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MEASURING THE PRICE OF RESEARCH AND DEVELOPMENT OUTPUT

BY ADAM COPELAND*

Federal Reserve Bank of New York

AND

DENNIS FIXLER

U.S. Bureau of Economic Analysis

We construct a price index for the scientific R&D services industry, a significant producer of R&D in the United States. Unlike most previous R&D price indexes, our index is not based on input costs but rather on measures of R&D sales. Consequently, unlike input-cost price indexes, our output-based index is able to account for changes in productivity and markups in the scientific R&D services industry. We compute that scientific R&D services prices increased, on average, by 7.14 percent at an annual rate from 1987 to 2006. Using our index, we find that real revenues grew at an annual average rate of 2.85 percent. We then propose using our index, in combination with an input-cost price index, to deflate total R&D nominal expenditures. We find that real total U.S. R&D expenditures grew at an average annual rate of 1.42 percent from 1987 to 2006.

JEL Codes: E01, O47, O3

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INTRODUCTION

The role of research and development (R&D) in the economy has spurred a vast literature. Macroeconomists have analyzed the link between investment in R&D and total factor productivity, while economists who study industrial organization have considered how market structure and institutions influence the rate of innovation. A wealth of work also examines the link between labor productivity and R&D investment. For the most part, however, these and other studies bypass problems of measurement. Indeed, because of the intangibility of R&D output, properly measuring it is difficult, a challenge that underlies all effort to quantify it.

In this paper, we focus on the problem of measuring real R&D output. A critical problem in constructing a time series of real R&D output is the lack of price data, which are difficult to find because R&D is often produced for in-house use only. Consequently, researchers often use R&D input prices to deflate R&D

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*Correspondence to: Adam Copeland, Money and Payment Studies, Federal Reserve Bank of New York, 33 Liberty Street, New York, NY 10045, USA (adam.copeland@ny.frb.org).

nominal output. Price indexes based on input costs, however, do not account for productivity changes or variations in markups and so can produce inaccurate measures of price change. The main contributions of this paper are to identify market-based data on R&D sales and describe a robust and transparent method that uses these data along with R&D output indicators to construct an R&D output-price index. Our price index improves on the existing R&D input-cost price indexes by virtue of using data on R&D output and so accounts for changes in productivity associated with producing R&D and for changes in markups as the competitive landscape for R&D output changes.

Our output-based R&D price index derives from U.S. Census Bureau revenue data for the scientific R&D services industry. Our paper focuses on two important features of this industry: first, that the primary source of receipts for establishments in this industry is sales of R&D services; and second, that the majority of establishments are single units and thus primarily sell their output to other firms. Consequently, we treat establishments in this industry as firms that produce R&D and sell it to other firms. The revenue figures from this industry, then, reflect market transactions as opposed to valuations based on costs of inputs.[1] Using these data, we construct an output-based R&D price index for scientific R&D services. This index is important in itself, because this industry typically accounts for one-quarter of total R&D investment. Furthermore, we find that this industry sells its output to a wide variety of other industries. Hence it may be the case that scientific R&D services are representative of R&D production across a number of industries. If so, it may be appropriate to use our output-based price index for scientific R&D services to deflate more general measures of nominal R&D output.

Our approach is to decompose the revenue data for scientific R&D services into quantity and price indexes, using the Frisch product rule. Because we do not directly observe quantity, we construct a proxy based on the number of successful patents and the employees hired. Using this proxy, we compute the average annual rate of price change for R&D output as 7.14 percent from 1987 to 2006. Over this period, the growth rate of price change slightly decelerated; for the first half of our sample, the average annual price change was 7.18 percent, while in the second half it was 7.10. Using our index, we find that real revenues for scientific R&D services grew at an average annual rate of 2.85 percent.

We then turn to computing real total U.S. R&D output. As a benchmark, we use an aggregate input-cost price index and compute that real total U.S. R&D output grew at an average annual rate of 2.66 percent. We then re-compute real total U.S. R&D output using a two-price-index approach. As recommended by the Organization for Economic Co-operation and Development (OECD) (see OECD, 2010), we use an output-based price index for those R&D purchases for which market-based data exist. For those R&D investment purchases without any market-based data, we use an aggregate input-cost price index. We implement this approach by deflating revenue from scientific R&D services by our R&D Output

[1]If R&D output in this industry was mainly transferred between establishments of the same firm, it is likely that reported revenues of these transfers would reflect input costs as opposed to market prices. See Hirschleifer (1956) for a classic text on this issue of transfer pricing.

Price Index. The remaining R&D investment purchases, about three-quarters of total nominal R&D investment, are deflated using an aggregate input-cost price index. With this approach, we find that real total U.S. R&D output grew at an average annual rate of 1.42 percent. The results of relying only on an aggregate input-cost price index, then, dramatically overstate the average growth rate of real total U.S. R&D investment. The difference in real expenditures between our preferred approach and the input-cost method, of course, lies in the deflation of nominal revenues for scientific R&D services. We show that using an aggregate input-cost price index overstates real total U.S. R&D expenditures by $41 billion, or 20 percent, over a 19-year horizon.

Although most of the literature on R&D does not focus on measurement issues, some papers have looked at constructing real measures of R&D output. Mansfield *et al.* (1983), Mansfield (1987), and Jankowski (1993) use input-cost price indexes, taking advantage of the data available on R&D input costs. One chief difference between our proposed output-based price index and the usual input-cost index is the inability of the latter to account for productivity or markup changes in the scientific R&D services industry. This significant failing of the input-cost approach makes the output-based approach all the more important. Identifying industries such as scientific R&D services where market data exist and then incorporating these data and their implications for R&D price change are crucial to improving our estimates of real R&D output.[2]

A number of researchers have focused on patents and licensing agreements to study the pricing of and returns to R&D output.[3] From a national accounts perspective, however, using only patent data to construct a price index for all innovation is worrisome because not all innovations are patented. For example, Cohen *et al.* (2000) report survey results showing that firms in manufacturing industries typically emphasize patents the least among the range of mechanisms used to protect profits due to invention.

