Measuring the Price of Research and Development Output

March 2011

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 5.8 percent at an annual rate from 1987 to 2005. Using our index, we find that real revenues grew at an annual average rate of 2.64 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 R&D expenditures grew at an average annual rate of 1.4 percent from 1987 to 2005.

Keywords: Research and development, price indices, innovation

JEL code: E01, O47, O3,

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 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 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 expenditures. Furthermore, we argue that this industry is fairly representative of overall R&D production in the United States. Indeed, final consumers purchase outputs from scientific R&D services and use them as inputs in a variety of industries, including innovation-intensive ones. For that reason, in some cases 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 a quantity-and-price index, 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 5.81 percent from 1987 to 2005. Over this period, the growth rate of price change decelerated; for the first half of our sample, the average annual price change was 6.53 percent, while in the second half it was 5.01 percent. Using our index, we find that real revenues for scientific R&D services grew at an average annual rate of 2.64 percent.

We then turn to computing real total R&D output. Under the assumption that scientific R&D services are representative of all R&D output, we deflate total R&D nominal output with our output-based price index. The resulting real total R&D output is essentially flat, with an average annual growth rate of -0.4 percent from 1987 to 2004. In contrast, using an aggregate input-cost price index, we find that real total R&D output grew at an average annual rate of 2.1

---

[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.

percent. This large difference in growth rates underscores the importance of accurately measuring price change for R&D output. Our preferred approach to measuring real total R&D output is to follow a two-price-index approach. As recommended by the Organisation for Economic Co-operation and Development (OECD) (see OECD 2010), we use an output-based price index for those R&D expenditures for which market-based data exist. For those R&D expenditures 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 Price Index. The remaining R&D expenditures, about three-quarters of total nominal expenditures, are deflated using an aggregate input-cost price index. With this approach, we find that total real R&D output grew at an average annual rate of 1.4 percent. The results of relying only on an input-cost price index, then, dramatically overstate the average growth rate of real total R&D expenditures. The differences 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 R&D expenditures on scientific R&D services by $25 billion, or 14 percent, over an 18-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 of the not all innovations are patented. For example, Cohen, Nelson, and Walsh (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 the first section. We then detail how we construct our Output Price Index for scientific R&D services in the second section and present the results in the third. 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 R&D expenditures. 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.

Section 1: The Scientific R&D Services Industry

---

[2] Another approach to deflating nominal R&D expenditures has been to use a general price index (for example, Corrado, Hulten, and Sichel 2006). This approach assumes that price changes in R&D output closely follow the average price change in the economy. See also Corrado, Goodrich, and Haskel (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* (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.

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 expenditures. 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

---

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

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. For those establishments subject to US federal tax, 8,644, or 70 percent, are single-unit establishments.[6] Of the remaining 30 percent that are multiunit establishments, more than half 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 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 is 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). As an intermediate input, such services are used by a number of innovation-intensive industries, including pharmaceuticals, semiconductor manufacturing, and management services. Final users also purchase a substantial portion of R&D services. Government, for both defense and nondefense services, acquires over 40 percent of

---

[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] 12,288 out of all 15,334 establishments in NAICS 5417 are subject to federal tax.

[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 of them are associated with manufacturing, 140 of them with computer and electronic product manufacturing, 68 with transportation equipment manufacturing, and 161 a 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.

NAICS 5417 output, while households and nonprofit organizations, labeled as personal consumption expenditures in table 1, use more than 10 percent. The broad variety of the use of such output suggests that establishments in scientific R&D services perform many different types of research. Consequently, these services are likely to be representative of overall R&D activity in the economy.

Section 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

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

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 appropriate 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

---

[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.

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 also sent us a mapping of patents to industries. This mapping is based on the Standard Industrial Classification structure, which predates NAICS and does not have an equivalent to NAICS 5417. Because we could not observe patents awarded to scientific R&D services, 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).[9] 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.

The number of successful patents has the advantage of accurately measuring the number of innovations each year, the goal of the quantity index.[10] 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

---

[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 *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] 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. Consequently, the results of our R&D output price index changed little when we used a quantity index based on all successful patents.

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 regulation or enforcement, as opposed to a change in the quantity of innovation (for example, see Griliches 1990; Hall and Ziedonis 2001; and 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.[11] 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.[12] Despite these shortcomings, patent counts are widely used in the literature because they are direct and transparent measures of R&D output.

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.[13] 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 fell and the quantity index stayed constant. From the Frisch product rule (equation 1), we then correctly deduce that prices must have fallen. Significantly, the input cost index approach

---

[11] 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).

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

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

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 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.

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.[14] 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.[15]

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

---

[14] 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.

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

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 nondrastic 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.[16] Examples of nondrastic innovations are the regularly occurring technology improvements in semiconductors. These small improvements lead to more powerful microprocessor chips, but different vintages of chips are still comparable.[17] 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

---

[16] Jones and Williams (2000) describe nondrastic 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.

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

assumption that the flow of revenue from scientific R&D services represents sales of nondrastic 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.[18] 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, Griliches, and Hausman (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.

Section 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. 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 4.5 percent. The employment-based price index has a faster average annual growth rate of 6.6 percent. Also, unlike the patent-based index, the employment-based index exhibits a slowing growth rate in prices. Before 1997, the employment-based index

---

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

measures prices growing at an annual rate of 7.9 percent, before slowing to an average rate of 5.6 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 quantity 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 Innovators' Output Price Index, hereafter, the Output Price Index.[19]

Using the Output Price Index, we find that the average price increase of R&D output over the entire sample is 5.81 percent (see figure 1). This price index reports a slowing in the annual price growth rate. From 1987 to 1997, the average growth rate is 6.5 percent, while from 1997 to 2006 it is 5.0 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 2.64 percent from 1987 to 2006 (see figure 3). In comparison, using the aggregate input-cost price index published in the satellite R&D accounts of the Bureau of Economic Analysis (BEA) results in a real revenue series that grows 5.69

---

[19] As shown in appendix A, another advantage of this approach is that it provides a nonlinear link between employment and output.

percent, more than double the growth rate we find when using our Output Price Index.[20] 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.[21] However, if NAICS 5417 is representative of all U.S. R&D (see section 1), then the costs of inputs used by NAICS 5417 should be representative of input costs for all R&D innovators.

