

We now turn to the details of these calculations and their sensitivity to various assumptions and data.

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. These weights are available from national R&D surveys on an industry-specific basis. We use industry-specific R&D input prices for labor and materials and economy-wide prices for other current costs and capital. The industry R&D PPPs rely most heavily on comparions of R&D personnel wages, derived primarily from the national surveys. We develop independent estimates for the price of material inputs, other current expenditures, and capital using various databases and the industry-of-orgin approach. We also use some information based on the expenditure approach (Kravis et al., 1982; Heston and Summers, 1996) after making appropriate adjustments to "peel-off" estimated margins for transportation and distribution (Jorgenson and Kuroda, 1992; Van Ark and Timmer, 2001).

Table 2 gives an overview of measures and sources used for the R&D input prices for the preferred R&D PPP measure, which we label version (a): "lab+mat+OC+cap." While there is a wealth of additional detail available in the Appendix, we spend some time explaining the input price measures and weights used in our preferred measure and the variants we examine.

Labor

Labor is the largest component of R&D cost, at about 48% 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 each country and industry, we calculate the price of R&D labor by dividing R&D labor expenditures by the corresponding number of full-time equivalent R&D

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[11] In practice this could mean that some of our pair-wise R&D PPP estimates are not transitive. As it turns out, this is not a problem based on experiments with a multilateral version of the index.

personnel. These labor prices are then divided by the rate for the base country, yielding the relative price (PPP) for R&D labor.

This procedure implicitly weights each person employed by his or her individual compensation within country and industry. Data limitations prevent us from grouping employees by type and comparing them separately, with appropriate price parity, across country before they are aggregated to form a R&D labor price parity. However, in the interviews firms said that the biggest differences in compensation are across technical fields and these variations are likely to be picked up by average compensation in each industry. Firms also indicated that the capabilities of R&D personnel were 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.[12]

A major hurdle in developing R&D compensation rates was the U.S. R&D survey, which only collects data on the number 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.[13] In order to determine the number of support personnel in the U.S., 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 the Appendix. 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 (NSF, 1998) made a large downward adjustment in personnel count. 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.

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[12] 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 one available outside the U.S.

[13] Information on the number of technicians is also not (explicitly) collected in the U.S. However, we 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% of R&D expenditure. The interviews suggest that this category is typically composed of the products of its own industry since a majority of the expenditures are for prototypes of new products. Therefore, we use own-industry output prices, adjusted for margins so that they represent the prices own-industry goods used as inputs.[14]

It was more difficult to identify prices for other current costs, but they are important at 23% of R&D expenditure. According to our interviews, this category includes an array of goods and services typically described as "overhead." Firms include such items as communications services, rent, utilities, and non-capital 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.[15] However, this information is not industry-specific. Since we do not have any information about the expenditure shares within this category, we use an unweighted average of 11 price "headings." There is a wide range in the spread of the prices of these inputs so that 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. Some simple experiments suggest that the impact on the aggregate R&D PPP is not great. It was also difficult to develop prices for capital expenditures; they are, however, the smallest category of R&D expenditure, at 9%. We followed 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.

Weights (shares)

Weights for each of the four categories of inputs by country are shown in Table 3. Each of these expenditure shares for total manufacturing was built-up from industry expenditure shares from the national R&D surveys. In addition, the shares conform quite well to the financial information we obtained from the firm level interviews.

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[14] Since output PPPs do not have transportation and distribution margins, we add these margins back in using input-output tables, in order to treat these goods as inputs to the industry.

[15] 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.

There were two categories of expenditure where we had to make assumptions about the shares. First of all, France, Germany and the Netherlands do not collect information on the expenditure on materials and supplies. For these countries we assigned the average of the U.S., U.K., and Japan's shares of non-labor, non-capital expenditure.

The second expenditure category where we had to make assumptions about the shares was capital. Since the U.S. R&D survey only collects R&D depreciation, it is not comparable to the other five countries' R&D capital expenditures. Moreover, because accounting requirements for R&D (at least in the U.S.) restrict the capitalization of R&D-specific assets, depreciation is likely to be quite different for 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%, compared to a 9.2% average for the other countries. The 9.2% 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 basis for our assumptions about the R&D input prices and weights are described in the Appendix.

3.3 Preferred R&D PPP

Table 4 provides estimates of the R&D PPP and the price level or cost of R&D for each country. These price levels are 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 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. If the PPP is the same as the exchange rate, the price level equals 100.

Based on the preferred R&D PPP manufacturing R&D in Germany and Japan is 5% to 10% more expensive than the U.S. in 1997, while in France, Netherlands, and the U.K., R&D is 10% to 15% 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 R&D input categories at the level of total manufacturing are shown in Table 5 for each input category. Lower prices in France, Netherlands, and the U.K. can be traced to lower R&D labor prices and, to a lesser extent, lower material prices for France and the Netherlands. Germany and Japan's higher prices are attributable to the high price of other current costs, or "overhead" expenses. For both countries, wholesale and retail trade, and transportation and storage had the highest relative prices (see Appendix). In Japan insurance is also expensive, while in Germany electricity, gas and water are expensive.

The approximate magnitude of the price differences that we observe using the preferred R&D PPP are similar in character to those that we heard in 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% range are consistent with these observations.

Labor prices and inter-industry variation

Since labor represents the largest share of R&D and the data are R&D- and industry-specific it is worth looking at this input a little 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 industry-to-industry. As shown in Table 6, labor costs do vary considerably across industries, and particularly across countries, even within industries.

Inter-industry variation is illustrated by the coefficients of variation (C.V.) for R&D labor prices. These are especially wide for the Netherlands and U.K., where the C.V.s are 0.36 and .37, respectively.[16] The highest price industry in these countries is Coke and Petroleum refining, while among the lowest is the Office, Accounting, and Computing Machinery industry. France has the narrowest range of labor prices, with a C.V. of 0.16, reflecting a relatively more equitable distribution of compensation across industries. This is consistent with what we heard from firms in interviews.

