“Measuring the Price of Research and Development Output”

By Adam Copeland and Dennis Fixler[1]
Bureau of Economic Analysis

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This paper develops a framework for constructing a R&D output price index. Based on a model of the innovator, we show that the price of innovation is equal to the expected discounted stream of profits attributable to the adoption of the innovation. Using this relationship, we construct an R&D output price index using data on NAICS 5417, Scientific R&D Services. We compute that R&D output prices increased, on average, by 2.87 percent at an annual rate from 1987 to 2005. We deflate nominal Scientific R&D Service revenues with our price index, and find that real Scientific R&D Services grew at an average rate of 5.64 percent. Because Scientific R&D Services is representative of all R&D activity, we use our price index to deflate total R&D output. While nominal R&D output grew at an average rate of 4.88 percent from 1987 to 2004, we find that the average growth rate of real R&D output is 2.64 percent. Finally, we compare and contrast our price index against alternative measures of price change, input cost and downstream industry output price indexes.

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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 industrial organization economists 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, these and other works brush past problems with measurement. Measuring R&D output and its real value, however, are issues underlying all these major questions.

In this paper, we focus on measurement; in particular the difficulty of measuring the price of R&D output and constructing a time-series of R&D output. We begin with the micro-foundations of the problem, and model the innovator. Drawing from the recent endogenous growth literature, we consider a profit-maximizing innovator who develops technology-improving ideas that are sold to a downstream firm. We then use this basic model as a framework for analyzing the determinants of the price of R&D output and, specifically, why this price might change over time. A main result of the model is that the price of an R&D innovation is equal to the change in the downstream firm's profits attributable to the adoption of the R&D innovation.

Using insights from the model, we analyze the industry, Scientific R&D Services (NAICS 5417). This industry closely fits our model of innovation because the primary source of receipts for these establishments is the sale of R&D services. As far as we know, this paper is the first to study this industry for the purposes of learning about R&D output prices. Unlike industries such as pharmaceutical or semiconductor manufacturing, scientific R&D services provides a clean look at the production of innovation. Of course, a number of establishments in NAICS 5417 transfer their R&D output to other establishments within the same firm, perhaps straining our assumption that R&D innovators are profit-maximizing. However, these internal research units can be viewed in the context of vertical integration models where the transfer price of R&D output between units of the firm should equal the price of R&D output in the market. Even if this institutional assumption is considered too strong, the model provides a basis for imputing the transaction price between establishments.

Even with the Census data on scientific R&D services, we do not have enough information to directly apply our model and estimate R&D output prices. In general, this is a difficult task since R&D output prices reflect future profit flows attributable to the adoption of a new innovation. The framework of the model, however, directs us to consider the annual revenue of NAICS 5417 as a stock of ideas multiplied by their appropriate prices. Accordingly, an indirect way to measure R&D output price change is to apply Frisch's product rule. Using the revenue figures from NAICS 5417 along with an appropriate quantity index, we construct a R&D output price index. Our index predicts an average annual price change of 2.87 percent over our time frame of 1987 to 2005. Over this period, there is an acceleration in the growth rate of price change; in the first half of our sample the average annual price change in 2.64 percent, while in the second half it is 3.10 percent. As a point of comparison, in the 2007 satellite accounts published by the Bureau of Economic Analysis (BEA), the featured aggregate downstream-industry R&D price index predicted average annual price change of -1.36 percent.

Using our index, we find that 5417 real revenues grew at an average annual rate of 5.64 percent. Because 5417 establishments sell their R&D services to a wide variety of intermediate and final users, we argue that our price index provides a good approximation of price change for R&D output at the aggregate level. Deflating total R&D nominal output by our index, results in total real R&D output growing at an average annual rate of 2.64 percent.

We compare our price index to alternative measures of R&D output price change. Though our index and an input cost price index have similar predictions about the average price change over the entire sample, the contours of the two price indexes differ. We claim this difference is due to the inability of the input cost price index to account for productivity changes in the Scientific R&D Services industry. Further, our index substantially differs from one based on downstream industries producer price indexes.

While most of the literature on R&D does not focus on measurement issues, a group of papers have focused on constructing real measures of R&D output. Both Mansfield et al (1983) and Jankowski (2006) use input cost price indexes, taking advantage of the data available on R&D inputs costs. The input cost approach assumes no change in the productivity of R&D innovators and this assumption seems strongly at odds with the aggregate data, where the growth rate of total factor productivity remains fairly constant while the growth rate of R&D expenditures is rapidly growing (Jones (1995), Kortum (1997)). Another approach has been to use a general price index to deflate nominal R&D expenditures (e.g. Corrado et al (2006)).

The rest of the paper is organized as follows. We begin by describing the model of the innovator and derive an equation describing the price of R&D output (section 1). Using the model as a framework, we then discuss how to measure constant-quality price change for R&D services (section 2). We use these insights to construct and compare several price indexes for the Scientific R&D Services industry (section 3), and then conclude.

Section 1: The Model of the Innovator

We assume there are two types of agents in our partial-equilibrium model, innovators and final-goods producing firms. Innovators attempt to generate ideas that improve the current level of technology used by final goods producers. Once an innovator produces a technology-enhancing idea, it is sold to, and adopted by, a final goods producer. Following the endogenous growth literature, we assume the innovator has market power. Further, final goods-producing firms are assumed to operate in a competitive market.

Turning first to the final goods producers, we assume that output, Y, is given by

$$Y = AF(L_Y),$$

where $A>0$ is a technology parameter and L_Y is the labor input. Let D denote the inverse demand function, w_Y the wage, and P a general price index, then the final goods producer's profit maximizing problem, in real terms, is

$$\max_{L_Y} \left\{ AF(L_Y)D(Y,t) \,/\, P(t) - w_Y(t)L_Y \,/\, P(t) \right\},$$

where t is a time subscript.

The innovator's problem focuses on increasing the technology parameter, A. To capture different types of innovation, we assume that innovators can work on drastic or non-drastic types of innovation (Arrow (1959)). Non-drastic innovations are those that are comparable over time. These are minor advances in technology that improve productivity, without dramatically altering the production process or the final goods market. In contrast, drastic innovations are major improvements that are difficult or impossible to compare with past improvements.[2] Examples of non-drastic 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 to one another.[3] In contrast, the invention of the transistor represents a drastic innovation. Its introduction transformed multiple markets along

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[2] Drastic innovations have also been called "General Purpose Technologies" (Jovanovic and Rousseau (2005)). Jones and Williams (2000) describe non-drastic innovations as those that can be classified within a cluster of technology. Drastic innovations, on the other hand, are those that fall outside the existing cluster of technology. Finally, the BLS in the producer price index for computers determines the manner of quality change along similar lines. The BLS terminology uses revolutionary and evolutionary, where revolutionary implies a quality change of an existing good while evolutionary implies the introduction of a new good.