The sharp contrast in average annual growth of real revenue reflects large differences in measured price growth between the Output Price Index and the aggregate input-cost price index. The aggregate input-cost price index reports that R&D prices grew at an average annual rate of 2.8 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 292, two-thirds more than the aggregate input-cost price index, which stands at 173.

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 costs—is often interpreted to mean that the marginal products of the inputs have negative growth rates. This inference, however, makes several strong assumptions about the underlying industry. As detailed in appendix B, 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

---

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

[21] 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.

product. Hence, for the production of R&D, the difference in growth rates between input and output prices does not have a straightforward implication for the growth rates of the marginal product of the inputs.

Section 4: Total R&D Expenditures

Extending the argument that the output of scientific R&D services is fairly representative of total R&D output, the Output Price Index could be used to deflate total R&D expenditures. The resulting real total R&D expenditures series is essentially flat; the average annual growth rate was -0.4 percent from 1987 to 2004.

Using the NAICS 5417 price index to deflate all R&D expenditures is arguable because much of the total comes from government and is measured on the basis of input costs. Thus our preferred approach is to use only our Output Price Index on scientific R&D services output, which makes up about one-quarter of total R&D expenditures. For the remaining three-quarters of R&D expenditures, we use the BEA R&D satellite account input-cost price index. 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 1.16 percent, while from 1997 to 2004 it was 1.79 percent.

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 2.1 percent (see the aggregate input cost real revenue series in figure 5). The input cost approach also results in an acceleration of growth in total real R&D expenditure over this horizon (see table 2 and note that these results are independent of the base year of the price index). Under the input cost approach, however, the difference in growth rates between 1987–97 and 1997–2004 is 0.45 percent. This is almost two-tenths of a percent less than the 0.63 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 2004, the difference between the two real series is roughly $25 billion or 60 percent of the level of real scientific R&D services under the Output Price Index. Hence, over 17 years the understatement of price growth by the aggregate input-cost price index leads to a dramatic $25 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 input-cost price index resulted in an overstatement of real total R&D expenditures of 13.7 percent in 2004, relative to the real expenditures series deflated using our preferred method.

Beyond overstating the growth rate, the aggregate input cost index also generates a real scientific R&D services revenue series whose growth rates slow over the 1987–2004 period (see table 3). This outcome is in sharp contrast to the real revenue results obtained when using our Output Price Index. That index generates a real scientific R&D services revenue series whose average growth rate increases by nine-tenths of a percent between 1987–97 and 1997–2004 (see table 3).

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.[22] 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 2.64 percent from 1987 to 2006. Turning to the aggregate economy, we recommend using a two-price-index approach to deflate total R&D nominal expenditures. To deflate the portion of total R&D nominal expenditures consisting of NAICS 5417 revenue, we use our Output Price Index. For the remaining portion of R&D nominal expenditures, about three-fourths of the total, we use an aggregate input-cost price index. With that approach, we find that real R&D expenditures grew at an average annual rate of 1.4 percent. In contrast, using the often-cited alternative, an aggregate input-cost price index, results in an average growth rate of 2.1 percent for real R&D total expenditures. We demonstrate that these differences in growth rates have substantial impacts on the level of real R&D expenditures. After 18 years, the aggregate input-cost price

---

[22] It is possible to construct an input-cost price index that accounts for productivity changes (see, for example, 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,. the 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 approach measures a level of real R&D expenditures that is $25 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 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 Roojen-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.

Our Output Price Index used patent and employment data, and although other R&D quantity indicators could be used, these two indicators are available for many countries. 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**.**

Appendix A: Nonlinear Link between Labor Inputs and Quantity Produced

In addition to the advantage of using information on both patents and total employment, the Output Price Index also has a nonlinear link between the labor inputs and the quantity produced. In contrast, the input-cost price index, by construction, assumes a constant, proportional relationship between changes in inputs and changes in outputs. The Output Price Index's nonlinear link between inputs (that is, employment) and outputs is driven by the averaging of the two quantity indicators. Letting *Q* denote the R&D quantity, *Z* the number of patents, and *E* the number of employees, we assume that

$$\frac{Q_t}{Q_{t-1}} = \left[\frac{Z_t}{Z_{t-1}}\frac{E_t}{E_{t-1}}\right]^{1/2}.$$

This can be written as

$$Q_t = \left[Z_t E_t\right]^{1/2},\; Q_{t-1} = \left[Z_{t-1} E_{t-1}\right]^{1/2}.$$

The implication is that the quantity index does not have a constant proportional relationship with the labor inputs.[23] This can be seen by taking the derivative of *Q* with respect to *E*,

$$\frac{\partial Q_t}{\partial E_t} = Z_t^{1/2}\frac{1}{2}E_t^{-1/2}.$$

It is important to stress that this is not a production function, although one can think of a production function extension where *Z* is affected by a lag value of *E*. This result does indicate, however, that our method of construction allows changes in *E* to have a varying impact on *Q*.

---

[23] This analysis goes through with measures of capital inputs.