The rest of the paper is organized as follows. We begin by describing the scientific R&D services industry in Section 1. We then detail how we construct our Output Price Index for scientific R&D services in Section 2 and present the results in Section 3. In Section 4, we pay considerable attention to how this approach yields significantly different predictions about the growth of real R&D output, compared to the case in which an aggregate input-cost price index is used, both for scientific R&D services and for total U.S. R&D investment. We conclude by summarizing our results and discussing how our approach can be implemented for all countries that follow the International Standard Industrial Classification of All Economic Activities.

[2]Another approach to deflating nominal R&D investment has been to use a general price index (e.g., Corrado *et al*., 2006). This approach assumes that price changes in R&D output closely follow the average price change in the economy. See also Corrado *et al*. (2010) for a growth-accounting approach that computes an R&D price index based on the prices of goods for which R&D is an input.

[3]Chapter 24 of the *Handbook of the Economics of Innovation* (Hall and Rosenberg, 2010) reviews the economic literature on measuring the returns to R&D. More generally, part 6 of the handbook provides a useful literature review on the measurement of innovation.

1. The Scientific R&D Services Industry

Most research, citing the lack of market-based R&D output data, has focused on using an input-cost approach to developing a price index for R&D. With an input-cost price index, changes in input prices are assumed to drive changes in the price of the output good. While such an assumption is well founded for goods sold in perfectly competitive markets, it seems implausible for the production of R&D. By definition, R&D output consists of unique goods that enable the innovator to wield market power and so charge a markup. With markups and the concomitant forces related to strategic pricing, changes in input prices may or may not influence the price of R&D. Furthermore, the input-cost approach cannot account for changes in productivity, an omission that seems particularly glaring for the production of R&D.

An overlooked source of R&D output data is revenue from the scientific R&D services industry (in the North American Industry Classification System, or NAICS, this is industry 5417). This industry is an important source of innovation, typically accounting for one-quarter of total U.S. R&D investment. Over 1987 to 2006, scientific R&D services have steadily increased its share of total U.S. R&D investment from 14 to 33 percent. According to the U.S. Census Bureau, this industry group contains establishments "engaged in conducting original investigation undertaken on a systematic basis to gain new knowledge (research) and/or the application of research findings or other scientific knowledge for the creation of new or significantly improved products or processes (experimental development)."[4] For establishments in this industry, then, the sales of R&D services are the primary source of receipts.

Sales of R&D services, however, might in reality be transfers of R&D between establishments of the same firm. Because the Census Bureau collects these data at an establishment level, as opposed to the firm level, it is possible that an establishment in NAICS 5417 is transferring R&D output to another establishment located in a different industry but within the same firm.[5] For our purposes, in-house transfers of R&D are problematic, because the revenue reported for these transfers would likely not reflect the market value of the R&D output but rather its input costs. As noted earlier, this is the central measurement issue in the case of transfer prices.

The organization of firms in NAICS 5417, however, suggests that production of R&D for in-house use is not prominent. In both 2002 and 2007, about 70 percent of establishments in NAICS 5417 were single-unit establishments. To better understand the nature of the multiunit establishments, we obtained confidential 2002 data on establishments subject to U.S. federal tax.[6] Using these data, we found that more than half of the multiunit establishments are located in NAICS 5417. NAICS 5417 is thus the parent industry for these multiunit establishments, making it highly unlikely that such an establishment is an R&D

[4]See http://www.census.gov/epcd/ec97/def/5417.htm.

[5]See Acemoglu *et al*. (2007) for an analysis of the determinants of vertical integration, with a focus on firms in technology-intensive industries.

[6]A total of 12,288 out of all 15,334 establishments in NAICS 5417 are subject to federal tax in 2002; 8,644 (about 70 percent), of these establishments are single-unit establishments. Thus establishments subject to U.S. federal tax and establishments not subject to federal tax are equally likely to be single-unit establishments in NAICS 5417.

TABLE 1

Scientific R&D Services Output Use

Industry	Percent of total output
Other basic organic chemical manufacturing (325190)	1.4
Plastics material and resin manufacturing (325211)	1.4
Pharmaceutical preparation manufacturing (325412)	3.8
Toilet preparation manufacturing (325620)	1.1
All other chemical product and preparation manufacturing (3259A0)	1.5
Semiconductor and related device manufacturing (334413)	1.4
Search, detection, and navigation instruments manufacturing (334511)	1.1
Motor vehicle parts manufacturing (336300)	1.3
Wholesale trade (420000)	3.9
Management of companies and enterprises (550000)	2.6
Junior colleges, colleges, universities, and professional schools (611A00)	1.8
Personal consumption expenditures (F01000)	10.1
General Federal defense government services (S00500)	20.3
General Federal nondefense government services (S00600)	14.6
General state and local government services (S00700)	5.7

Note: Table includes all industries that used more than 1 percent of total 5417 output.
Source: BEA's Input/Output Use tables.

outpost for a firm whose main revenue source is non-R&D output.[7] Overall, then, the evidence on establishments in NAICS 5417 shows that most are firms whose primary receipts come from the sale of R&D output to other firms. Hence, the revenue data largely reflect market transactions, as opposed to in-house transfers between establishments within the same firm.

An additional advantage to studying scientific R&D services is that this industry may be representative of innovative activity in the economy. Output from scientific R&D services flows to a variety of industries and final users (see Table 1). The broad variety of the use of such output demonstrates that establishments in scientific R&D services perform many different types of research. Consequently, a price index based on scientific R&D services could possibly be used to deflate nominal R&D output from other industries.