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

many dimensions, making a comparison between the transistor and what came before it difficult-to-impossible.

We model a non-drastic innovation as an increase in the level of A. Formally, new innovation A' is defined as $A'=\gamma A$ where A is the previous innovation and $\gamma \in [1,\varphi]$. The upper bound on γ reinforces the idea that non-drastic innovation has limited potential for improvement upon the current technology. Innovating is a risky business, where innovators often fail to produce valuable output. To capture the stochastic nature of non-drastic innovation, we denote

$$\mathrm{g}(x;\varphi,A,l_A)$$

as the probability of an successful innovation $x \in [1,\varphi]$, where l_A is the innovator's labor input.

Drastic innovation is more sparsely modeled. We assume that a successful drastic innovation results in a $\widetilde{A} > A$ where $\widetilde{A}$ is such a large change that the inverse demand function for the final good shifts out, from D to $\widetilde{D}$. If an innovator chooses to work on producing a drastic innovation, the probability of success is given by $h(l_D)$, where l_D is the labor input.

There are many innovators at work in each period. Let (L_A, L_D) define the total amount of labor used by innovators working on non-drastic and drastic innovations, respectively. For the market as a whole, the probability of a non-drastic and drastic innovation is given by $G(\varphi,A,L_A)$ and $H(L_D)$ respectively.

Using this notation, we can write the non-drastic innovator's problem, in real terms, as

$$\max_{l_A}\left\{\int_1^{\varphi} V(xA,t)g(x;\varphi,A,l_A)dx \,/\, P(t) - w_A(t)l_A \,/\, P(t)\right\}$$

where V is the nominal price of an idea, and w_A is the nominal wage of researchers. Because innovations are, by definition, novel, we assume that innovators have market power over the sale of their output. In addition, we assume that producers of final goods operate in a competitive market. Consequently, innovators are able to extract all the gains in profits that a final goods producer receives from the adoption of a new innovation.[4] Pricing an idea, then, is quite similar to pricing a capital asset. Assets are typically priced according to the future discounted stream of dividends they produce

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[4] These are common assumptions in the literature, see for example Kortum (1997), Aghion and Howitt (1992), and Jones (1995).

(Lucas (1978)). Similarly, innovations are priced according to the future discounted increases in expected profits the idea will generate for the final goods producer.

To formally define *V*, we first let π be the nominal increase in final goods producer's profits attributable to the adoption of a new innovation, *A'*, in period *t*. Let $\left(\widehat{L_Y}, \widehat{Y}\right)$ be the profit maximizing choice of labor and output given *A'* and $\left(\overline{L_Y}, \overline{Y}\right)$ be the profit-maximizing choice of labor given *A*, then we have:

$$\pi(A',t) = \left[A'F(\widehat{L_Y}(t))D(\widehat{Y},t) - \widehat{L_Y}(t)w_Y(t)\right] - \left[AF(\overline{L_Y}(t))D(\overline{Y},t) - \overline{L_Y}(t)w_Y(t)\right]$$

Using this notation, the nominal price to the rights of a new, non-drastic, technology improvement *A'*, is, where *r* is the interest rate,

$$(1)\quad V(A') = \pi(A',t) + \sum_{s=t+1}^{t+N}\left(\frac{1}{1+r}\right)^{s-t}\pi(A',s)[1-G(\varphi,A',\widehat{L_A}(s))][1-H(\widehat{L_D}(s))] .$$

In the formulation above, we assume that profits attributable to the innovation A' are driven to zero after *N* periods because of imitation.

This main equation details how the price of a new innovation depends on several important forces: the stream of future profit flows, the interest rate used to discount them, and the probability of obsolescence. Obsolescence depends on *G*, *H*, and *N*, where the first two terms are the probabilities that a non-drastic or drastic innovation will come along and usurp the market. The last term captures imitation, which ensures that an innovation's flow of profits last at most *N* periods. Obsolescence greatly complicates the problem of pricing an innovation. For a typical capital asset, pricing only depends upon the expected future stream of profits and the relevant interest rate. Because innovations face an expected obsolescence rate, pricing new ideas entails an extra dimension of difficulty relative to pricing a capital good.

The drastic innovator's problem is quite similar to the non-drastic innovator's problem. Letting *W* denote the nominal price of a drastic innovation $\widetilde{A}$, we can write the drastic innovator's profit maximizing problem, in real terms, as:

$$\max_{l_D}\left\{W(\widetilde{A})h(l_D)/P(t) - w_A(t)l_D/P(t)\right\}.$$

As before, the price of $\widetilde{A}$ is equal to the increase in profits to the final goods producer attributable to the innovation. The nominal increase in profits attributable to $\widetilde{A}$ in period *t* is

$$\widetilde{\pi}(\widetilde{A},t) = \left[\widetilde{A}F(\widetilde{L_Y}(t))\widetilde{D}(\widetilde{Y},t) - \widetilde{L_Y}(t)w_Y(t)\right] - \left[AF(\overline{L_Y}(t))D(\overline{Y},t) - \overline{L_Y}(t)w_Y(t)\right],$$

where $(\widetilde{L_Y},\widetilde{Y})$ are the profit maximizing choice of labor and output given $\widetilde{A}$ and $\widetilde{D}$. Using this notation, the nominal price to the rights of drastic technology improvement $\widetilde{A}$ is

$$(2)\quad W(\widetilde{A}) = \widetilde{\pi}(\widetilde{A},t) + \sum_{s=t+1}^{t+M}\left(\frac{1}{1+r}\right)^{s-t}\widetilde{\pi}(\widetilde{A},s)[1-G(\varphi,\widetilde{A},\widetilde{L_A}(s))][1-H(\widetilde{L_A}(s))]\,,$$

where *M* represents the number of periods before imitation completely erodes the flow of profits attributable to the drastic innovation. Comparing equations 1 and 2, we see that the price formulations of non-drastic and drastic innovations are similar. The major difference lies with the change in the inverse demand function that accompanies the adoption of drastic innovations. From a measurement perspective, this difference is crucial, because it breaks the comparability of innovations over time. Because drastic innovations have such large effects on the market place, comparing drastic innovations to other innovations necessarily entails making quality adjustments. Nordhaus (1997) lays out the importance for properly measuring quality change to account for major technological leaps as well as detailing the difficulties inherent in this exercise. In contrast, comparing non-drastic innovations to one another is an exercise in comparing roughly similar objects and thereby the proper focus for the construction of an output price index.