Appendix B: The Inapplicability of a Linear Comparison of Growth Rates of Input Price and Output Price Indexes

In this appendix, we review the relationship among input prices, marginal product, and output prices in a competitive setting. We then add uncertainty to the relationship and discuss the complications it adds to an empirical analysis of this relationship. Finally, we demonstrate that considering an environment in which firms have market power muddies the elegant relationship among input prices, marginal product, and output prices.

Starting with the standard competitive case, we denote**:**

p:	output price
w:	input price
z:	inputs
q:	production function

A price-taking innovator maximizes profits by choosing inputs to

$$\max_{z} pq(z) - wz .$$

First-order conditions give us

$$p\frac{dq}{dz} = w .$$

Denoting *dq/dz* as *MP*, for marginal product, we take logs of the above expression, rearrange terms, and get

$$\ln(MP) = \ln(w) - \ln(p).$$

The above equation provides us with a linear relationship in the logs of marginal product, input price, and output price. Because we want to compare input and output price indexes, we convert the above linear relation into growth rates by differentiating with respect to time, and get

$$\text{(B1)}\ \frac{\dot{MP}}{MP} = \frac{\dot{w}}{w} - \frac{\dot{p}}{p},$$

where the dot above a variable indicates a derivative of that variable with respect to time. Equation (B1) gives us the standard result that the growth rate of the marginal product is equal to the growth rate of input prices minus the growth rate of output prices. Because the growth rate of the marginal product should be nonnegative, equation (B1) constrains the growth rate of output prices from being greater than the growth rate of input prices**.**

Equation (B1), however, misses key elements central to the production of R&D. First, the output of R&D is binary because an idea is either produced or not. Effort may accumulate knowledge, but at some point knowledge must be bundled into an idea that can be sold. Furthermore, the production of an idea involves a lot of uncertainty. We incorporate these features in a general way. Let $g(x;\varphi,A,z)$ denote the probability of producing an innovation x, given the parameter φ, the current state of knowledge A, and the input choice z. We write the innovator's problem as

$$\max_z \int_A^{\varphi} p(x) g(x;\varphi,A,z)dx - wz,$$

where we integrate over all possible outcomes from nondrastic innovation. The first-order condition of this problem is

$$(B2)\int_A^{\varphi} p(x)\frac{dg(x;\varphi,A,z)}{dz}dx - w = 0.$$

Equation (B2) highlights the difficulties of comparing growth rates in the output price, input price, and marginal productivity, as in equation (B1). In particular, there is no longer a linear relationship between the growth rates of input prices and those of output prices. Furthermore, while the growth rate of the derivative of g with respect to z plays an important role, little is known about how this derivative changes over time.[24]

Second, even in the case of certainty, it is not clear that equation (B1) holds because the innovator does not operate in a perfectly competitive industry. The innovator has exclusive property rights over the innovation for some time period, changing the nature of the problem. To provide an easier comparison to the competitive case, we assume that the firm chooses quantity to maximize profits:

$$\max_{z} p\left(q(z)\right)q(z) - wz .$$

The first-order condition is now

$$\text{(B3)} \quad \frac{dp}{dq}\frac{dq}{dz}q(z) + p\frac{dq}{dz} = w,$$

where the object on the left-hand side is marginal revenue, and the object on the right-hand side is marginal cost. Comparing equation (B3) to equation (B1) highlights how there is no longer a straightforward connection among marginal product, output price, and input price. The first term on the left-hand side of equation (B3) breaks the elegant relationship expressed in equation (B1).

Assuming the firm chooses price reinforces the complex relationship between input and output prices:

$$\max_{p} pq(p) - wq(p),$$

---

[24] See Doraszelski and Jaumandreu (2007) for recent work on estimating R&D production functions, as well as Griliches and Mairesse (1984).

where *q(p)* denotes quantity demanded at price *p*. Taking the derivative with respect to price and manipulating it, we get the standard result linking markups and the inverse of the elasticity of demand with respect to price

$$\frac{p-w}{p} = -\frac{dp}{dq(p)}\frac{q}{p} = -\frac{1}{\varepsilon}$$

where ε is the elasticity of demand with respect to price. The difference in growth rates between input and output prices, which alters a firm's markup, is tightly linked to the output product's own-price elasticity.

In summary, we argue that the standard approach for comparing input and output price indexes, as laid out in equation (B1), is inappropriate for the production of R&D. First, an empirical analysis of input and R&D output price indexes is complicated by the significant role that uncertainty plays in the production of R&D. The introduction of uncertainty complicates the relationship between input and output prices and, significantly, no longer allows for a linear comparison of their growth rates (see equation B3). Second, market power is a central element in the production of R&D. Innovators create a unique product and so are able to set its price. Adding market power to the environment obscures the relationship between input and output prices through the introduction of markups. Adding both uncertainty and market power into the framework results in a complex nonlinear relationship among input prices, output prices, and marginal product.

While we cannot use input and output price indexes to make inferences about the growth rates of the marginal product of inputs, we can use our results to provide rough estimates of labor productivity. Using the Output Price Index, we construct a time series for real 5417 output (see figure 3). Dividing real output by the number of employees in 5417 provides us with a rough approximation of labor productivity, which we plot in figure 7. Reassuringly, this measure of labor productivity rises over our sample period at an average annual growth rate of 1.54 percent.

Bibliography

Acemoglu, Daron, Philippe Aghion, Rachel Griffith, and Fabrizio Zilibotti, 2007. "Vertical Integration and Technology: Theory and Evidence," *Institute for Empirical Research in Economics* working paper no. 342.

Adams, James. 1990. "Fundamental Stocks of Knowledge and Productivity Growth," *Journal of Political Economy*, vol 98(4), pp. 673-702.

Aizcorbe, Ana and Samuel Kortum. 2005. "Moore's Law and the Semiconductor Industry: A Vintage Model," *Scandinavian Journal of Economics*, vol. 107(4), pp. 603-630.