An important question is whether the differences across industries are larger or smaller than the differences across countries. We performed a two-way ANOVA and found significant differences across both industries and countries, with more of the variation coming from countries, than from 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

[16] Coefficients of variation are calculated as standard of deviation divided by the unweighted average of the industry PPPs.

in R&D labor prices across both countries and industries illustrate the importance of including R&D labor explicitly in R&D PPPs.

Non-labor input prices

The three remaining categories of input prices used in the preferred R&D PPP specification are materials, other current costs, and capital expenditures. Only the materials prices are industry-specific. They are shown in Table 7 and the variation in materials prices across industries is nearly as large as that for labor. The coefficient of variation across industries for each of the five comparison countries is 0.35 to 0.38. As with labor an ANOVA analysis shows that the differences across industries and countries are highly significant statistically.

Preferred R&D PPPs for 1987

Using the same methods and data sources, we estimate relative prices in 1987 for the same four categories of R&D inputs and aggregate them using R&D expenditure weights to derive a preferred R&D PPP. Although for some countries the source material is less extensive and detailed (mainly for the Netherlands), we are able follow very similar procedures. The results of this exercise at the level of total manufacturing are shown by country in Table 8.

Comparing the relative price levels for R&D shows that the U.K. is least expensive, 12% cheaper than the U.S., and France, Germany, and the Netherlands are most expensive, at 7% to 8% more expensive than the U.S.; Japan is nearly tied with the U.S. Lower R&D prices in the U.K. are driven most importantly by lower R&D labor prices, while higher prices in France, Germany, and the Netherlands can be linked to the high price of capital. The input category price levels are shown in Table 9.

3.5 Sensitivity of the R&D PPP; alternative measures

The main question for our interpretation of the results is the sensitivity of the R&D PPP to the assumptions we make. The accuracy of the R&D PPPs estimates depends on the appropriateness of the choices of price measures in each of the input categories, the comparability of those prices, and the similarity of the weights we use in aggregation.

Of the four R&D input categories, we are most confident in our measure of the price of R&D labor, since it is collected specifically for R&D within each industry and country, and is nearly comprehensive across countries.[17] The selection of appropriate price measures for the categories of materials, other current costs, and capital costs is more problematic. Nonetheless, our choices of price proxies were informed by interviews of R&D-intensive firms, enabling us to develop industry-specific prices for materials, and national prices for other and capital costs. The assumption of a national price is probably tolerable for these later categories.

In many respects the choices we face are simply echoes of the earlier studies. But here we decided to develop several alternative versions of the R&D PPP, and use them to ascertain the sensitivity of the resulting R&D PPP. Thus, in addition to the "Preferred" R&D PPP that is estimated based on specific input prices, we estimated three other versions, labeled (c) through (d), in addition to the current practice labeled (e). The specific input prices used in developing these alternative R&D PPP estimates are described in Table 10.

All of the alternatives use the same R&D and industry-specific measure of the price of R&D labor. They also all use the same weights for the individual inputs. Thus the only variations involve the input prices for the categories. Version (a), the preferred R&D PPP, uses the most detailed information on each of the four R&D inputs. Alternative (b) uses the GDP PPP to proxy the price of the non-labor inputs (thus referred to as "lab+GDP"). This alternative PPP is analogous to the Jaffe-Griliches R&D deflator for comparing R&D over time. It combines measures of the price of labor with a broader measure of economy-wide price changes (Jaffe, 1972; Griliches, 1984).[18] Alternative (c) adds the industry-specific materials price and uses the GDP PPP for the other two categories of inputs. Thus, it is referred to as "lab+mat+GDP." Alternative (d) uses the other cost proxy for both materials and other costs with capital being priced by the capital proxy. This is referred to as "lab+OC+cap." 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. Finally, we also show the current practice alternative (e), which is simply the GDP PPP as the price of all R&D inputs.

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[17] 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.

The use of these alternatives obviously does not cover the entire range of possible measurement errors. Although we do not have any systematic quantitative estimates, we examined some simple changes in assumptions within each of the alternative estimates to see if they produced major changes in the resulting R&D PPP. For instance, we excluded some outliers from the set of prices we use for other current costs in calculating Germany and Japan's preferred R&D PPP. This causes a drop in the input prices in the range of 6-13% relative to the U.S. But in such instances the resulting R&D PPPs are only affected by 1.0-3.5%. This result is typical of the tests we conducted.

When we use the Fisher PPP aggregation formula described above to aggregate prices across countries, large differences in the weights can also cause measurement error. This error is referred to as a Paasche-Laspeyres spread, and is typically large when countries have very different price structures. Since 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 spread is on the order of 2-3% in 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.

One final note regards the bilateral nature of the comparisons. Ideally, when making comparisons between more than two countries, PPPs should be re-aggregated to ensure that they are fully transitive. This can be done through an aggregation of the bilateral PPPs using a multilateral index number. We applied an EKS aggregation procedure to one set of 1997 industry-level results and found that the use of this multilateral method did not meaningfully affect the estimates (Dougherty et al., 2002). This is probably a result of the similarity of the price structures of the six OECD countries in this study that are all at a similar level of development.

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[18] The Jaffe-Griliches deflator originally referred to a proxy R&D price index for the U.S. that combined the hourly compensation index with a 51% weight and the implicit deflator for non-financial corporations with a 49% weight (Griliches, 1984). It has been interpreted more broadly to refer to a price index that equally weights R&D labor compensation and the GDP deflator (Mairesse, 199x). 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.

Alternative versions of the R&D PPP at the country level, 1997

Table 11 shows the different versions of the R&D PPP, labeled (a) through (d), and alternative (e), the GDP PPP used in current practice. As discussed above these alternatives make different assumptions about what prices to use to represent non-labor R&D input prices. The alternative R&D PPPs, (b) through (d), are quite similar to the preferred R&D PPP (a). They differ by 2.6 to 7.0 percentage points from the preferred specification (a) for each country except Japan. For Japan alternative (d) differs by 13 percentage points from preferred version (a). Except for that one outlier, the estimates are all within 7 percentage points of the preferred R&D PPP. Alternative R&D PPP (b), which combines R&D labor and the GDP PPP, yields results that are within about 6.5 percentage points of the preferred R&D PPP (a). Recall that alternative (b) is the Griliches-Jaffe version of the R&D PPP and this is also perhaps the most straightforward to compute since it only requires the price of R&D labor in addition to the price level of GDP.