Section 2: Measurement of R&D Output Prices

Though equation (1) sets out the conceptual framework for the price of an innovation it is difficult to transform it into a concrete measure. Instead, we indirectly obtain an output price by decomposing the movement in the innovator's sales into price and quantity indexes. According to the Frisch product rule the change in innovator's revenue, R, is equal to the product of price, P, and quantity, Q, indexes (Frisch (1930))

$$(3)\quad \frac{R(t+1)}{R(t)} = P(t,t+1)Q(t,t+1)\,.$$

The price index captures the movements in general price inflation and the R&D output price. Accordingly, to get at the R&D output price the left-hand side of (3) must be deflated by a general price index. From the perspective of equation 1, such a deflation makes sense because we know R&D prices are derived by considering how profits of the final-goods producer are increased with the adoption of the innovation. The general price movement throughout the economy does not affect this calculation. We then turn to decomposing the resulting time series of adjusted revenue into price and quantity indexes.

Equation (3) requires data on prices, quantities and revenues all of which are not readily available. Only a small amount of R&D is licensed or sold in the market place.[5] Furthermore, in certain instances bundles of innovations are traded, obscuring the price of individual assets. Finally, innovations are sometimes given away freely. Open-source software is a prime example, and its adoption by a large number of users suggests these software are valuable. In addition, to create networks effects, firms may provide innovations to consumers for free.

Because the data exist, a number of researchers have focused on patents and licensing agreements to study the pricing of and returns to R&D output (e.g. Pakes (1985)). From a national accounts perspective, however, using this data to construct a price index for all innovation is worrisome, because of the selection effect over which type of innovators sell patents or create licensing agreements.

A less-used source is Census data on NAICS industry 5417, Scientific R&D Services. Sales of research and development output are the primary source of receipts for these establishments. Because Census collects these data at an establishment level, as opposed to the firm level, these data capture R&D output produced for in-house use as well as R&D output transferred between firms. Output from these establishments flows to both industries and final users (see table 1) and accounts for 25 percent of total R&D expenditures. As an intermediate input, 5417 output is spread among a number of industries, including pharmaceuticals and semiconductors manufacturing as well as management services. This broad variety in the use of 5417 output is suggestive that studying R&D activity in this industry is representative of R&D activity in the economy.

As can be seen on table 1, R&D services are also purchased by final users. Government, for both defense and non-defense services, acquires over 40 percent of 5417 output, while households and non-profit organizations, labeled as personal consumption expenditures in table 1, use more than 10 percent.

While our model describes the sale of R&D output to industries, it can also be applied to sales to final users, with a change in terminology. Rather than producers of a final good, consider final users as cost-minimizing agents. For instance, the federal government seeks to minimize costs when producing defense services. With this change in terms, the same framework described in section 1 applies. Rather than setting price of

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[5] Why a market for R&D has not developed is an interesting and open question. Hold-up problems or difficulties in enforcing property rights to intangible capital may force firms to develop R&D in-house.

an idea equal to discounted flow of expected profits attributable to the adoption of an innovation, however, we use the discounted flow of expected cost-savings.

Table 1: 5417 Input/Output Use Table:
(All industries that used more than 1 percent of total 5417 output)

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

From the Census Survey of Annual Services, we know the annual revenue flow to establishments in Scientific R&D Services. Through the lens of our model, these revenues reflect the summation of prices paid for innovation, the right-hand side of equation 1. These revenues flows, then, can inform us on the change in price for innovation, given we can control for quantity. We assume that the flow of revenue to 5417 establishments is payment for non-drastic R&D innovations. As mentioned earlier, we can compare non-drastic innovations over time without performing quality adjustments. It is possible, however, that drastic innovations are included in these data, polluting our measure of the change in price of R&D output. The smooth flow of 5417 nominal revenues over our 1987-2006 time frame, however, suggests that the probability of a drastic innovation biasing our results is low (see chart A).

To begin we first strip out general price inflation from 5417 revenue flows, which we accomplish using the gross domestic purchases price index. Our approach is to find a good indicator of the change in the quantity of R&D output and then use this quantity index to solve for the accompanying price index. We try two different quantity measures: the change in the number of successful patents and the change in the number of scientists and engineers (S&E) employed in R&D activities. The patent data come from US Patent and Trademark Office, while the S&E data were drawn from several National Science Foundation sources. The number of successful patents has the advantage of accurately measuring the number of innovations each year. Its does, however, 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 where innovators are not inclined to patent (Cohen et al (2000)) . Second, U.S. patent regulations may have changed over enough our sample so as to provide different incentives to patent. Hence, a change in patents may reflect a change in regulation, as opposed to a change in the quantity of innovation (Griliches (1990)).

Our second proxy for an R&D output quantity index has the advantage of consistently measuring a major input into R&D activity, the number of scientists and engineers. Unfortunately, this quantity measure does not account for productivity change, due to either technology or quality change. These changes could bias the price index in either direction, depending on the corresponding movements in the quantity of scientists and engineers hired and revenue earned.

With these caveats in mind, we use these two quantity indexes to compute the associated price indexes for R&D output (chart B). These two price indexes provide different contours to R&D output price-change. The patent-based price index is roughly flat between 1987 and 2001, except for upwards tics in 1988, 1990 and 1997. In contrast, the S&E-based price index steadily climbs from 1987 to 2005. These different contours lead to significant differences between the real 5417 revenues associated with each price index (chart A). The absolute value of the difference between the two real revenue series averages 14% of the level of the S&E-based real revenue series, and reaches over 30%, more than $20 billion, for 2000 and 2001.

Because we do not have a list of criteria to judge whether patents or the number of scientists and engineers is the better indicator of R&D output quantity, we take the geometric mean of the indexes' growth rates.[6] We label this average index the Hybrid price index and, because it combines information on the quantity of R&D from two independent sources, consider it our preferred price index. Using this price index, we find that the average price increase of R&D output over the entire sample is 2.87 percent.

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[6] In a similar tack, Adams (1990) uses measures of article counts and number of scientists to construct a measure of the stock of knowledge.

The Hybrid index illustrates a change in the rate of price growth around 1997; from 1987 to 1996 the average percent change in price is 2.64 percent, while it is 3.10 percent from 1997 to 2005.

It is important to emphasize the significance of the model's insight to not include general price increases when computing the change in price of R&D output. Not stripping out general inflation and blindly applying the Frisch product rule, results in a significant increase in the measured price change of R&D output. Over our sample, skipping this step misleadingly results in an average growth rate of 5.3 percent for R&D output prices, almost double the rate given by our Hybrid index.

Using the Hybrid price index to deflate nominal revenues for Scientific R&D Services, we find that real revenue grew at 5.64 percent from 1987 to 2005 (chart C).[7] Reflecting the more rapid growth rate of prices at the end of our time frame, real revenues are roughly flat from 2000 to 2005. Given that 5417 output is representative of total R&D output, we argue that our Hybrid index is appropriate for deflating total R&D expenditures in the US economy (a proxy for total R&D output). The resulting real R&D output series grows at an average rate of 2.64 percent from 1987 to 2004 (see chart D). Over the time period, however, the growth rate of real total R&D output is quite variable. There is period of slow growth from 1987 to 1997, a spurt of growth in 1998, 1999, and 2000, followed by a period of no growth from 2001 to 2004.