Arrow, Kenneth. 1959. "Economic Welfare and the Allocation of Resources for Invention." *Rand Working Paper P-1856-RC.*

Cohen, W.M., R.R. Nelson and J.P. Walsh, 2000. "Protecting their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not)," *NBER Working Paper 7552*, revised 2004

Copeland, Adam and Gabriel Medeiros and Carol Robbins, 2007." Estimating Prices for R&D Investment in the 2007 R&D Satellite Account" *Bureau of Economic Analysis* working paper.

Corrado, Carol, Charles Hulten, and Daniel Sichel. 2006. "Intangible Capital and Economic Growth" , *NBER Working Paper 11948*.

Corrado, Carol, Peter Goodridge and Jonathan Haskel, 2010. “Constructing a Price Deflator for R&D: Calculating the Price of Knowledge Investment as a Residual.” Prepared for the CRIW workshop, 2010 NBER Summer Institute, Cambridge, MA.

De Haan, Mark and Myriam van Rooijen-Horsten . 2004. “Measuring R&D output and knowledge capital formation in open economies,” Paper prepared for the 28th general conference of the International Association for Research on Income and Wealth, Cord, Ireland, August 22-28, 2004 (discussion paper, CBS internet, nr. 04009).

Diewert, Erwin. 2008. “The Measurement of Nonmarket Sector Outputs and Inputs Using Cost Weights.” *University of British Columbia Discussion Paper* 08-03.

Doraszelski, Ulrich, and Jordi Jaumandreu, 2007. “R&D and productivity: Estimating production functions when productivity is endogenous.” *Harvard University working paper*.

Fisher, Irving 1922. The Making of Index Numbers, Houghton Mifflin Company, Boston and New York.

Frisch, R., 1930. “Necessary and Sufficient Conditions Regarding the Form of an Index Number which shall Meet Certain of Fisher’s Tests,” *American Statistical Association Journal* 25, pp. 397–406.

Griliches, Zvi. 1990. "Patent Statistics as Economic Indicators: A Survey." *Journal of Economic Literature*, 28(4), pp. 1661-1708.

Griliches, Zvi and Jacques Mairesse, 1984. "Productivity and R&D at the firm level," in R&D, Patents, and Productivity. Edited by Zvi Griliches, University of Chicago Press, Chicago IL.

Hall, Browyn H., 2005. "Exploring the Patent Explosion," *Journal of Technology Transfer,* vol 30, pp. 35-48.

Hall, Browyn H., Zvi Griliches, and Jerry A. Hausman. 1986. "Patents and R and D: Is there a lag?" *International Economic Review*, vol 27, no. 2, pp. 265-283.

Hall, Browyn H. and Nathan Rosenberg. 2010. Handbook of the Economics of Innovation. London, UK: North-Holland.

Hall, Browyn H, and R.H. Ziedonis. 2001. "The patent paradox revisited: an empirical study of patenting in the U.S. Semiconductor Industry: 1979-1995," *Rand Journal of Economics*, vol 32, pp. 101-128.

Hirschleifer, Jack, 1956. "On the Economics of Transfer Pricing" *The Journal of Business,* 29(3), pp. 172-184.

Holmes, Thomas and Matthew Mitchell. 2008. “A Theory of Factor Allocation and Plant Size," *Rand Journal of Economics,* 39(2), pp. 329-351.

Jankowski, John. 1993. "Do we need a Price Index of Industrial R&D?" *Research Policy* vol 22*,* pp. 195-205.

Jones, Charles and John Williams. 2000. "Too Much of a Good Thing? The Economics of Investment in R&D" *Journal of Economic Growth,* vol 5(1), pp. 65-85.

Mansfield, E. 1987. “Price Indexes for R and D Inputs, 1969-1983” *Management Science* vol 33, p.124-129.

Mansfield, E., Romeo, A., and Switzer, L. 1983. "R&D Price Indexes and Real R&D Expenditures in the United States" *Research Policy* vol 12, pp. 105-112

Nordhaus, William. 1997. “Quality Change in Price Indexes”, *Journal of Economics Perspectives* vol 12, pp 59-68.

OECD, 2010. Handbook on Deriving Capital Measures of Intellectual Property Products, Paris.

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

Source: BEA’s Input/Output Use tables.

Note: Table includes all industries that used more than 1 percent of total 5417 output.

Table 2: Growth Rates of Real Total R&D Expenditures, 1987–2004

Price indexes[a]	1987–2004	1987–97	1997–2004
Output and aggregate input cost	1.42	1.16	1.79
Aggregate input cost	2.05	1.87	2.32

a. Price index used to deflate nominal expenditure series.

Table 3: Growth Rates of Real Scientific R&D Services Revenues, 1987–2004

Price index[a]	1987–2004	1987–1997	1997–2004
Output	3.01	2.64	3.54
Aggregate input cost	5.75	6.07	5.29

a. Price index used to deflate nominal expenditure series.