In sharp contrast, the current practice of using the GDP PPP by itself yields substantially different results from the preferred measure. Compared to the preferred R&D PPP (a), current practice version (e) varies by more than 15 percentage points on average and by as much as 28.4 percentage points in the case of Japan. Only for Germany are the results similar to 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.

Alternative R&D PPPs at the industry level, 1997

R&D PPPs using the preferred version (a) and alternative (b) are shown for individual industries in Table 12. The coefficient of variation is about the same for both R&D PPP versions, and we see 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 correlation between the two sets of price levels (a) and (b) is 0.96. If we correlate the industry-specific prices with GDP PPPs by themselves, the correlation is only about 0.5.

These results suggest that it is important that the R&D be industry-specific, but not 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, the alternative (b) that combines R&D-

specific measures of the price of labor with the GDP PPP 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 compare the preferred R&D PPP and several alternatives with the GDP PPP, just as we did for the 1997 PPPs. Table 13 shows the different versions of the 1987 R&D PPPs, labeled (a) through (d), and summarizes the key findings.

The alternative R&D PPPs, (b) through (d), are again quite similar to the preferred R&D PPP (a). They differ by 0.9 to 9.2 percentage points from the preferred R&D PPP for each country except Japan. As before Japan is the outlier differing by 12 percentage points for alternative (b). While the differences between alternative (b) and (a) are somewhat greater in 1987, they are still within about 10 percentage points. Interestingly, in 1987 most of the PPP levels are lower using the preferred alternative. The reverse was true in 1997.

The current practice of using the GDP PPP by itself yields quite different results. The preferred R&D PPP (a) varies on average by over 17% from the price level of GDP, and as much as 45.7% in the case of Japan. The size of these differences again suggests that the use of R&D PPP yields comparative prices that vary substantially from the current practice of using GDP PPPs, even at the level of total manufacturing.

We tried to compare these results with those of Kiba et al., (1992) by using exchange rate and GDP deflator adjustments to put their results on the basis of 1987 prices. The results of this exercise were substantially different from ours, varying by 8.7 to 31.6 percentage points from the preferred alternative. We attribute the large differences to their use of economy-wide ICP prices for government and educational workers to proxy R&D labor rates, rather than the R&D-specific measure that we use.

Alternative R&D PPPs at the industry level

The R&D PPP for the preferred alternative (a) and alternative (b) versions of the index at the industry level are provided in the Appendix. As with the 1997 values shown earlier, there is substantial variation across industries and great similarity between R&D PPP versions (a) and (b). As noted earlier, the closeness of these alternatives is in large part due to the importance of labor cost variation. Arguably, alternative (a) is too difficult to calculate systematically year-by-year, but it is relatively simple to obtain (b) and this alternative provides R&D price levels reasonably close to the preferred ones. We come back to this issue in our closing comments.

3.6 Comparing the distribution of relative prices over time

With estimated R&D PPPs for two different points in time now in hand, we turn to an examination of changes in R&D cost (input price relative to the U.S.) over the 1987 to 1997 period. Table 14 shows a summary of the price levels for the preferred R&D PPP (a) and the percentage change (log-differences) in price level over the period 1987 - 1997, at the level of total manufacturing. The last column shows the change in price level holding exchange rates fixed. This is identical to the change in the underlying R&D PPP. Since the U.S. is the base country in each point-in-time comparison, by definition it does not show any change in price.

R&D cost moved in quite different directions depending on the country. In France and the Netherlands, R&D costs fell by 16.8% and 23.3%, respectively, relative to the U.S., over the decade. This meant that both countries went from being *more* expensive than the U.S. in 1987 to being *less* expensive in 1997. This change is primarily attributable to the drop in the relative cost of R&D labor in these two countries, but in the Netherlands the share of expenditure devoted to labor also increased from 44.4% to 50.8%.

Germany's relative R&D cost remained stable over the 10-year period, at about 8.5% more expensive than the U.S., as relative input prices and weights for labor and capital stayed roughly the same. Moreover, moderate changes in the relative prices for materials and other costs prices were mitigated by offsetting changes in their weights.

The U.K. had the largest increase in R&D cost, becoming 11.9% more expensive than the U.S. over the time period. But since it was 22% cheaper than the U.S. in 1987 (77.9), R&D in the U.K. remained 12% less expensive in 1997 (87.8). The convergence in R&D costs came from increases in the price of both labor and capital in the U.K.

The cost of R&D in Japan became somewhat more expensive over the 1987 to 1997 period, but unlike the changes in the other countries, this is primarily attributable to fluctuations in exchange rates (although labor prices did rise slightly). The underlying R&D PPP for Japan actually dropped from 144.0 to 130.5 Yen per U.S. dollar, a decline of 9.9%. But because the exchange rate appreciated from 144.6 to 121.0, the net change in the relative R&D price level for Japan is a positive 8.0%.

Comparison of changes over time in the R&D PPPs and current practice

Even though the relative cost levels are measured with error in each benchmark year, the errors come from the same sources and tend to cancel out for measures of change over time. This argument is often invoked in the context discussions of productivity growth estimates (for example, Hulten et al. (2001)). Since we used the same methodology and data sources in construction of the benchmarks, this argument would suggest that change estimates for the preferred measure are better in the time domain. But the argument will not carry over to the alternatives.

This argument can be made separately for each of the alternative R&D cost estimates, but it is not be valid for comparisons among them. The point-in-time comparisons of R&D PPPs with current practice suggest that the GDP PPPs do not provide a good approximation of our best estimate of the R&D PPP or its close approximation. Thus there is no reason to anticipate that the changes in the alternative will improve on the measured changes in the preferred measure. Nonetheless, we examine direct comparisons between the changes in the preferred and the alternatives to get an idea of the magnitude of the difference between "truth" and the alternatives.