2. Constructing the Price Index

Our goal is to use the revenue data for scientific R&D services to compute a price index for R&D output. Using the Frisch product rule (Frisch, 1930), we can indirectly compute a price index by decomposing the movement in revenues into price and quantity indexes. Let $R(t)$ be revenue in year t, and denote $P(t, t+1)$ and $Q(t, t+1)$ as price and quantity indexes, respectively, describing the change in price and quantity from year t to year $t+1$. We know that

[7]The next major parent industry, interestingly, is merchant wholesalers. Of the 607 establishments affiliated with merchant wholesalers, 34 are associated with motor vehicles, 93 with computers, and 111 with drugs. The remaining 1,189 multiunit establishments, 33 percent of the total, are affiliated with many industries; 744 are associated with manufacturing, 140 with computer and electronic product manufacturing, 68 with transportation equipment manufacturing, and 161 with other industries in professional, scientific, and technical services (that is, industries other than NAICS 5417) consisting of 94 percent of the "other than NAICS 5417" affiliated establishments. The remaining 6 percent of establishments are scattered throughout other industries.

$$\frac{R(t+1)}{R(t)} = P(t,t+1)Q(t,t+1). \tag{1}$$

While the Census Bureau collects revenue data for scientific R&D services, it does not collect quantity data. Hence, the main obstacle to computing an R&D output price index is constructing an index to approximate the change in quantity over our sample. Our strategy is to construct two different quantity measures and use their average as our final quantity index.[8] Our two quantity measures are: (1) the change in the number of successful patents for NAICS 5417-related R&D; and (2) the change in the number of employees in NAICS 5417 establishments.

The patent data come from the U.S. Patent and Trademark Office (USPTO), which sent us a correspondence between patent classifications and the industries from which the patents are likely to have been developed.[9] Because innovations developed by establishments in scientific R&D services could involve almost any technology, it is not possible to connect a particular set of patent classifications to scientific R&D services. Consequently, we selected the number of successful patents (that is, patents awarded by the USPTO) attributed to five industries that are heavy users of NAICS 5417 output (see Table 1). Our assumption is that patenting activities in these industries are highly positively correlated with patenting activity in NAICS 5417. These five industries are chemical and allied products, rubber and miscellaneous plastic products, electrical and electronic machinery equipment, transportation equipment, and professional and scientific instruments.[10]

The number of successful patents has the advantage of accurately measuring the number of innovations each year, the goal of the quantity index.[11] Furthermore, patents are a well-understood and fairly transparent measure of innovation. As a measure of innovation, however, patents do have at least two main disadvantages. First, the propensity-to-patent differs across industries; hence, this quantity measure of R&D output may miss upticks in innovative activity in areas in which innovators are not inclined to patent (Cohen *et al.*, 2000). Second, U.S. patent regulations have changed over enough of our sample that different incentives to patent have emerged. Hence, a change in patents may reflect a change in

[8]Our approach is similar to Adams (1990), who uses measures of article counts and number of scientists to construct a measure of the stock of knowledge.

[9]The USPTO categorizes patents into industries based on information claimed and disclosed in the patent. Data on patent counts appearing in this document were prepared under the support of the Science Indicators Unit, National Science Foundation, by the Patent Technology Monitoring Branch, U.S. Patent and Trademark Office. Any opinions or recommendations expressed in this document are those of the authors and do not necessarily reflect the views of the National Science Foundation or the Patent and Trademark Office. For more information, see the *Review and Assessment of the OTAF Concordance between the U.S. Patent Classification and the Standard Industrial Classification System: Final Report, OTAF, 1984*. We thank Raymond Wolfe and Francisco Moris for assisting us with the USPTO data.

[10]The USPTO sent us the correspondence for the years 1988 to 2004. We extrapolate the growth rate of patents for 2005 and 2006 for these five industries using the aggregate growth rate of all patents.

[11]While this narrow definition provides the cleanest quantity indicator for NAICS 5417, in practice we found that from 1987 to 2006, this quantity measure aligned closely with one based on all successful patents (see Appendix A). Consequently, the results of our R&D output price index changed little when we used a quantity index based on all successful patents.

regulation or enforcement, as opposed to a change in the quantity of innovation (see, e.g., Griliches, 1990; Hall and Ziedonis, 2001; Hall, 2005). Indeed, there was a large jump in patents granted from 1997 to 1998 across all five industries used in our patent-based index.[12] While a change in the quantity of innovation may have driven this surge in successful patents, the surge could also have been related to a 1995 rule change stipulating that a patent's life would be 20 years from the date of application rather than 17 years from the date of approval. These rule changes often lead to strategic responses by innovators in the patent application process, which would then be observed in the time series of successful patents in later years.[13] Despite these shortcomings, patent counts are widely used in the literature because they are direct and transparent measures of R&D output.

A last issue with regard to patents is choosing the patent statistic. Should the number of patent applications or patents granted be used as a measure of R&D output? One view is that the number of patents granted is a noisy measure of R&D output because it is largely subject to the workflow considerations of the USPTO. Indeed, from 1987 to 2006 the average time taken to award a grant increased, roughly, from 2 to 3 years. However, over our sample period the level of patents granted is typically about half the amount of patent applications. This large difference is worrisome given the assumption that patents granted, as opposed to patents applied for, are the main drivers of revenue derived from R&D. For this reason, in our work we use patents granted (or successful patents) to construct our R&D Output Price Index. In Appendix A, we describe our re-computation of our main results using patent applications statistics and our finding that there is not a qualitative difference between the two approaches.