Figure 1: NAICS 5417 Price Indexes

(base year is 1997)

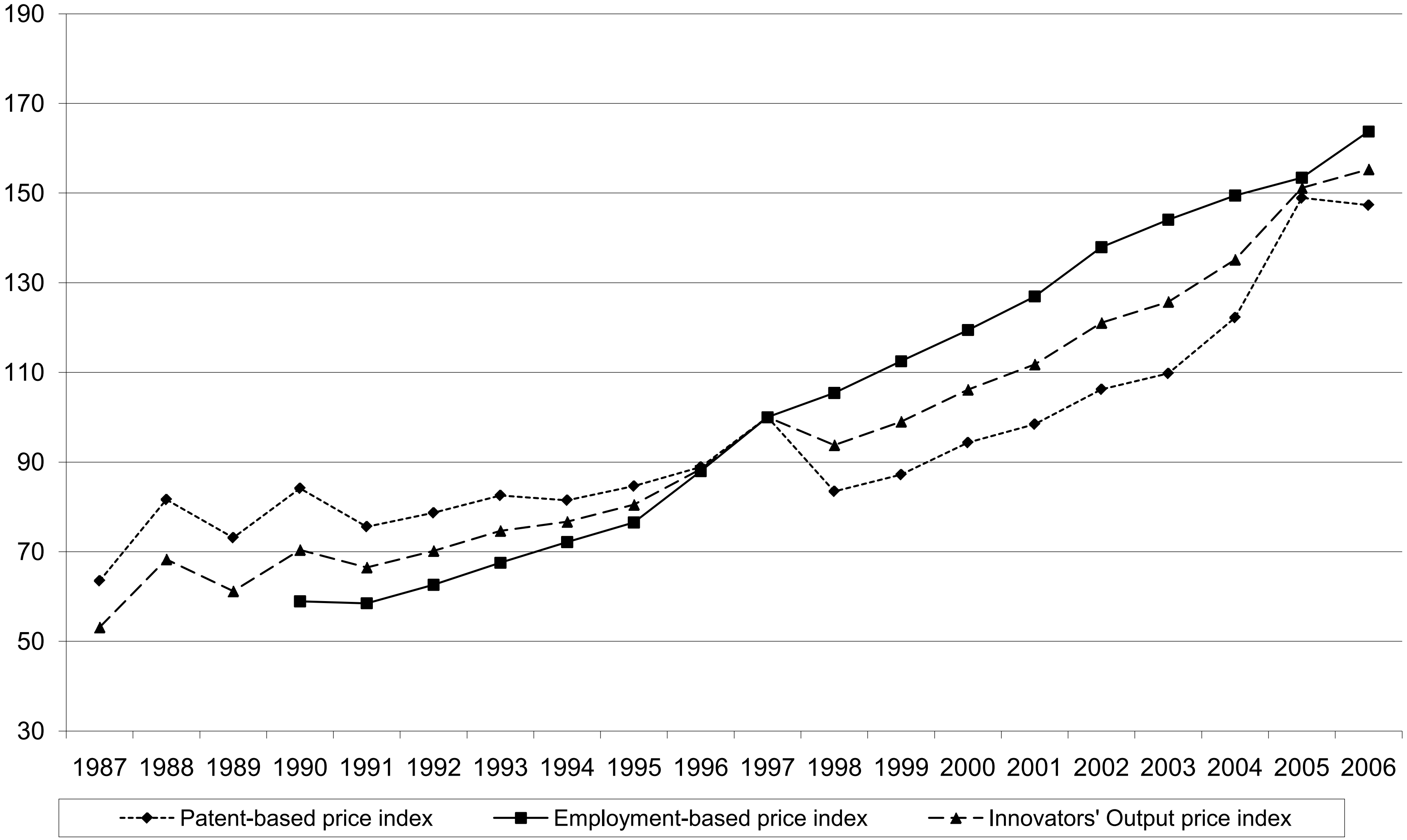

Figure 2: NAICS 5417 Nominal and Real Revenues

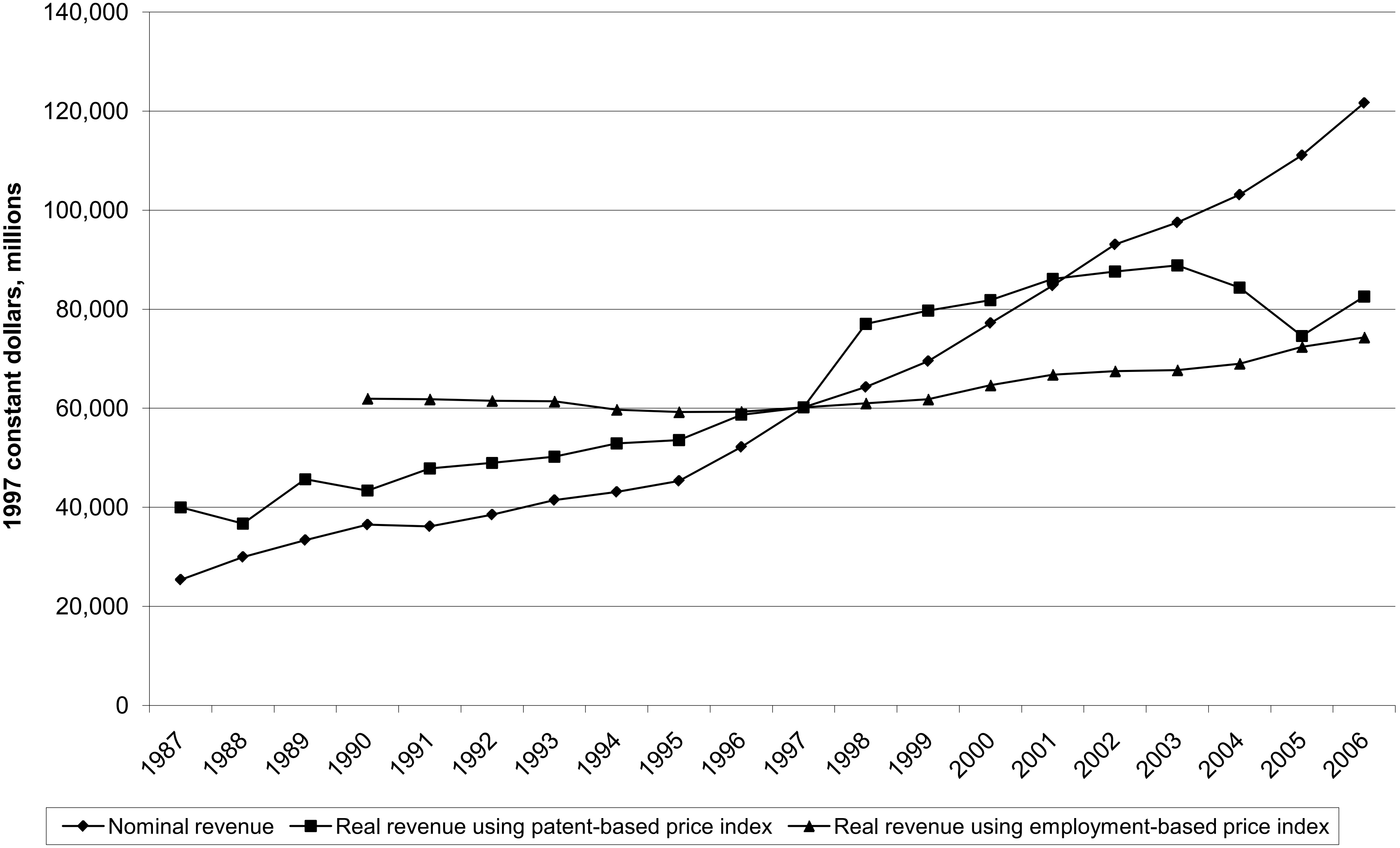