Table 15 shows a summary of the price levels (relative costs) for the two R&D PPP versions and the current practice GDP PPP, at the level of total manufacturing. Percentage changes (log-differences) in the price levels from 1987 to 1997 are also shown. In each country except the U.K., alternative R&D PPP (b) exhibits changes in cost that are closer to that of the preferred R&D PPP than the current practice GDP PPP (e). Yet the changes in cost for both still differ from the preferred R&D PPP in both sign and magnitude. The current practice GDP PPP shows changes in sign that differ substantially from the preferred R&D PPP in two of the five comparison countries. The alternative R&D PPP differs in one country, but this is for Germany where the change in both measures is close to zero. The country where the measure of change in the alternative R&D PPP is furthest from the preferred R&D PPP is France. For this country, the difference between the change is 12.2 percentage points (-4.6% minus -16.8%), or 1.2%

annualized. This gap is primarily the result of non-labor R&D costs decreasing from 1987 to 1997 while the relative price level of GDP did not change much, as France maintained an 11-13% price premium on the U.S.

Changes in the alternative R&D PPP from 1987 to 1997 differ in magnitude from changes in the Preferred R&D PPP by 7.5% on average (0.7% annually), while changes in the current practice GDP PPP differ from the preferred R&D PPP by 10% (1.0% annually). Given that nominal growth rates of R&D are only a few percent per year, errors of this magnitude are quite significant. Jankowski (1993) created an R&D deflator for the U.S. using a similar approach to what we use for the R&D PPPs (alternative (b)), except in the time domain. He found that in the U.S., the GDP Deflator accurately tracked economy-wide changes in the price of R&D. While the relationship appears to be valid for the base country (the U.S.), if the domestic price of R&D does not follow GDP for the other five countries in this study, then the changes in the GDP PPPs will not match closely changes in the R&D PPPs.[19]

The differences among the alternatives appear to be stronger at the industry level, most likely since some of the variation is averaged out in the aggregation. The correlation between the preferred and alternative R&D PPP is very high (0.927), meaning that the alternative R&D PPP ("lab+GDP") does a good job of representing changes in R&D cost at the industry level. Thus, the alternative R&D PPP (b) not only performs well in matching the preferred R&D PPP price levels in 1987 and 1997, but also replicates the changes between them. For industry comparisons, there is little choice other than the preferred or alternative (b). The correlation of the preferred and current practice GDP PPP is only 0.05.[20]

The comparison at the level of total manufacturing suggests that over extended periods of time, there may not be a good substitute for the "Preferred" R&D PPP. While the "lab+GDP" Jaffe-Griliches R&D PPP (Alternative (b)) held up well in the point-in-time comparisons and does a good job of approximating industry-specific changes in price, it is not a very good substitute when making comparisons over the period of a decade. This result resonates with the

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[19] Due to a number of factors related to measurement error, price measurement methodology, and index number issues, benchmark comparisons of PPPs are not always consistent over time with price deflators (Hill, 2003).

[20] At the aggregate level, the correlation is higher between changes in price using the current practice GDP PPP and the preferred R&D PPP (0.57). But this correlation is still much lower than the correlation between the alternative (Jaffe-Griliches type) R&D PPP and the preferred (0.84).

common wisdom in ICP and ICOP work that says benchmark PPP comparisons need to be performed every 5 or 10 years in part to resolve discrepancies between point-in-time PPP comparisons and national accounts measures of price change. Therefore, a reasonable approach to creating a full set of R&D PPPs would be to compute the "Preferred" R&D PPP for benchmark years and then use the Jaffe-Griliches R&D PPP for intermittent years. This way, variations in the largest R&D input, labor, can be taken into account in all years and across industries, and changes in the price of other inputs can be updated from the benchmarks.

4. Real R&D intensities

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. Since such comparisons of R&D intensities often rely upon nominal figures to make comparisons, they are an important application where the results of this study may have an impact. We therefore examine the effect of R&D and output PPP adjustments on R&D intensities at the level of total manufacturing and for individual industries.

4.1 Adjusting R&D intensities for differences in price structure

Real R&D intensity measures require that R&D expenditure be deflated by the R&D PPP, and output by an appropriate output PPP. In this paper we have developed preferred and alternative R&D PPPs, both of which we employ. For output, the PPPs come from industry-of-origin studies conducted at the University of Groningen and The Conference Board (Van Ark, 1993; Van Ark and Timmer, 2001; Inklaar et al., 2002). These output PPPs are based on series of individual product prices from individual industries in each country. Output prices are based on comparisons of item-level matches of industrial census data. These matches are used to compute unit value ratios (UVRs) which are used as PPPs. When there are large numbers of product matches, UVRs yield reliable results.[21]

Real R&D Intensities and ranking

The nominal and real R&D intensities at the level of total manufacturing are shown in Table 16, for 1987 and 1997. The nominal R&D intensity that is used in current practice 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.[22] The difference between the real and nominal intensities results from two adjustments, one using the R&D PPP and the other the output PPP. These adjustments divide R&D expenditures by the R&D PPP and output by the output PPPs.

The U.S. R&D intensity is highest in all cases, even after the price adjustments.[23] The typical adjustment 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. This is true for both 1987 and 1997, except in Germany where it decreases very slightly in 1997. These results suggest that the efforts devoted to R&D in each country are in fact 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 U.K.: before adjustment, its R&D intensity is only 2.07% in 1987 and 1.92 in 1997 (in nominal terms). After adjustment, the U.K.'s R&D intensity is over one percentage point higher: 3.07% in 1987 and 3.09% in 1997 (in real terms). In 1997, these adjustments shift the rank of the U.K. from next-to-last among the six countries in this study to second place after the U.S., displacing Germany and Japan. The R&D PPP contributed about 1/3rd of the adjustment in this year.

One way to gauge the significance of these differences in intensity is to consider the magnitude of the challenge set by the Lisbon European Council. The Council set a goal of to increasing R&D from 1.8% of GDP to 3.0% by 2010. Since our measures are just for

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[21] However, in some high-tech industries, there are not very many matches and quality differences may arise. Research comparing the matched model approach with a hedonic approach to develop PPPs for motor vehicles has shown that there can be significant differences (Van Mulligen, 2002).
[22] 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 are similar and the changes in rank are identical.
[23] Since the U.S. is the base country in the PPPs, its own intensity does not change.

manufacturing, comparisons to GDP must be made with some care, but as a simple way to illustrate the importance of PPP adjustments it seems appropriate.[24]

Not only are the levels of R&D intensity affected by price adjustments, but also the *changes* in R&D intensity. From 1987 to 1997, nominal R&D intensity in France increased by 0.16 percentage points. This would be interpreted under current practice as increasing national effort to R&D. But real R&D intensity for France dropped by 0.12 percentage points, suggesting declining effort devoted to R&D. For Germany, the difference is even larger in magnitude. Here, nominal R&D intensity dropped by –0.21 percentage points from 1987 to 1997. But using real R&D intensity, the drop was –0.63 points.