Section 3: Assessing the R&D Output Price Index

A check on the reliability of our Hybrid price index is provided by Kortum (1997). This paper develops and solves a general equilibrium model of endogenous growth. This model reconciles the sharp rise in research employment with the roughly constant level of patenting over the recent past. It further ties these two time series to the observed constant growth rate of total factor productivity. In this equilibrium model of endogenous growth, the price of R&D output is defined as the future discounted flow of profits attributable to the adoption of the new innovation, much like our simple model above. A result from Kortum (1997) is that in steady-state, the price of R&D output grows at the same rate as gross domestic product (GDP).[8] Given the similarity between our models, we expect our measure of R&D output price growth to accord with this result. Reassuringly, we find that over our time frame GDP grew at an average annual

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[7] This, and all other, real revenue measures are not adjusted for general inflation. The time series of revenue adjusted for general inflation is solely used as a step in computing our Hybrid price index.

[8] In Kortum (1997), the model "exhibits a steady state in which: (i) research grows at a constant rate, (ii) productivity grows at a constant rate, (iii) patenting is constant, and (iv) research intensity is constant" (pages 1405-6).

rate of 3.00 percent, quite close to the 2.87 percent average annual growth rate of prices as measured by our Hybrid price index.

To further assess our price index, we compare it against two alternatives: the input cost and downstream output price approaches. A standard measure of R&D output price change is an input cost price index. This approach is often used in the national accounts for hard-to-measure output, such as government services. Comparing the input cost and Hybrid price indexes, we see that both trend upwards at roughly the same rate (chart E).[9] The input cost price index, however, has a much smoother contour and registers a slowdown in price increases from 3.03 percent to 2.54 percent, when comparing 1987-1996 to 1997-2005. The Hybrid index, on the other hand, measures an increase in the growth rate of prices after 1997.

A weakness of input cost price indexes is the underlying assumption of no change in productivity. This strong assumption leads to the smooth and steadily increasing input cost price index. Our Hybrid index, on the other hand, fully captures productivity changes by relating the quantity and price indexes with changes in revenue through the Frisch product rule. In the 2006 satellite account on R&D, the BEA constructed a productivity-adjusted input cost price index.[10] This index falls over our time frame, in stark contrast to the Hybrid index (chart E). Using the Frisch product rule, the productivity-adjusted input cost price index implies an extraordinary 5 percent average annual rate of growth in the quantity of 5417 output from 1991 to 2000. This implausible growth in quantity casts doubt on the productivity-adjusted input cost price index and its implication of falling R&D prices.

The second approach to constructing R&D output price indexes involves the use of downstream firm output prices. As detailed in Copeland, Medeiros and Robbins (2007), under a set of assumptions, changes in the price of R&D output can be inferred from movements in the downstream product's price. The intuition is that the adoption of R&D innovations by a downstream firm will either shift its demand or marginal revenue curve. We associate product-oriented innovations with shifts in the demand curve, and process-oriented innovations with shifts in the marginal revenue curve. With product-oriented R&D, a relationship can be drawn whereby, holding everything else constant, there is a positive, proportional relationship between the change in the price of R&D output and the change in the price of the downstream product. In contrast, for process-oriented innovations, there is a negative, proportional relationship between the change in

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[9] We use the input cost price index published by the BEA in its 2006 R&D satellite account.

[10] Diewert (2008) lays out a different approach to construct input cost price indexes which account for productivity growth.

price of R&D output and the change in price of the downstream product. Clearly, classifying innovations as largely product or process-oriented is crucial in building these downstream industry output price indexes.

As a first step in constructing a downstream industry output price index, we identify which industries are the major users of R&D output from the Scientific R&D Services industry. From the BEA's Input/Output Use table (table 1), there are seven major groupings of industries which use Scientific R&D Services output as an input: Pharmaceutical and medicine manufacturing (NAICS 3254), All other chemical manufacturing (NAICS 325X), Semiconductor manufacturing (NAICS 3344), Navigational manufacturing (NAICS 3345), Motor vehicle parts manufacturing (NAICS 3363), Wholesale trade (NAICS 420000) and Management of companies (NAICS 550000). The use of 5417 output by the wholesale trade sector, however, is mainly a mis-allocation issue. In large part, the wholesale trade establishments using R&D are tied to the pharmaceutical industry, and so more appropriately classified in NAICS 3254. For this reason, we do not use the output price index for wholesale trade, but assume that the price changes of 5417 output to this industry are captured by the output price index for pharmaceutical manufacturing. We also do not use the output price index for management of companies. This industry includes establishments from a mix of different industries, which dilutes the ties between the industry's output price index and the price change of R&D output. This leaves us with five industries representing the main users of the Scientific R&D Services output as an input.

While four of these five industries have output price indexes with a positive slope, semiconductor manufacturing output prices are declining (chart F). The contrast between semiconductor manufacturing and other industries highlights a disadvantage of the downstream output price approach—the need to classify R&D innovations as product or process-oriented. In the construction of downstream industry output price indexes for the 2007 R&D satellite accounts, the BEA assumed that the majority of innovation was product-oriented.[11] Using this same assumption, we take the geometric mean of the five industries' output price indexes (see the Industries A price index in chart G). The

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[11] As detailed in Copeland, Medeiros and Robbins (2007) on page 16, "Mansfield, "Industrial R&D in Japan and the United States: A Comparative Study" (AEA Papers and Proceedings, 78, 2, 1988, p.224-228) … characterizes the majority of U.S. industrial R&D activity as product innovation. A 2006 IBM Global Business Services study of the chief executive officers also found that the emphasis of corporate innovation was a third more likely to be directed toward new products, services, or markets compared with operational innovation that improved effectiveness and efficiency (Expanding the Innovation Horizon, The Global CEO Study 2006, page 12)."

resulting price index implies that R&D output prices fell over the time period by more than 7 percent. The contour of the price index is non-linear, with a period of price increases from 1987 to 1994, followed by seven years of price declines. From the industry output price indexes in chart F, it is clear that the price of semiconductors heavily influences the resulting R&D output price index by driving the price declines in 1995 and onwards.