Figure 3: NAICS 5417 Nominal and Real Revenues: the Output Price Index

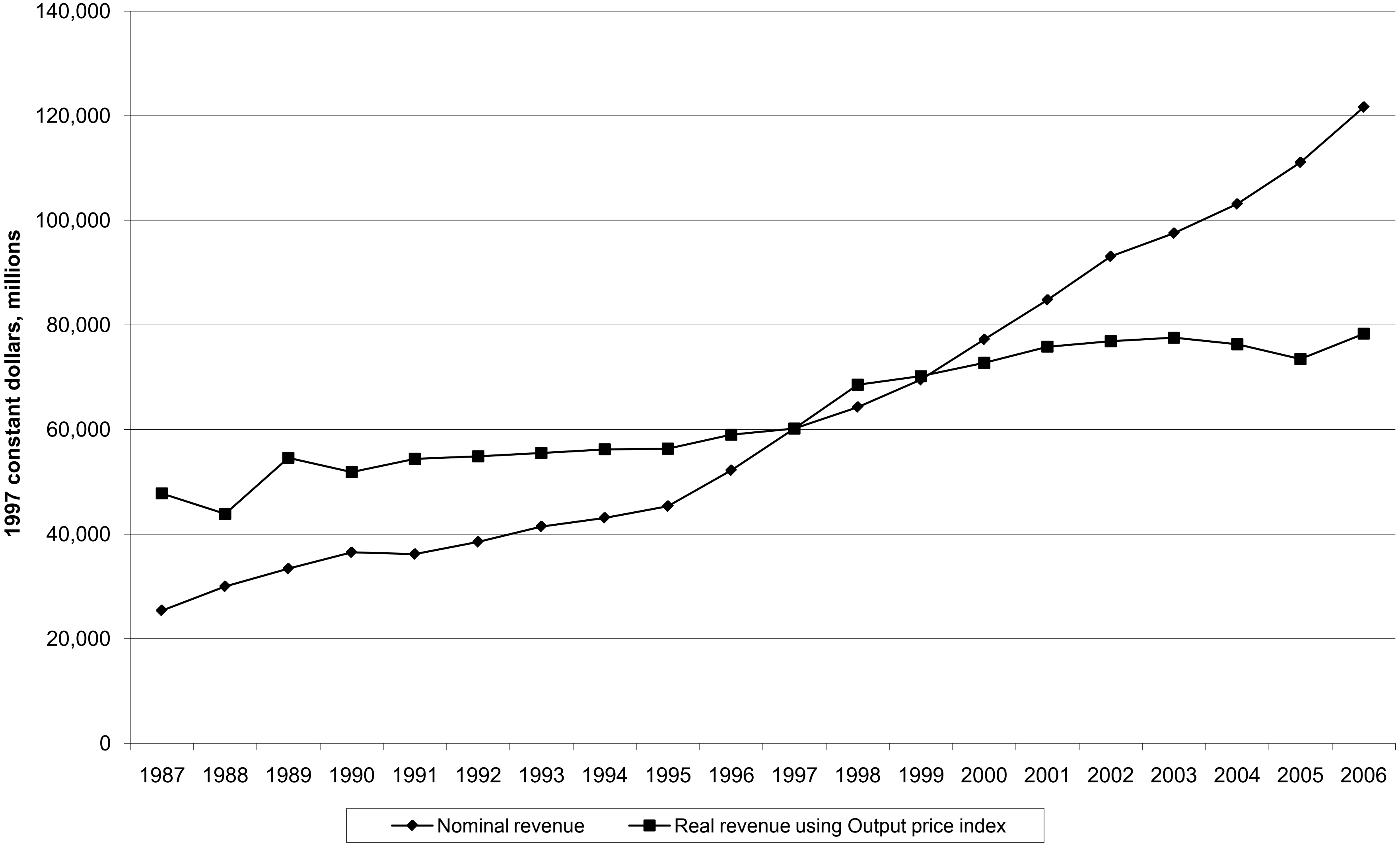

Figure 4: R&D Price Indexes

(base year is 1987)