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 prices. If we use industry-specific R&D PPP and output PPP price adjustments to adjust nominal industry-level R&D intensities, we get real R&D intensities for individual industries. As a result of the large variations in the R&D PPPs (because of large R&D labor price variation), output PPPs, and nominal R&D intensities across industries, these adjustments are often larger in percentage points than those at the total manufacturing level. The typical magnitude of price adjustment to industry-level R&D intensity is 0.63 percentage points in 1997.

A key question for the interpretation of these differences is how important are the adjustments in price compared with underlying differences in R&D intensity or effort. We use an ANOVA analysis to examine this question. Table 17 shows a two-way ANOVA between real and nominal R&D intensity among the six countries and 19 industries. The analysis demonstrates that the variation among industries is enormous, and statistically significant, while differences across countries are relatively small, and not significant. The variation among industries is 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 probably a result of internationalization of R&D and increased competitiveness due to globalization.

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[24] The intensities we show use gross output, the correct measure for sectoral analysis. If value added is used instead as the output measure, the nominal R&D intensity in each country is approximately three

5. Concluding Comments

This study developed R&D PPPs that are conceptually "correct" in that they are based on 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 at the level of individual industries for 1997 and 1987. Previous comparisons of R&D PPPs did not utilize such R&D-specific or detailed price and weight data as this study, nor did they use interviews to guide the application of their methodology. Thus the R&D PPPs we develop allow us to better evaluate the importance of having R&D-specific measures of R&D price across space.

Comparison of the current practice of using GDP PPPs in place of R&D PPPs with the "true" R&D PPPs do not support current procedures. While there is some netting of industry differences at the economy-wide 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 simply inappropriate. The differences in the levels of the R&D PPPs and GDP PPPs are very large and a substantial fraction of this can be traced to variations in the price of labor exist across industries. This led us to consider a relatively simple alternative to the preferred R&D PPP, one that can be readily calculated and that could easily be adopted by statistical agencies. Using the relatively easy-to-measure alternative R&D PPP based on a Jaffe-Griliches type index performs nearly as well as the "true" R&D PPP in approximating differences in R&D price across industries and countries.

While the most important sources of differences at the economy-wide level is still R&D labor cost, the other inputs to R&D can and do vary across industries. So by advocating this alternative, which focuses on labor cost, we are not suggesting that other inputs to R&D should be ignored.

For comparisons over time, fewer substitutes for a "true" R&D PPP are available. While industry-level changes in the "true" R&D PPP over time correlate well with those of the alternative R&D PPP, even differences at the total manufacturing level are large enough to cause significant errors of interpretation in R&D expenditures and even intensities. This suggests that periodic benchmark estimates of the "true" R&D PPP would be necessary to ensure that an

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times higher than with gross output, at the level of total manufacturing.

alternative R&D PPP that relied upon variations in R&D labor prices maintained a solid grounding over time.

Our results in the inter-spatial domain also suggest that inter-temporal R&D deflator work be given further attention. Given the differences between changes in the GDP PPP and the R&D PPPs, we suspect that Jankowski's (1993) finding of a correlation between GDP and the R&D deflator in the U.S. may not hold in other countries. 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 from ICOP. Further improvements in price measurement and ongoing harmonization of R&D statistics and survey instruments could make future comparisons easier. Rapid growth of global R&D activities makes it vital that accurate comparisons be made of R&D, regardless of where it is performed.

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TABLE 1
Previous studies of R&D PPPs -- R&D price levels (cost relative to the U.S.)*

Country	Freeman & Young 1962	Bruner** 1961-2	MacDonald*** 1963-4	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
Netherlands	52.6	-	66.7	68.1	-
U.K.	55.6	34.0	60.0	58.8	68.0
U.S.	100.0	100.0	100.0	100.0	100.0

**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. **Refers to research costs only. ***Price levels are converted to use the U.S. as base country (original study used the U.K. as base country).*

TABLE 2
R&D PPP input categories and price measures

R&D input category	Input prices: Measure	Input prices: Source	Industry-specific?	Avg. weight
1. Labor compensation	Average wages for R&D personnel	NSF/OECD	Yes	48%
2. Materials and supplies	Price of industry's output adj. for margins	ICOP	Yes	20%
3. Other current costs	Prices of overhead goods and services	ICOP/ICP	No	23%
4. Capital expenditure	Prices of plant and equipment	ICOP/ICP	No	9%
Total R&D*			Yes	100%

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

TABLE 3
R&D expenditure shares, total manufacturing, 1997

R&D input category	Shares of total manufacturing R&D expenditure						Average from Interviews**
	France	Germany	Japan	Netherlands	U.K.	U.S.	
1. Labor compensation	52.8%	61.7%	42.7%	50.8%	37.0%	44.9%	46.7%
2. Materials and supplies	18.8%*	14.7%*	20.3%	18.2%*	26.1%	21.3%	19.7%
3. Other current costs	21.3%	16.7%	27.3%	20.6%	24.8%	24.6%	24.4%
4. Capital expenditure	7.1%	6.9%	9.7%	10.3%	12.1%	9.2%*	9.2%
Total R&D cost	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

**See text for description of assumptions made to determine weights.*
***Average of 10 firms' expenditures that provided detailed financial data for total R&D in interviews.*
Source: National R&D surveys (NSF/OECD)

TABLE 4
Preferred R&D PPPs and R&D price levels (cost relative to the U.S.), total mfg., 1997