While strong cases that R&D innovation is product-oriented can be made for industries such as Pharmaceutical manufacturing, it is harder to do so for industries such as semiconductor manufacturing. Indeed, this industry's use of innovations to build more powerful chips can be persuasively characterized as process-oriented. As mentioned, the designation of R&D output used in this industry as process or product-oriented is crucial for the resulting R&D output price index, because of the rapid fall in semiconductor prices over this time period. By assuming the semiconductor industry, and only the semiconductor industry, uses process-oriented R&D as inputs, we transform the price index and make it consistent with the other downstream industries. Specifically, we use the fact that process-oriented R&D implies a *negative* relationship between the industry price and R&D output price indexes. The resulting R&D price index reports price increases in every year from 1987 to 2005, where the average annual rate of price change is 4.00 percent; this is 40 percent higher than 2.87 percent average measured by the Hybid price index (see Industries B in chart G). For two reasons, our preferred downstream industry output price index is this second index, Industries B, where R&D innovations used in semiconductor manufacturing are characterized as process-oriented. First, we believe this is the correct characterization of R&D innovations used in semiconductor manufacturing. Of course, determining for which industries R&D innovations are process or product-oriented is a difficult and often subjective task. Second, this assumption implies that R&D output prices increased from 1987 to 2005, in line with the predictions from the other 4 industries we examined.

Despite the disadvantages of the downstream industry output approach, it does account for productivity changes missed by the input cost price index. In the spirit of Irving Fisher, a sound strategy may be to average the downstream industry output and input cost R&D price indexes. Averaging can be viewed as an extension of the downstream industry output approach, as roughly half of Scientific R&D Services are purchased by government and non-profits. In the national accounts, government and non-profit output is assumed to equal the sum of input costs, which implies that the appropriate output price index for these final users is an input cost price index. Taking the geometric mean of the input cost and Industries B price indexes, results in an output price index, denoted "All Users" in chart H, that partly reconciles the difference between the Hybrid and Industries B price indexes. From 1987 to 2005, the All Users price index reports an average annual price increase of 3.39 percent for R&D output, 0.52 percent more than the Hybrid price index's average annual price increase of 2.87. This difference in average annual price change translates into not insignificant differences to real total R&D output. With the Hybrid index, real total R&D output grew 49 percent from 1987 to 2004, while using the All Users price index results in growth of 27 percent. The All Users price index also has a linear profile, where the average R&D price increase is fairly constant throughout the time horizon. In contrast, the Hybrid price index shows an acceleration in the growth rate of R&D output prices after 1997.

In spite of the differences, there is a rough similarity between the All Users and Hybrid indexes. The standard error of the average annual price change under the Hybrid index is 1.53, which places the All User's average annual price change (3.39 percent) just within one standard error of Hybrid's average annual price change (2.87 percent). Of course, the year-to-year changes across the two indexes are quite different, as revealed in chart H. For example, in the late 1980's the Hybrid index runs higher while after 1997 the Hybrid runs lower. Despite these differences, both the All Users and Hybrid index tell the same story about the path of R&D prices over the period. Because of the difficulties inherent in measuring R&D output prices, we propose that averaging of the downstream industry output and input cost price indexes provides a valid first approximation of R&D output price change.

Conclusion

This paper has derived an R&D price index based on a model of an independent innovator. The price index was computed by using data from NAICS 5417 Scientific R&D Services, an industry that consists of independent innovators and the R&D establishments of firms located in other industries (e.g. pharmaceuticals). We have shown that our R&D output price index differs from the price indexes associated with the often cited alternatives, an input cost and downstream industry output price indexes. Our approach has the distinct advantage of using market-generated data for an industry that produces R&D services, inline with the 1993 SNA recommendations. Though further research is needed to identify the attributes of a suitable R&D output price index, our comparison with alternative price indexes provides a sense for the potential measurement error associated with these other indexes. Given the illustrated difference between the input cost index and our output price index, there is ample reason to be cautious about using the input cost index to determine R&D output.

Though our computed price index was 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). De Haan and Van Roojen Horsten (2004) discuss how data from this industry was collected and subsequently used to construct R&D output measures in the Netherlands.

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Chart A: 5417 Revenue

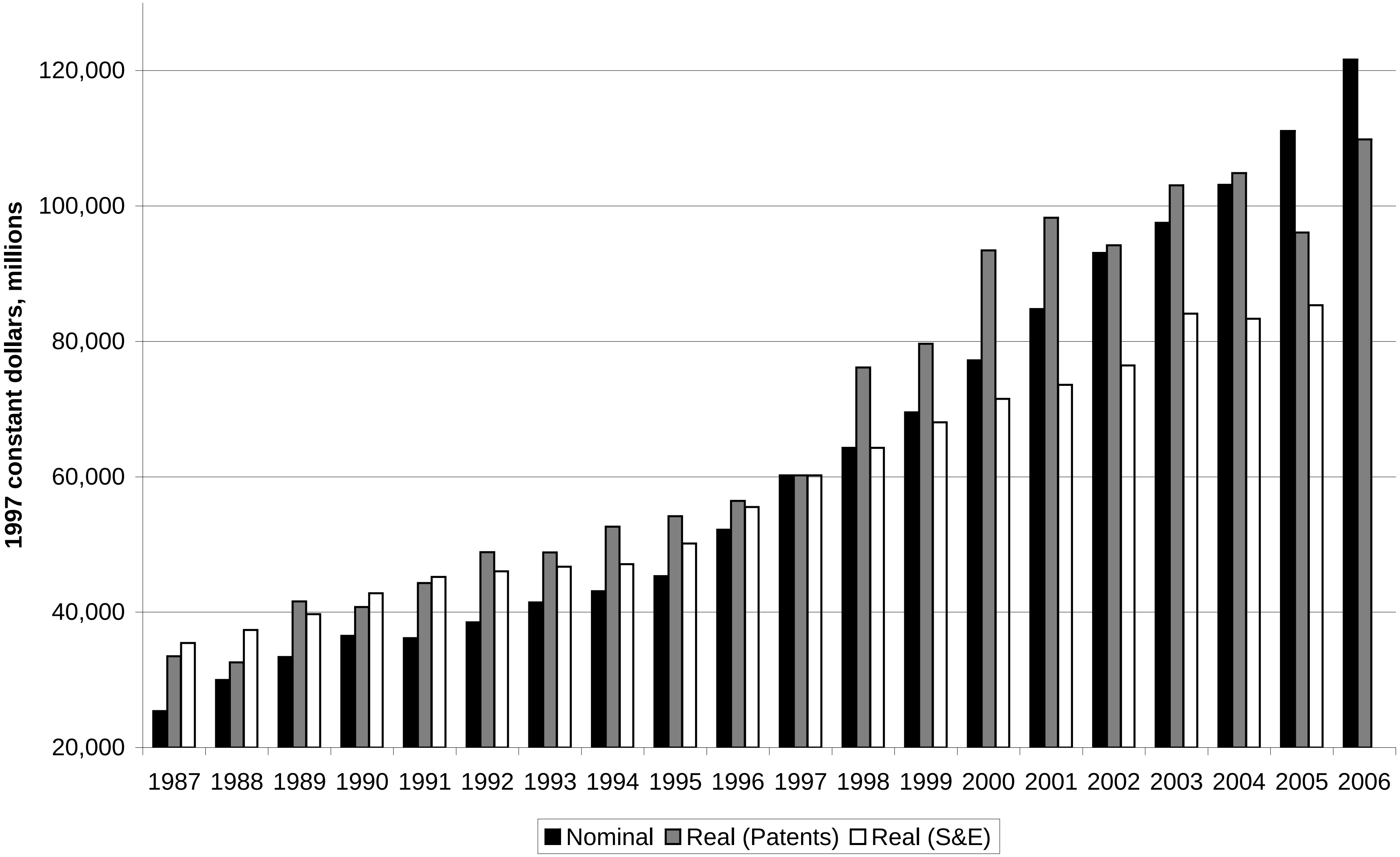


Chart B: 5417 Price Indexes

(base year is 1997)