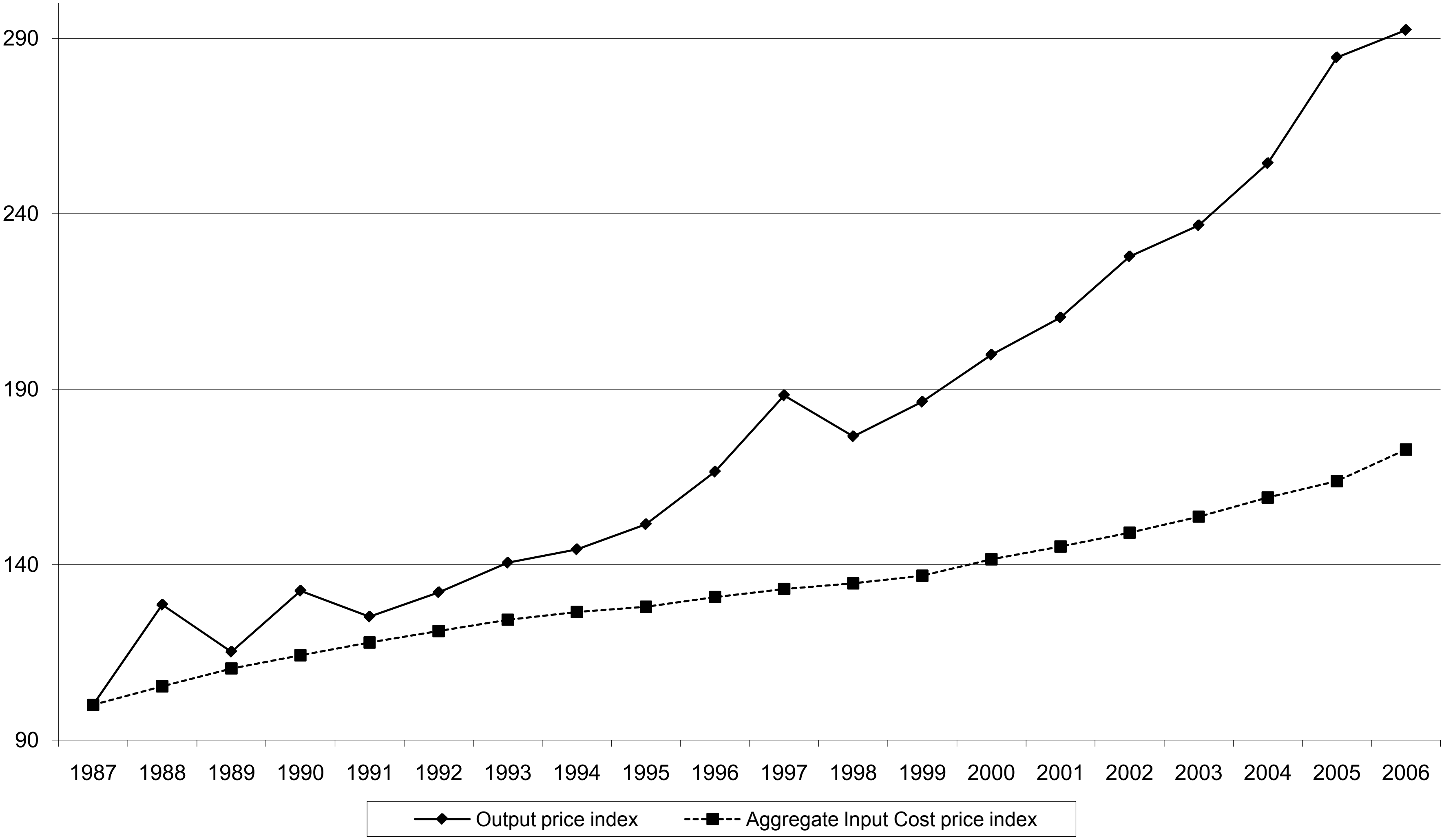

Figure 5: Total R&D Nominal and Real Expenditures

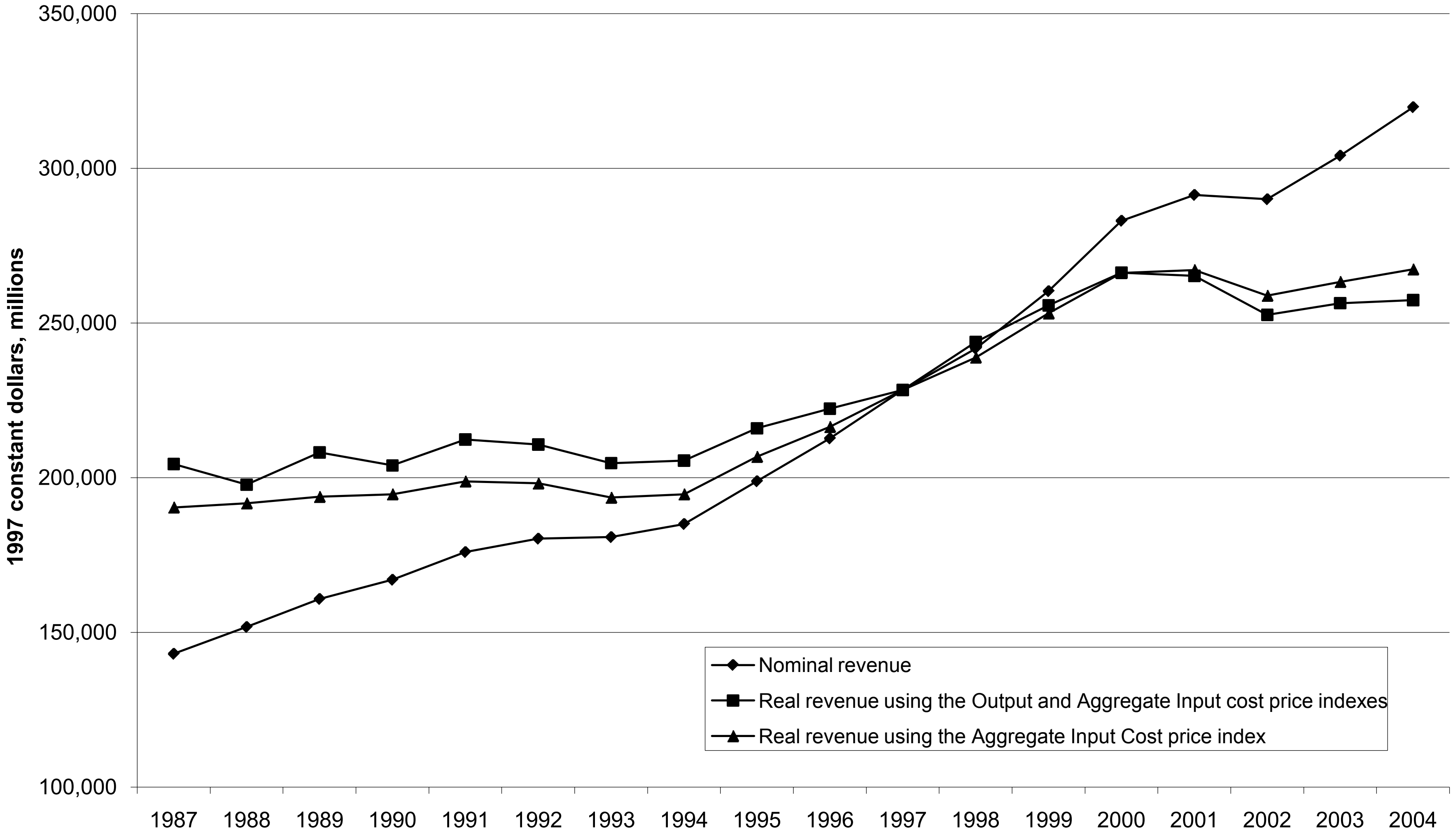