	France	Germany	Japan	Netherlands	U.K.	U.S.
Preferred R&D PPP (a):						
R&D (lab+mat+OC+cap)	0.81 €/$	0.96 €/$	130 ¥/$	0.75 €/$	0.54 £/$	1.00
Exchange rates*	0.89 €/$	0.88 €/$	121 ¥/$	0.88 €/$	0.61 £/$	1.00
*R&D price level:** *						
(cost relative to the U.S.)	91.0	108.5	107.8	84.6	87.8	100.0

**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 5

R&D input price levels (cost relative to the U.S.), total manufacturing, 1997

Input category	France	Germany	Japan	Netherlands	U.K.	U.S.
1. Labor compensation	84.6	97.1	87.9	75.0	61.7	100.0
2. Materials and supplies	86.1	116.2	95.2	85.6	126.0	100.0
3. Other current costs	102.9	131.1	169.2	95.3	105.4	100.0
4. Capital expenditure	114.7	121.4	107.0	118.4	105.7	100.0

Note: 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 6

R&D labor price levels (cost relative to the U.S. per unit of R&D labor) by industry, 1997

Industry	France	Germany	Japan	Netherlands	U.K.	U.S.	C.V.
Food, beverages & tobacco	77.9	71.6	78.1	76.3	71.1	100.0	0.13
Textiles, fur & leather	70.4	79.0	91.2	72.4	46.7	100.0	0.24
Wood, paper, printing & publishing	93.0	95.1	75.3	80.0	42.1	100.0	0.26
Coke, refining of petroleum products	95.2	82.0	110.0	177.9	132.3	100.0	0.30
Chemicals (excluding pharmaceuticals)	92.2	114.1	104.4	89.2	68.6	100.0	0.16
Pharmaceuticals	78.1	83.2	99.1	64.7	60.2	100.0	0.21
Rubber & plastic products	88.8	104.6	112.2	82.6	74.7	100.0	0.15
Non-metallic mineral products	106.4	111.4	98.1	-	62.8	100.0	0.20
Basic metals, ferrous	61.5	77.8	73.7	*62.7*	53.5	100.0	0.23
Basic metals, non-ferrous	93.1	93.2	103.8	*62.7*	77.0	100.0	0.18
Fabricated metal products	79.1	82.8	80.7	61.3	40.9	100.0	0.27
Machinery, nec	106.8	116.1	122.6	96.5	87.1	100.0	0.12
Office, accounting & computing mach.	69.4	63.8	*86.6*	46.2	25.3	100.0	0.41
Electrical machinery	86.4	95.8	106.3	*86.3*	60.2	100.0	0.18
Electronic equipment	97.5	96.5	*86.6*	*86.3*	60.8	100.0	0.16
Instruments, watches & clocks	74.1	68.7	59.6	*86.3*	41.7	100.0	0.28
Motor vehicles	68.1	94.4	80.6	*58.8*	60.3	100.0	0.23
Other transport equipment	107.6	164.8	132.5	*58.8*	69.8	100.0	0.37
Furniture, other manufacturing nec	80.2	76.4	149.1	-	-	100.0	0.33
Total manufacturing	84.6	97.1	87.9	75.0	61.7	100.0	0.17
Average across industries (unweighted)	85.6	93.2	97.4	79.4	63.1	100.0	
Coefficient of variation (C.V.)	0.16	0.25	0.23	0.36	0.37	0.00	

Note: 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 7
R&D material price levels by industry, 1997

Industry	France	Germany	Japan	Netherlands	U.K.	U.S.	C.V.
Food, beverages & tobacco	136.4	97.7	174.1	134.2	197.0	100.0	0.28
Textiles, fur & leather	170.4	166.8	133.6	166.4	243.4	100.0	0.29
Wood, paper, printing & publishing	111.8	99.2	141.9	76.3	135.7	100.0	0.22
Coke, refining of petroleum products	99.1	106.3	122.2	103.2	149.6	100.0	0.17
Chemicals (excluding pharmaceuticals)	108.1	108.4	144.6	108.4	158.2	100.0	0.20
Pharmaceuticals	105.2	109.2	141.0	102.8	149.3	100.0	0.18
Rubber & plastic products	88.9	110.5	93.9	86.6	125.7	100.0	0.15
Non-metallic mineral products	88.5	72.8	102.9	87.2	125.5	100.0	0.19
Basic metals, ferrous	109.2	100.5	112.8	108.2	151.0	100.0	0.17
Basic metals, non-ferrous	103.1	95.3	106.6	103.4	148.5	100.0	0.18
Fabricated metal products	92.5	87.0	145.6	88.8	133.0	100.0	0.23
Machinery, nec	74.8	120.1	98.5	73.3	101.1	100.0	0.19
Office, accounting & computing mach.	133.2	100.3	105.0	130.7	188.7	100.0	0.27
Electrical machinery	78.8	115.0	82.2	78.4	108.5	100.0	0.17
Electronic equipment	76.4	122.3	78.4	75.1	109.0	100.0	0.21
Instruments, watches & clocks	73.1	74.6	87.0	69.6	104.4	100.0	0.17
Motor vehicles	84.4	125.4	103.4	82.4	121.4	100.0	0.18
Other transport equipment	85.4	125.0	103.8	85.3	124.8	100.0	0.17
Furniture, other manufacturing nec	110.6	105.1	116.2	111.2	161.4	100.0	0.19
Total manufacturing	86.1	116.2	95.2	85.6	126.0	100.0	0.16
Average across industries (unweighted)	101.6	107.4	115.5	98.5	144.0	100.0	
Coefficient of variation (C.V.)	0.24	0.19	0.22	0.25	0.25		

Note: 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 8

Preferred R&D PPPs and R&D price levels (cost relative to the U.S.), total mfg., 1987

	France	Germany	Japan	Netherlands	U.K.	U.S.
Preferred R&D PPP (a):						
R&D (lab+mat+OC+cap)	0.99 €/$	1.00 €/$	144 ¥/$	0.98 €/$	0.48 £/$	1.00
Exchange rates*	0.92 €/$	0.92 €/$	145 ¥/$	0.92 €/$	0.61 £/$	1.00
*R&D price level:** *						
(cost relative to the U.S.)	107.7	108.4	99.6	106.8	77.9	100.0

**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 9
R&D input price levels (cost relative to the U.S.), total manufacturing, 1987