Our second proxy for an R&D output-quantity index is based on a major input into R&D activity, the number of employees in the industry.[14] The strength of this quantity index is that it will capture shifts in the size of the industry, which should be closely tied to shifts in output. Furthermore, while not a direct measure of output, this quantity index allows us to capture changes in prices due to changes in the markup of R&D output. To see this, consider the simple case in which the number of employees does not change between the years t and $t + 1$ but prices fall because of a change in the competitive landscape. We will observe that reported revenues fall and the quantity index stays constant. From the Frisch product rule (equation (1)), we then correctly deduce that prices must have fallen. Significantly, the input cost index approach assumes that changes in inputs drive changes in prices, ruling out the possibility of changes in markups. Hence, in the simple case above, with an input cost approach, the lack of change in employees leads to the incorrect result that prices have not changed. A weakness of our employment-based quantity index, however, is that it will not account for changes in labor productivity. This is a general weakness in the approach to using inputs as a proxy for quantity produced.

[12]This surge in successful patents is seen in the aggregate. There was a 31.5 percent increase in patents awarded by the USPTO from 1997 to 1998 (USPTO press release #99-5, February 24, 1999).

[13]Consistent with a strategic response story, the number of successful patents decreased from 1996 to 1997 in four out of the five industries.

[14]The data come from the U.S. Bureau of Labor Statistics.

While we use a measure of all employees to build our quantity index, an alternative measure of labor inputs would be to include only the number of scientists and engineers in NAICS 5417. This narrow measure would focus on only the high-skilled labor inputs that, presumably, are central to the production of innovation. Although time-series data on the number of scientists and engineers in NAICS 5417 are lacking, we also believe this measure of labor inputs to be overly narrow.[15] Technical assistants and other occupations not deemed to be scientists or engineers are likely to be important in the production of R&D. Indeed, with technological progress, the ratio of scientists to assistants in NAICS 5417 establishments is likely to change, a dynamic not captured by a narrow, scientist-and-engineer focused measure of labor inputs.[16]

Both the patent- and the employment-based quantity indexes have their strengths and weaknesses. While the patent-quantity index directly measures output, there is a worry that a significant amount of R&D produced in NAICS 5417 is not patented. While the employment-quantity index is applicable across the range of R&D output and accurately captures changes in markups as an input measure, it fails to capture changes in labor productivity. Given the relative strengths of each quantity index and because we do not know enough to weight these two indexes, it seems prudent to take the geometric mean of the two, in the spirit of Fisher (1922).

It is important to reemphasize that using changes in labor inputs as an indicator for our quantity index does not imply that the resulting price index will be close to an input-cost price index. Under our output-based approach, the price index is equal to the change in revenue divided by the quantity index. An input-cost price index, in contrast, equates changes in inputs to changes in outputs without using any information about the change in revenues.

Our strategy comes with two important caveats. First, we assume that innovations are comparable from one period to another. Because R&D output is, by definition, a unique output, any comparison of R&D output over time is challenging. We make the reasonable assertion that revenue flows from scientific R&D services are for minor innovations. These non-drastic innovations are minor advances in technology that improve productivity, without dramatically altering the production process or the final goods market (Arrow, 1959). Thus, these innovations are at least somewhat comparable over time. In contrast, drastic innovations are major improvements that are difficult or impossible to compare with past improvements.[17] Examples of non-drastic innovations are the regularly

[15]The National Science Foundation collects employment data on the number of scientists and engineers but has data only for NAICS 5417 from 1998 onward. In addition to the employment data we use in this paper, the U.S. Bureau of Labor Statistics also publishes employment figures by occupation and industry. Unfortunately, for NAICS 5417 these occupational data are available only from 2002 onward.

[16]See Holmes and Mitchell (2008) for an analysis of substitution among high-skilled labor, low-skilled labor, and capital.

[17]Jones and Williams (2000) describe non-drastic innovations as those that can be classified within a cluster of technology. Drastic innovations, in contrast, are those that fall outside the existing cluster of technology. Finally, in its producer price index for computers, the Bureau of Labor Statistics (BLS) determines the manner of quality change along similar lines. The BLS terminology uses *revolutionary* and *evolutionary*, where *evolutionary* implies a quality change of an existing good while *revolutionary* implies the introduction of a new good.

occurring technology improvements in semiconductors. These small improvements lead to more powerful microprocessor chips, but different vintages of chips are still comparable.[18] In contrast, the invention of the semiconductor represents a drastic innovation. Its introduction transformed multiple markets along many dimensions, making a comparison between the semiconductor and what came before it difficult to impossible. Our assumption that the flow of revenue from scientific R&D services represents sales of non-drastic R&D output and is thus comparable over time is necessary. Indeed, any approach for constructing an R&D price index needs to make this assumption or else explicitly adjust R&D output for quality.[19] However, the assumption is also reasonable since drastic innovations rarely occur.

The second caveat relates to timing. With both the patent-based and the employee-based quantity indexes, we assume a contemporaneous relationship between changes in quantity and revenue. In reality, there may be lags between the two. Patents awarded in one year may not affect revenue until one or two years later. The same lag may or may not occur for hiring new employees. Whether there is a lag between patents and R&D activity is an open question in the literature. Hall *et al.* (1986) tackle this question and find that the evidence of lags between patent applications and R&D activity is weak. Consequently, we adopt the straightforward approach of assuming a contemporaneous relationship between changes in patents and employees and changes in revenue.