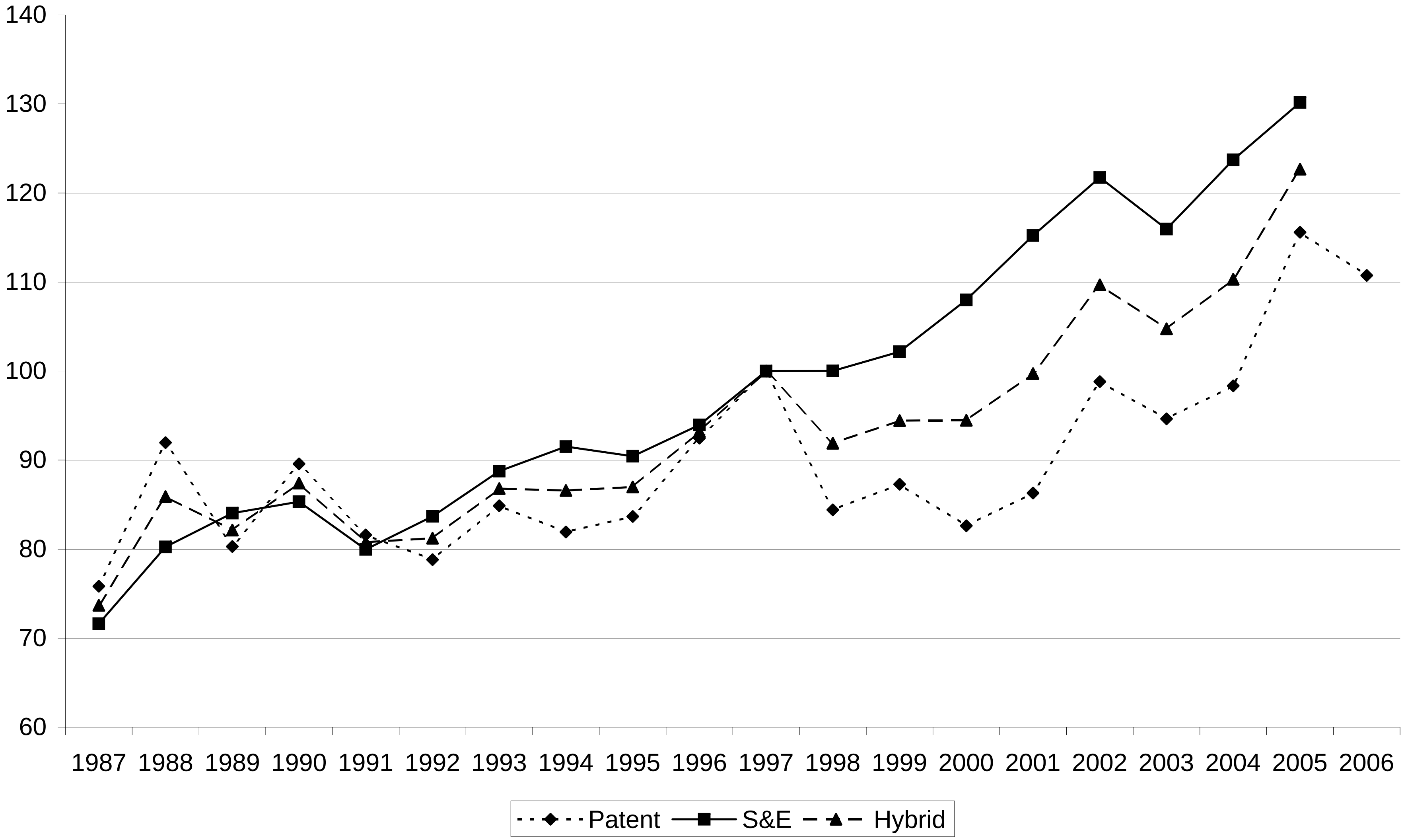
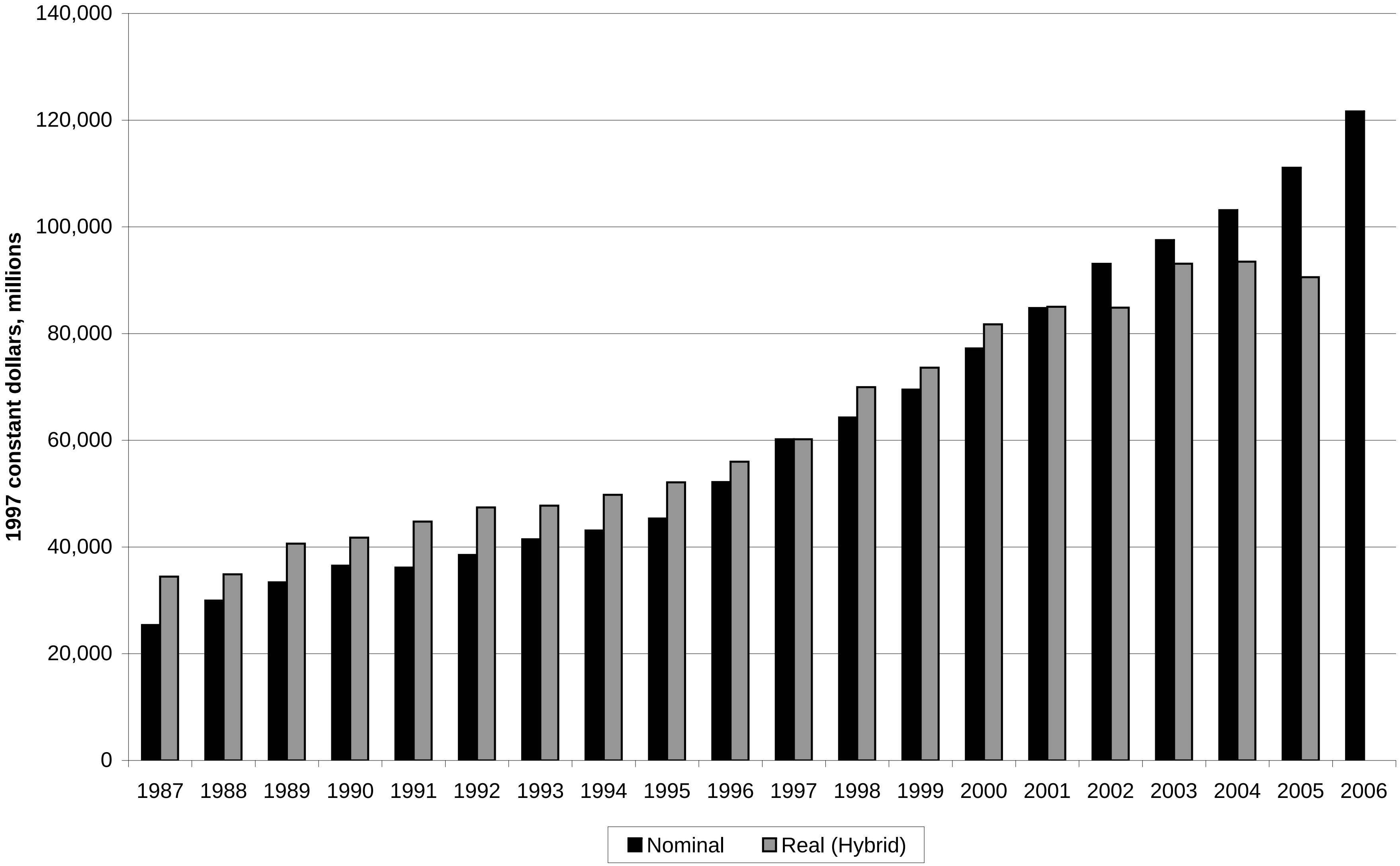