Input category	France	Germany	Japan	Netherlands	U.K.	U.S.
1. Labor compensation	91.7	96.1	81.0	91.1	48.4	100.0
2. Materials and supplies	129.5	123.0	120.1	114.5	115.7	100.0
3. Other current costs	119.2	120.8	117.7	114.0	105.0	100.0
4. Capital expenditure	131.1	125.4	103.7	142.2	116.0	100.0

Note: 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
Selection of input price measures for alternative versions of R&D PPP, by input category

<table>
<tr><th rowspan="2">R&D input category</th><th colspan="4">Price measure</th></tr>
<tr><th>Alternative (b)</th><th>(c)</th><th>(d)</th><th>(e)</th></tr>
<tr><td>1. Labor compensation</td><td>Labor price parity</td><td>Labor price parity</td><td>Labor price parity</td><td rowspan="4">GDP PPP*</td></tr>
<tr><td>2. Materials and supplies</td><td rowspan="3">GDP PPP*</td><td>Materials price parity</td><td rowspan="2">Other current price parity*</td></tr>
<tr><td>3. Other current costs</td><td rowspan="2">GDP PPP*</td></tr>
<tr><td>4. Capital expenditure</td><td>Capital price parity</td></tr>
<tr><td>Name of alternative:</td><td>"lab+GDP"</td><td>"lab+mat+GDP"</td><td>"lab+OC+cap"</td><td>"GDP"</td></tr>
</table>

*Notes: Price parity is price of good in comparison country divided by price of same good in base country (U.S.); The labor price parity and materials price parity are available at the level of specific industries. *Categories with the same price measure use the total weight of the merged categories for R&D PPP aggregation.*

TABLE 11
Comparison of price levels (cost relative to the U.S.) using preferred R&D PPPs and alternative R&D PPPs, total manufacturing, 1997

R&D PPP Version	France	Germany	Japan	Netherlands	U.K.	U.S.
Preferred:						
(a) R&D (lab+mat+OC+cap)	*91.0*	*108.5*	*107.8*	*84.6*	*87.8*	*100.0*
Alternatives:						
(b) R&D (lab+GDP)	*97.1*	*103.8*	*111.4*	*87.2*	*83.3*	*100.0*
(c) R&D (lab+mat+GDP)	92.5	104.4	103.7	84.6	87.1	100.0
(d) R&D (lab+OC+cap)	94.2	110.8	121.3	86.3	84.3	100.0
Current practice:						
(e) GDP (GDP PPP)	*111.4*	*112.3*	*134.7*	*100.9*	*103.2*	*100.0*
Difference between (a) and (b)	*+6.1*	*-4.7*	*+3.5*	*+2.5*	*-4.5*	
Difference between (a) and (e)	*+20.4*	*+3.8*	*+26.9*	*+16.3*	*+15.4*	

Note: Alternative R&D PPPs are described in Table 10.

TABLE 12

Price levels for R&D PPP using "Preferred" and Alternative methods by industry, 1997

(a) Labor + Materials + Other + Capital	France	Germany	Japan	Netherlands	U.K.	U.S.	C.V.
Food, beverages & tobacco	92.9	91.0	108.0	88.7	94.0	100.0	0.07
Textiles, fur & leather	93.5	102.4	114.2	91.4	82.0	100.0	0.11
Wood, paper, printing & publishing	99.7	106.0	103.9	85.6	76.5	100.0	0.12
Coke, refining of petroleum products	100.2	101.6	127.0	140.8	121.9	100.0	0.15
Chemicals (excluding pharmaceuticals)	98.7	118.8	125.1	95.7	91.7	100.0	0.13
Pharmaceuticals	92.3	102.8	126.5	83.1	92.6	100.0	0.15
Rubber & plastic products	94.9	113.2	120.8	90.6	93.8	100.0	0.12
Non-metallic mineral products	103.8	112.5	118.9	-	86.3	100.0	0.12
Basic metals, ferrous	78.8	93.7	103.3	80.4	75.2	100.0	0.14
Basic metals, non-ferrous	98.4	102.4	115.6	80.4	98.2	100.0	0.11
Fabricated metal products	88.4	95.9	107.3	74.5	72.3	100.0	0.16
Machinery, nec	100.1	119.8	125.1	94.1	95.5	100.0	0.13
Office, accounting & computing machinery	86.1	84.9	99.9	67.6	64.8	100.0	0.18
Electrical machinery	91.8	108.0	118.0	89.8	84.0	100.0	0.13
Electronic equipment	92.8	109.7	99.9	89.8	85.2	100.0	0.09
Instruments, watches & clocks	82.5	83.4	90.0	89.8	65.6	100.0	0.13
Motor vehicles	82.8	110.0	107.6	74.5	88.7	100.0	0.15
Other transport equipment	101.1	146.7	134.3	74.5	94.8	100.0	0.25
Furniture, other manufacturing nec	88.3	85.5	142.8	-	-	100.0	0.25
Total manufacturing	91.0	108.5	107.8	84.6	87.8	100.0	0.11
Average across industries (unweighted)	93.0	104.6	115.2	87.7	86.8	100.0	
Coefficient of variation	0.08	0.14	0.12	0.18	0.16	0.00	