3. Results

We first construct R&D output price indexes using each quantity index separately (see Figure 1), to understand better how each quantity index affects the computed price index.[20] The two resulting price indexes provide different contours to real scientific R&D services. The patent-based price index exhibits steady growth over our sample period of 1987–2006, with an average annual growth rate of 5.8 percent. The employment-based price index has a faster average annual growth rate of 8.0 percent. Also, unlike the patent-based index, the employment-based index exhibits a slowing growth rate in prices. Before 1997, the employment-based index measures prices growing at an annual rate of 8.3 percent, before slowing to an average rate of 7.7 percent for the period after 1997. These different contours lead to significant differences between the real NAICS 5417 revenues associated with each price index (Figure 2). In particular, the employment-based price index results in a flatter stream of real NAICS 5417 revenue. While real revenue computed using the employment-based price index grew 20 percent between 1990 and 2006, real revenue computed using the patent-based price index rose 90 percent over the same period.

As discussed in the previous section, our preferred quantity index is the geometric average of the patent- and employee-based quantity indexes. This quan-

[18]Aizcorbe and Kortum (2005) develop a vintage-capital model where different generations of microprocessor computer chips are explicitly compared to one another.

[19]See Nordhaus (1997) for a discussion of quality adjustment and price indexes.

[20]The revenue data for NAICS 5417 were taken from the 2010 BEA satellite account. See http://bea.gov/national/newinnovation.htm.

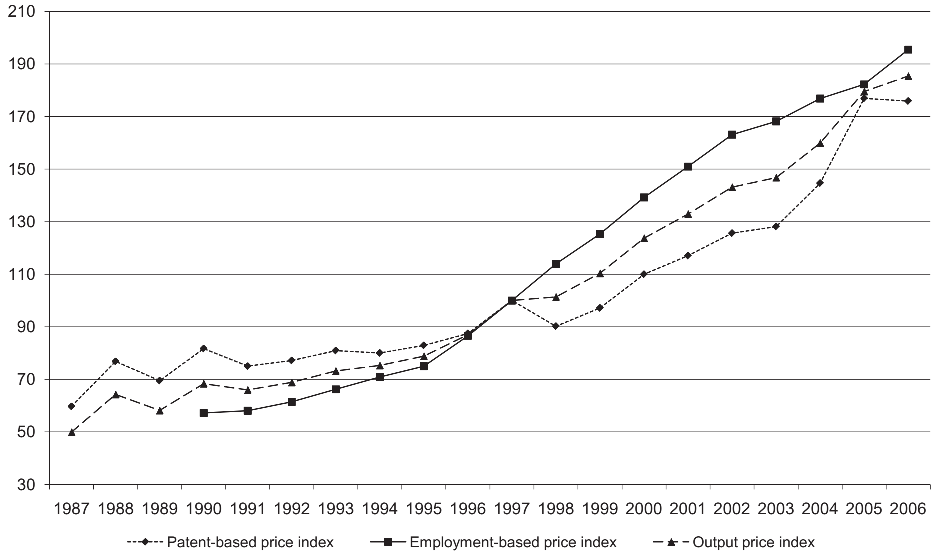

Figure 1. NAICS 5417 Price Indexes (base year is 1997)

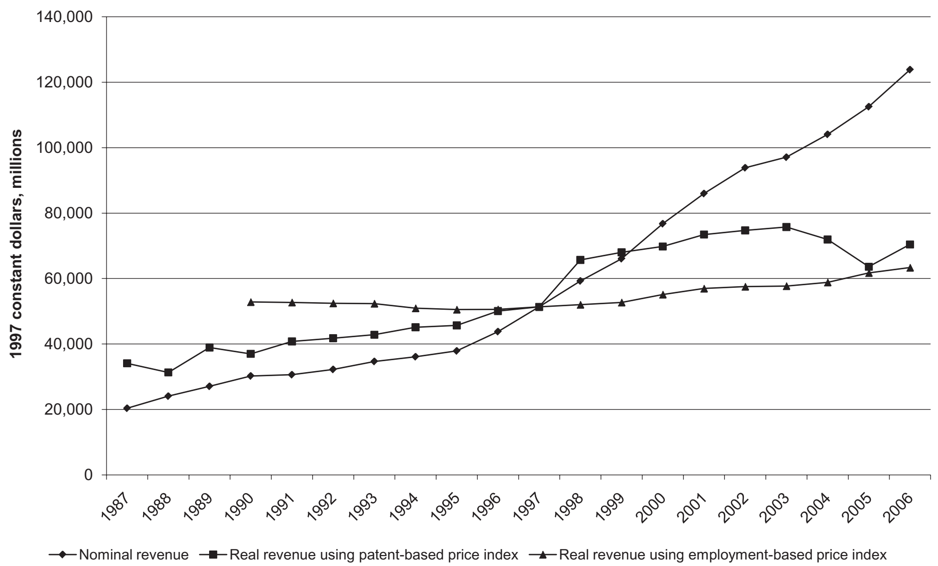

Figure 2. NAICS 5417 Nominal and Real Revenues

tity measure combines a direct, transparent measure of output that is captured by counting patents with an accurate accounting of the major input into R&D, the number of employees. Using this quantity index, we compute the corresponding price index that we label the Output Price Index.[21]

[21]As shown in Appendix B, another advantage of this approach is that it provides a non-linear link between employment and output.