Figure 6: NAICS 5417 Nominal and Real Revenues

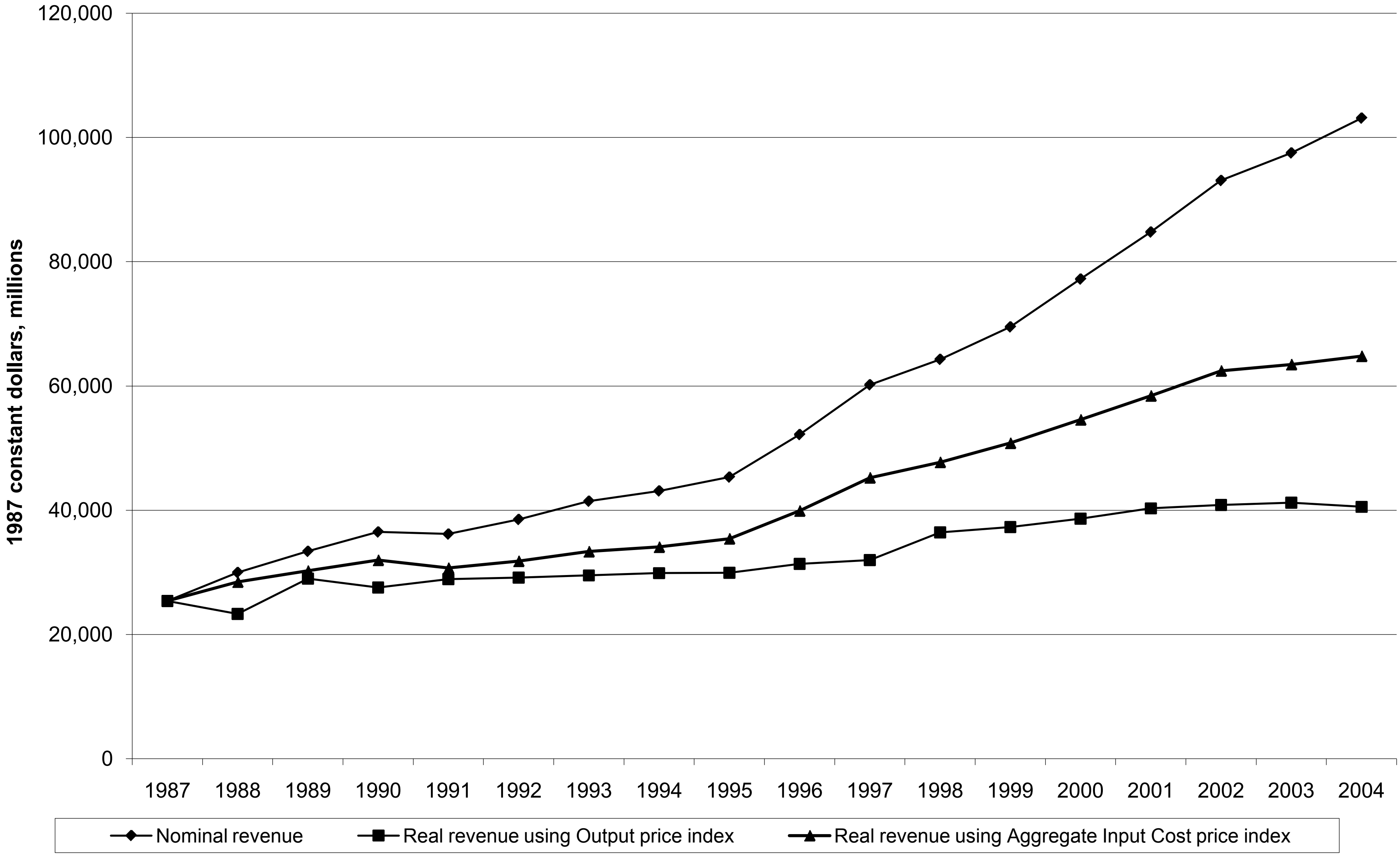

Figure 7: NAICS 5417 Labor Productivity