Chart C: 5417 Revenues



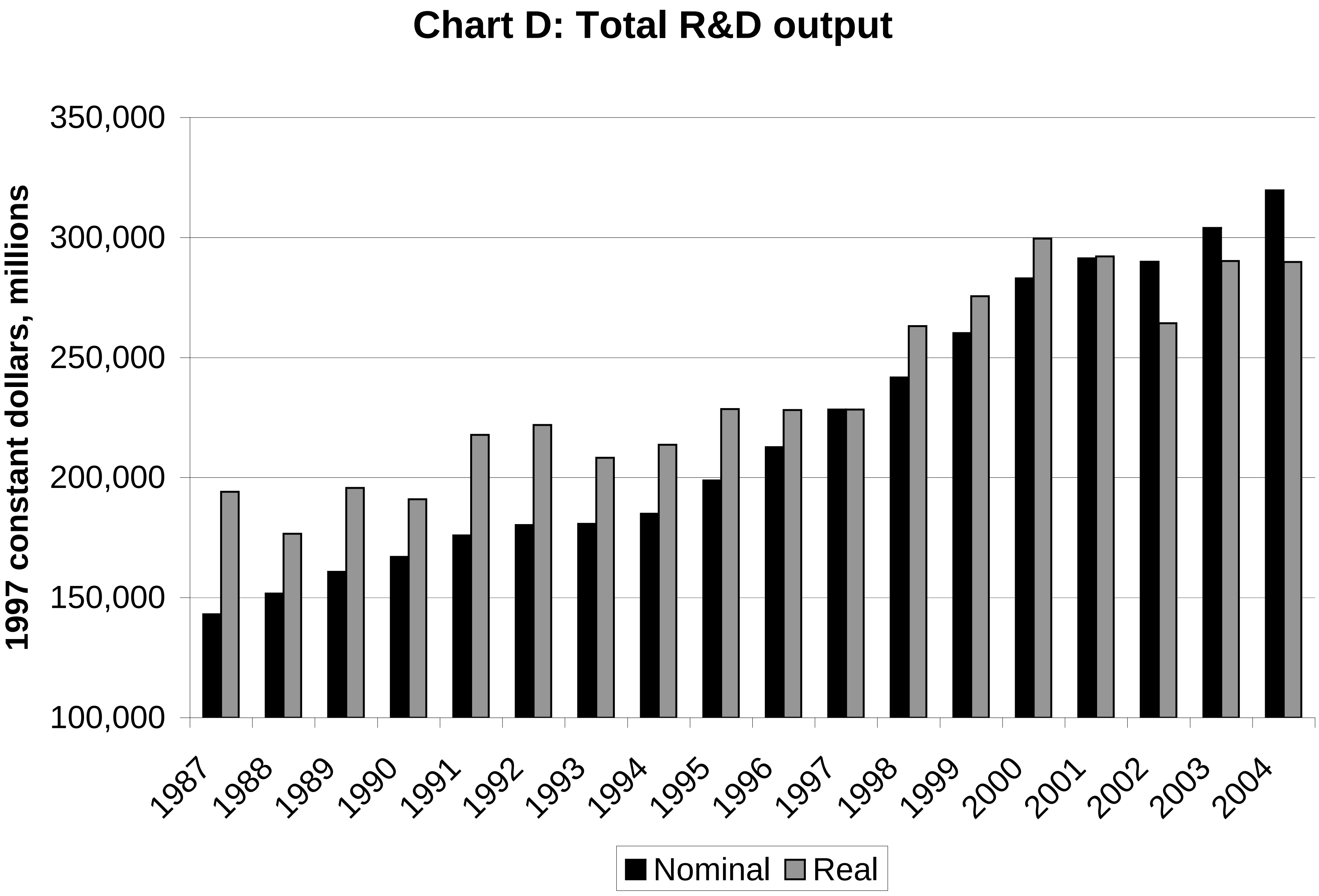


Chart D: Total R&D output
1997 constant dollars, millions
350,000
300,000
250,000
200,000
150,000
100,000
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
■ Nominal
▨ Real

Chart E: R&D Output Price Indexes

(base year is 1997)