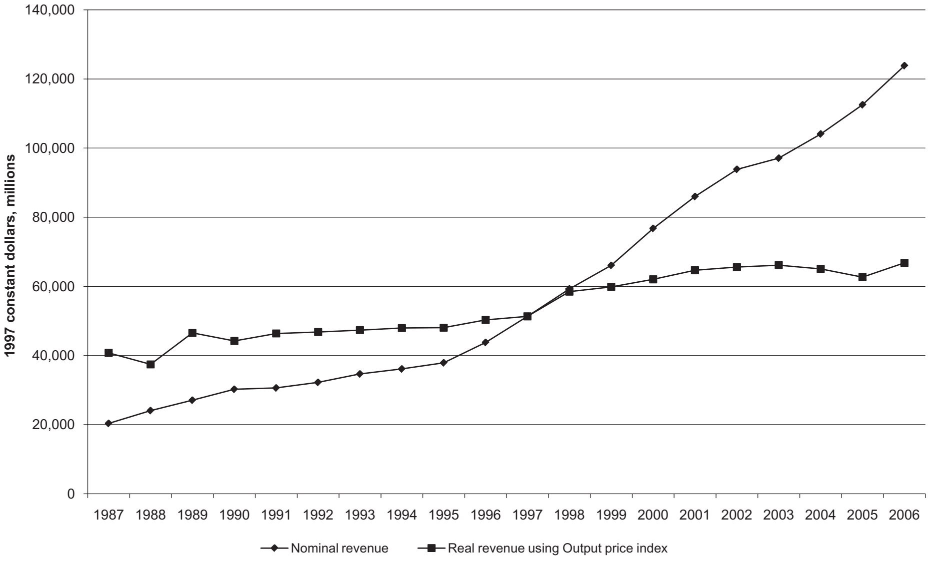

Figure 3. NAICS 5417 Nominal and Real Revenues: The Output Price Index

Using the Output Price Index, we find that the average growth rate of R&D output prices increase over the entire sample is 7.14 percent at an annual rate (see Figure 1). This price index reports a slowing in the annual price growth rate. From 1987 to 1997, the average growth rate is 7.18 percent, while from 1997 to 2006 it is 7.10 percent.

Using the Output Price Index to deflate nominal revenues for scientific R&D services, we find that real revenue grew at an annual rate of 2.85 percent from 1987 to 2006 (see Figure 3). In comparison, using the aggregate input-cost price index published in the 2010 satellite R&D account of the Bureau of Economic Analysis (BEA) results in a real revenue series that grows 7.16 percent, more than double the growth rate we find when using our Output Price Index.[22] Admittedly, the aggregate input-cost price index we use is based on input costs for all R&D performed in the economy, while our Output Price Index focuses on a narrower slice of R&D activity.[23] Hence, this comparison of price indexes depends upon scientific R&D services input costs being well-approximated by the aggregate input-cost price index.

The sharp contrast in average annual growth of real revenue reflects large differences in measured price growth between the Output Price Index and the

[22]See Copeland *et al.* (2007) for a detailed description of the R&D price indexes constructed by the BEA.

[23]Using BLS occupational data on number of employees and the mean wage for NAICS 5417 from 2002 to 2006, we computed a simple labor-cost price index. Over these four years, this NAICS 5417-specific index grew faster than the general R&D input-cost price index used in the paper. This difference is most likely due to the inclusion of capital measures in the general R&D input-cost price index. Nevertheless, in the future when more data are available, it would be interesting to determine if NAICS 5417 costs are closely correlated with general R&D costs.

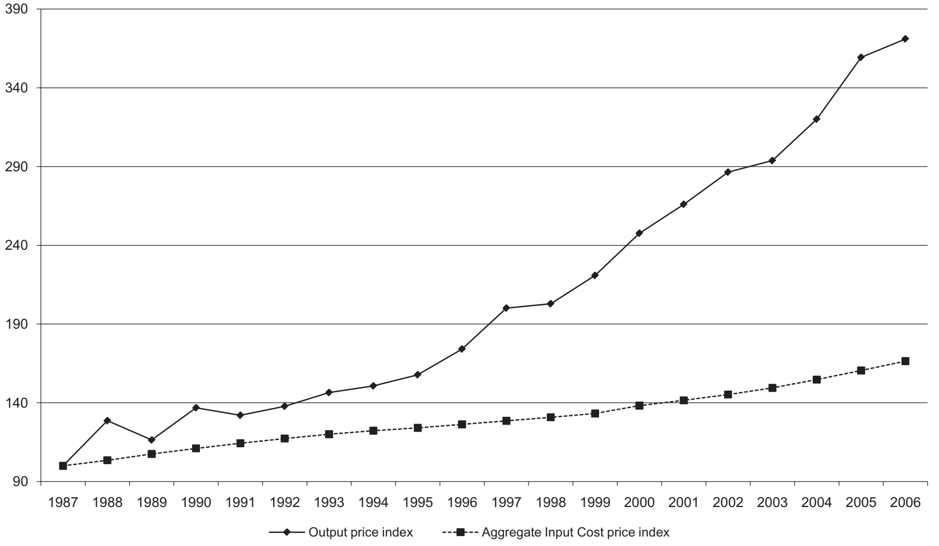

Figure 4. R&D Price Indexes (base year is 1987)

aggregate input-cost price index. The aggregate input-cost price index reports that R&D prices grew at an average annual rate of 2.7 percent, less than half the rate given by the Output Price Index. To fully illustrate the differences between the aggregate input-cost index and the Output Price Index, we plot them in Figure 4 with a base year of 1987. By 2006, after 19 years, the Output Price Index equals 371, two-thirds more than the aggregate input-cost price index, which stands at 166.

When comparing input and output price indexes for an industry, economists typically make inferences about the growth rates of the marginal product of the inputs. The result in Figure 4—that input costs grow faster than output—is often interpreted to mean that the marginal products of the inputs have negative growth rates. This inference, however, is based on the assumption that the industry is perfectly competitive. This is clearly not the case for innovating industries, which by definition produce unique products. As detailed in Appendix C, once innovators' market power and the uncertainty behind the production of R&D are accounted for, there is no longer a simple linear relationship among the growth rates of input prices, output prices, and marginal product. With market power, prices are no longer set at marginal cost and so changes in output prices reflect changes in input prices, productivity, and mark-ups. With uncertainty, the relationship between input and output prices is further complicated by expectations over the profitability of potential R&D output. Hence, given the existence of market power and uncertainty in the market for R&D, the results in Figure 4 by themselves do not provide enough information to make inferences about productivity. To properly decompose the changes in output price into its various components requires a formal model of the innovator's problem and the market for R&D, a topic we leave for future research.