(b) Labor + GDP	France	Germany	Japan	Netherlands	U.K.	U.S.	C.V.
Food, beverages & tobacco	92.7	87.6	101.7	86.2	85.7	100.0	0.08
Textiles, fur & leather	87.6	92.5	111.4	83.6	68.3	100.0	0.16
Wood, paper, printing & publishing	101.2	102.8	100.7	87.5	71.7	100.0	0.13
Coke, refining of petroleum products	103.5	96.6	122.9	140.8	113.4	100.0	0.15
Chemicals (excluding pharmaceuticals)	101.1	113.2	118.8	95.1	85.7	100.0	0.12
Pharmaceuticals	95.2	97.3	118.5	83.3	86.0	100.0	0.13
Rubber & plastic products	99.9	108.4	123.4	91.2	89.6	100.0	0.12
Non-metallic mineral products	109.0	111.8	117.4	-	82.9	100.0	0.13
Basic metals, ferrous	80.4	90.6	101.7	*79.3*	71.4	100.0	0.14
Basic metals, non-ferrous	100.7	101.5	119.2	*79.3*	90.0	100.0	0.14
Fabricated metal products	92.0	94.7	103.1	75.1	68.5	100.0	0.16
Machinery, nec	108.8	114.5	128.7	98.6	95.4	100.0	0.12
Office, accounting & computing machinery	85.8	82.1	*110.6*	65.5	58.1	100.0	0.24
Electrical machinery	98.2	102.9	122.1	*93.9*	82.5	100.0	0.13
Electronic equipment	104.0	103.1	*110.6*	*93.9*	80.7	100.0	0.10
Instruments, watches & clocks	88.8	83.4	92.5	*93.9*	65.0	100.0	0.14
Motor vehicles	89.7	103.2	110.7	*77.5*	84.4	100.0	0.13
Other transport equipment	109.7	138.0	133.9	*77.5*	89.6	100.0	0.22
Furniture, other manufacturing nec	88.7	84.1	143.8	-	-	100.0	0.26
Total manufacturing	97.1	103.8	111.4	87.2	83.3	100.0	0.11
Average across industries (unweighted)	96.7	100.4	115.4	88.4	81.6	100.0	
Coefficient of variation	0.09	0.13	0.11	0.18	0.16		

Note: Italicied figures cannot be fully disaggregated across industries shown.

TABLE 13
Comparison of price levels (cost relative to the U.S.) using preferred R&D PPPs and alternative R&D PPPs, total manufacturing, 1987

R&D PPP Version	France	Germany	Japan	Netherlands	U.K.	U.S.
Preferred:						
(a) R&D (lab+mat+OC+cap)	*107.7*	*108.4*	*99.6*	*106.8*	*77.9*	*100.0*
Alternatives:						
(b) R&D (lab+GDP)	*101.7*	*107.5*	*111.3*	*103.2*	*68.7*	*100.0*
(c) R&D (lab+mat+GDP)	106.5	108.4	103.9	105.1	76.3	100.0
(d) R&D (lab+OC+cap)	106.3	108.1	99.3	106.8	76.6	100.0
Current practice:						
(e) GDP (GDP PPP)	*113.2*	*122.6*	*145.3*	*115.3*	*92.1*	*100.0*
Difference between (a) and (b)	*-6.0*	*-0.9*	*+11.7*	*-3.6*	*-9.2*	
Difference between (a) and (e)	*+5.5*	*+14.2*	*+45.7*	*+8.5*	*+14.2*	

Note: Alternative R&D PPPs are described in Table 10.

TABLE 14
Price levels (costs relative to the U.S.) and changes in R&D PPP and exchange rates, total manufacturing, 1987 and 1997

	Preferred (a) "lab+mat+OC+cap"			Change
Country	1987	1997	Change	holding exchange rates constant*
France	107.7	91.0	-16.8%	-19.7%
Germany	108.4	108.5	0.1%	-3.7%
Japan	99.6	107.8	8.0%	-9.9%
Netherlands	106.8	84.6	-23.3%	-27.1%
U.K.	77.9	87.8	11.9%	11.6%
U.S.	100.0	100.0	0.0%	0.0%

*Note: Percent changes are log differences. *Change holding exchange rates constant is simply the change in the R&D PPPs from 1987 to 1997. This change is not affected by shifts in exchange rates over time.*

TABLE 15
Price levels (relative costs) and changes in R&D PPPs compared with current practice, total manufacturing, 1987 and 1997

	Preferred (a)			Alternative (b)			Current practice (e)		
	"lab+mat+OC+cap"			"lab+GDP"			GDP PPP		
Country	1987	1997	Chg.	1987	1997	Chg.	1987	1997	Chg.
France	107.7	91.0	-16.8%	101.7	97.1	-4.6%	113.2	111.4	-1.6%
Germany	108.4	108.5	0.1%	107.5	103.8	-3.5%	122.6	112.3	-8.8%
Japan	99.6	107.8	8.0%	111.3	111.4	0.1%	145.3	134.7	-7.6%
Netherlands	106.8	84.6	-23.3%	103.2	87.2	-16.9%	115.3	100.9	-13.3%
U.K.	77.9	87.8	11.9%	68.7	83.3	19.3%	92.1	103.2	11.4%
U.S.	100.0	100.0	0.0%	100.0	100.0	0.0%	100.0	100.0	0.0%

*Note: Percent changes are log differences. *Exchange rates are annual averages.*

TABLE 16
Nominal and real R&D intensity (R&D / gross output) using preferred R&D PPP and output PPPs, total mfg.

Country	Current practice Nominal	With R&D PPP and output PPP Adjustments Real	Difference
	Year 1987		
France	2.06	2.48	+0.42
Germany	2.71	3.08	+0.37
Japan	2.24	2.70	+0.46
Netherlands	2.04	2.19	+0.15
U.K.	2.07	3.07	+1.00
U.S.	3.81	3.81	0.00
	Year 1997		
France	2.22	2.36	+0.14
Germany	2.50	2.44	-0.05
Japan	2.89	3.11	+0.22
Netherlands	1.59	1.82	+0.24
U.K.	1.92	3.09	+1.17
U.S.	3.28	3.28	0.00
	Change from 1987 to 1997		
France	0.16	-0.12	-0.28
Germany	-0.21	-0.63	-0.42
Japan	0.65	0.41	-0.24
Netherlands	-0.46	-0.37	+0.09
U.K.	-0.15	0.02	+0.16
U.S.	-0.53	-0.53	0.00

Note: Adjustments for R&D PPP divide R&D expenditures by the R&D PPP;
Adjustments for Output PPP divide gross output by the Output PPP;
Real intensity includes both adjustments

TABLE 17
Two-way ANOVA on real R&D intensities, 1997

Source of variation	Sum of Sq.	D.F.	Means Sq.	F-stat	Prob.
Countries	52	5	10.5	1.17	0.328
Industries	1,482	18	82.3	9.23	0.000
Error (Residual)	785	88	8.92		
Total	2,309	111	20.8		

Note: See Appendix for real and nominal R&D intensities for each industry.