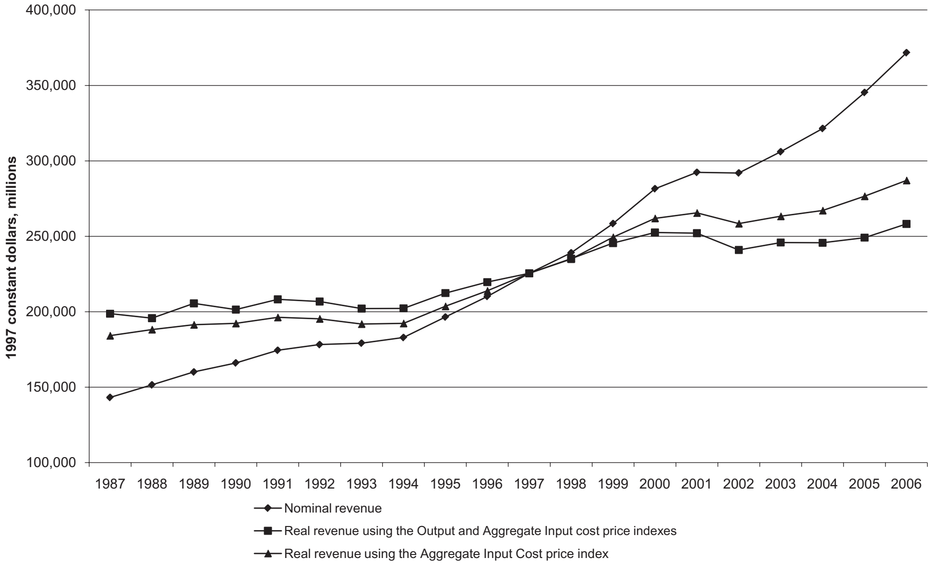

Figure 5. Total U.S. R&D Nominal and Real Investment

4. Total U.S. R&D Investment

We now turn to constructing a measure of real U.S. total R&D investment. Our use of NAICS 5417 revenue data is an opportunity to incorporate market information in the construction of real total U.S. R&D investment. An approach is to argue that scientific R&D services are representative of all R&D output, and so use the Output Price Index to deflate total U.S. R&D investment. Under this scenario, the resulting real total R&D investment time-series is slightly decreasing; the average annual growth rate was –1.6 percent from 1987 to 2006. This lack of growth seems implausible and raises doubt about the strong assumption that scientific R&D services are representative of all R&D investment.

Our preferred, and more conservative approach, is to use a two price-index approach. We use our Output Price Index for scientific R&D services and use an aggregate input-cost price index for all other R&D investment. Our measure of total U.S. R&D investment comes from the BEA, which uses NSF survey data to measure investment in own-account and purchased R&D.[24] Over our sample period, revenues from scientific R&D services account for one-quarter of U.S. total R&D investment. Using this two-price-index approach, we find that real total R&D grew at an average annual rate of 1.4 percent from 1987 to 2004 (see the output and aggregate input cost real revenue series in Figure 5). Real revenue growth accelerated over this period; from 1987 to 1997, the average annual growth rate of real total R&D was 1.31 percent, while from 1997 to 2006 it was 1.55 percent.

[24]The data can be found at http://bea.gov/national/newinnovation.htm.

In contrast, if we forgo our Output Price Index and use only an aggregate input-cost price index to deflate nominal total R&D expenditures, real total R&D is shown to grow at an average annual rate of 2.4 percent (see the aggregate input cost real revenue series in Figure 5). The input cost approach also results in a faster acceleration of growth in total real R&D expenditure over this horizon, relative to our preferred approach (see Table 2 and note that these results are independent of the base year of the price index). Under the input cost approach, the difference in growth rates between 1987–97 and 1997–2006 is 0.63 percent. This is more than double the 0.24 percent difference in growth of average real revenue measured using our two-price-index approach over these same two periods.

To reveal fully the sources of these differences, we plot real revenues of scientific R&D services using the two price indexes, with 1987 as the base year instead of 1997 (see Figure 6). In 2006, the difference between the two real series is roughly $41 billion or 55 percent of the level of real scientific R&D services under the Output Price Index. Hence, over 19 years the understatement of price growth by the aggregate input-cost price index leads to a dramatic $41 billion overstatement of the real output of NAICS 5417. This has a substantial impact on the real total R&D expenditures. With 1987 as the base year, using only an aggregate

TABLE 2

Annual Growth Rates of Real Total U.S. R&D Investment, 1987–2006

Price indexes[a]	1987–2006	1987–97	1997–2006
Output and aggregate input cost	1.42	1.31	1.55
Aggregate input cost	2.66	2.52	3.15

Note: [a]Price index used to deflate nominal R&D investment series.

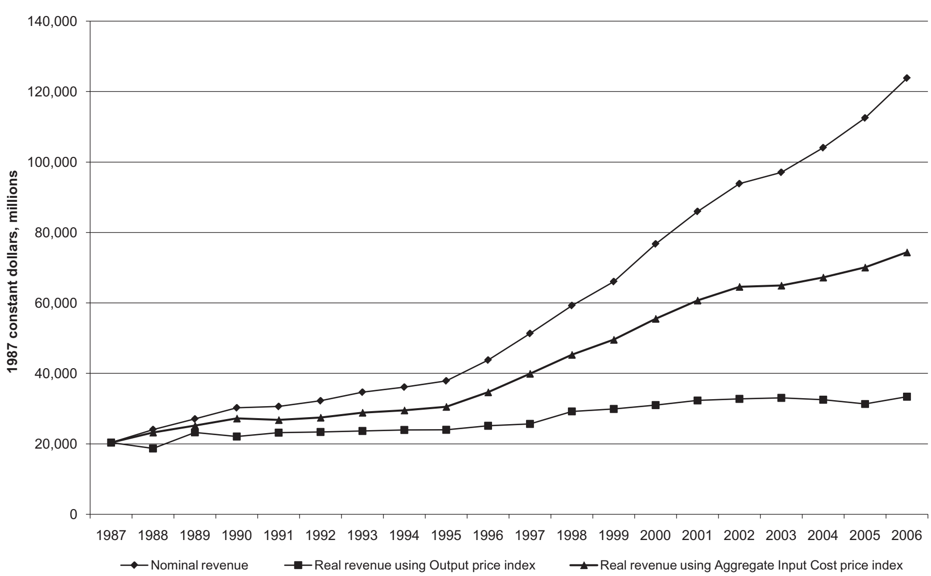

Figure 6. NAICS 5417 Nominal and Real Revenues

input-cost price index resulted in an overstatement of real total R&D expenditures of 22.5 percent in 2006, relative to the real expenditures series deflated using our preferred method.

The difference between our Output Price Index and the aggregate input-cost price index is likely due to the well-known weakness that input-cost price indexes fail to capture changes in productivity and markups. Our Output Price Index, in contrast, is able to capture both productivity and markup changes by relating the quantity and price indexes to changes in revenue through the Frisch product rule.[25] The significant differences between the Output Price Index and aggregate input-cost price index highlight the importance of incorporating market data on output, such as revenues, when possible. Identifying industries where such data exist, and incorporating the data into our measures of the price change of R&D output, is crucial to improving real estimates of R&D output.

Conclusion

This paper computes an R&D output price index using data from scientific R&D services, an industry that consists mostly of independent innovators. Using our Output Price Index, we find that real revenues from scientific R&D services grew at an average annual rate of 2.85 percent from 1987 to 2006. Turning to the aggregate economy, we suggest using a two-price-index approach to deflate total R&D nominal investment. To deflate the portion of total U.S. R&D nominal investment consisting of NAICS 5417 revenue, we use our Output Price Index. For the remaining portion of R&D nominal investment, about three-quarters of the total, we use an aggregate input-cost price index. With that approach, we find that real total U.S. R&D investment grew at an average annual rate of 1.42 percent. In contrast, using the often-cited alternative, an aggregate input-cost price index, results in an average growth rate of 2.66 percent for real total U.S. R&D total investment. We demonstrate that these differences in growth rates have substantial impacts on the level of real R&D investment. After 19 years, the aggregate input-cost price index approach measures a level of real total U.S. R&D investment that is $41 billion higher than what is found using our recommended two-price-index approach.

Our approach has the distinct advantage of using market-generated data for an industry that produces R&D services, in line with the recommendations of the 2010 *OECD Handbook on Deriving Capital Measures of Intellectual Property Products* (for example, recommendation 21, that output or pseudo-output price data should be used when available). Our comparison with the aggregate input-cost price index provides a sense of the potential measurement error associated with that index. Given the illustrated difference between the aggregate input cost

[25]It is possible to construct an input-cost price index that accounts for productivity changes (see, e.g., Diewert, 2008). In the 2006 satellite account on R&D, the BEA constructed an input-cost price index that was adjusted for productivity in the downstream industry (for example, pharmaceuticals). Because this productivity adjustment is based on the productivity of the R&D-adopting industry, and not the productivity of the R&D innovator, the BEA's productivity-adjusted input-cost price index and our Output Price Index are not comparable.

index and our Output Price Index, researchers have ample reason to be cautious about using the input-cost price index to determine R&D output.

Although our computed price index is based on NAICS 5417, our approach is implementable in countries that follow the International Standard Industrial Classification of All Economic Activities (ISIC). More specifically, NAICS 5417 is comparable to ISIC 7310 (research and experimental development on natural sciences and engineering) in ISIC Rev. 3; in ISIC Rev. 4 the comparable industry is 7210, with the same title. De Haan and van Rooijen-Horsten (2004) discuss how data from this industry were collected and subsequently used to construct R&D output measures in the Netherlands. In using ISIC 7310 or 7210, however, researchers should confirm that reported revenues are generated from market trades (as is the case for NAICS 5417), as opposed to transfers across establishments within the same firm.

In addition to revenue data, our Output Price Index relies upon finding good approximations of real R&D output. We argue that patents and employment data are good indicators of real NAICS 5417 output. Although other R&D quantity indicators could be used, these two indicators are available for many countries. Indeed, the OECD regularly collects data from countries on patents, and in fact a working group is exploring how to make patent statistics more useful to the analysis of innovative activity. A component of that work focuses on valuing patents—which ties naturally into the price of R&D output. In addition, the OECD compiles country data on R&D personnel. Thus, in principle, our Output Price Index can be constructed in any OECD country. Researchers, of course, should carefully check the validity of using patents and employment statistics as indicators of real R&D output. While we believe the combination of patent and employment measures provide a good approximation of real output in NAICS 5417, it is possible that such an approach may not work as well in other countries.

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Supporting Information

Additional Supporting information may be found in the online version of this article:

Appendix A: Robustness of Results to Difference Patent Statistics
Figure A1. Alternative Price Indexes for NAICS 5417 (base year is 1987)
Figure A2. NAICS 5417 Labor Productivity
Appendix B: Non-Linear Link between Labor Inputs and Quantity Produced
Appendix C: The Inapplicability of a Linear Comparison of Growth Rates of Input Price and Output Price Indexes

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