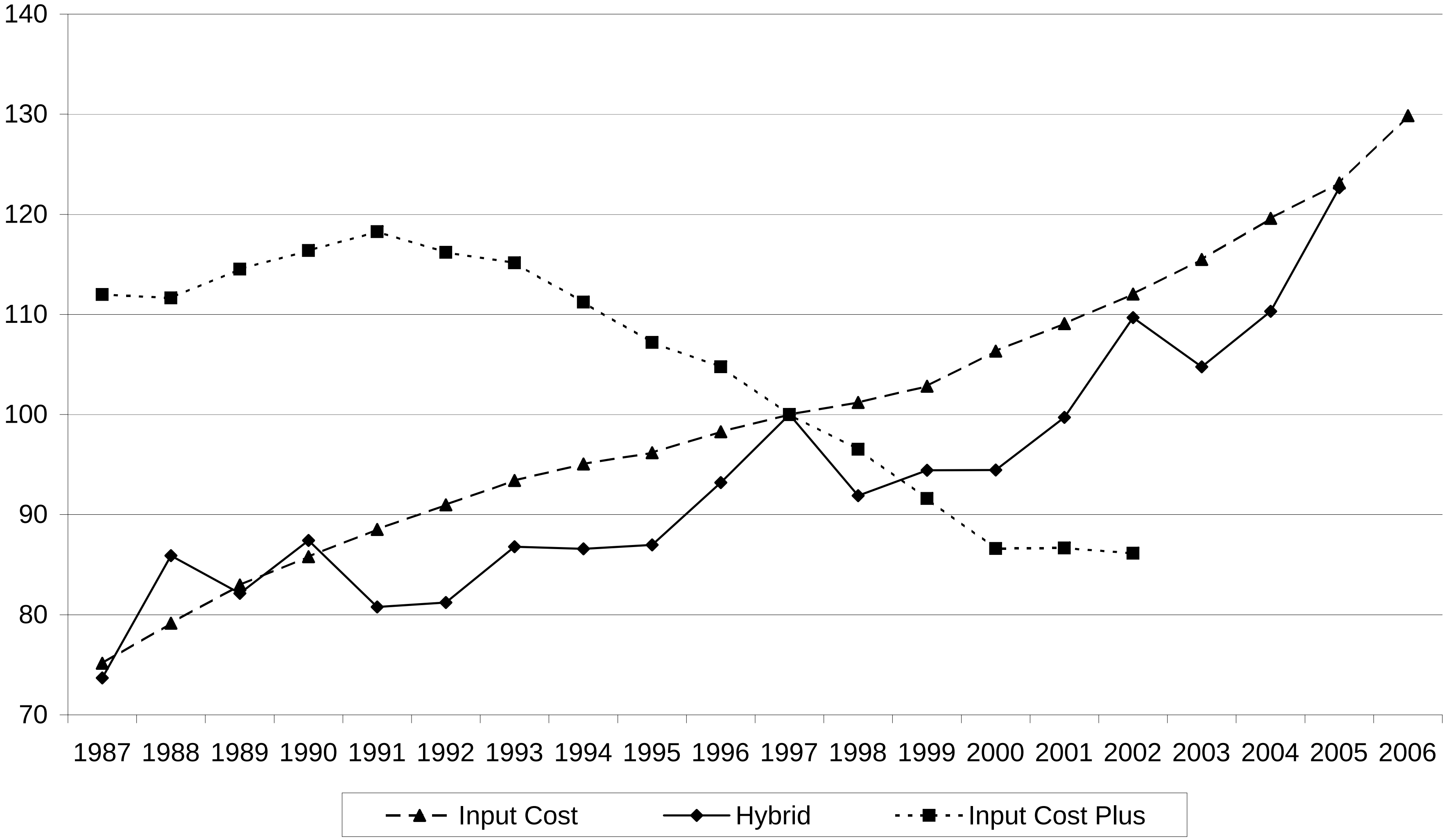


Chart F: Downstream Industry Price Indexes

(base year is 1997)

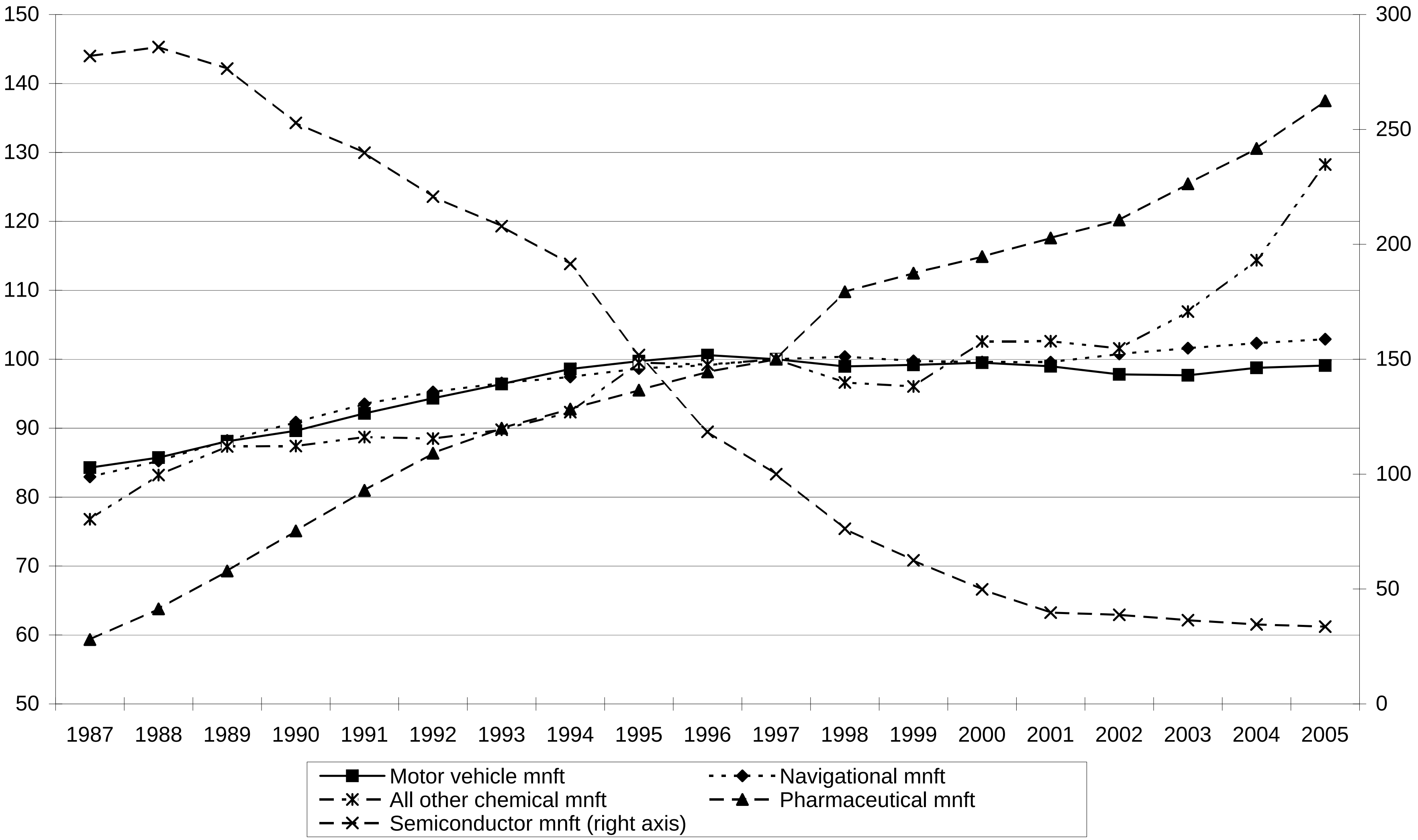


Chart G: Downstream Output R&D Price Indexes
(base year is 1997)

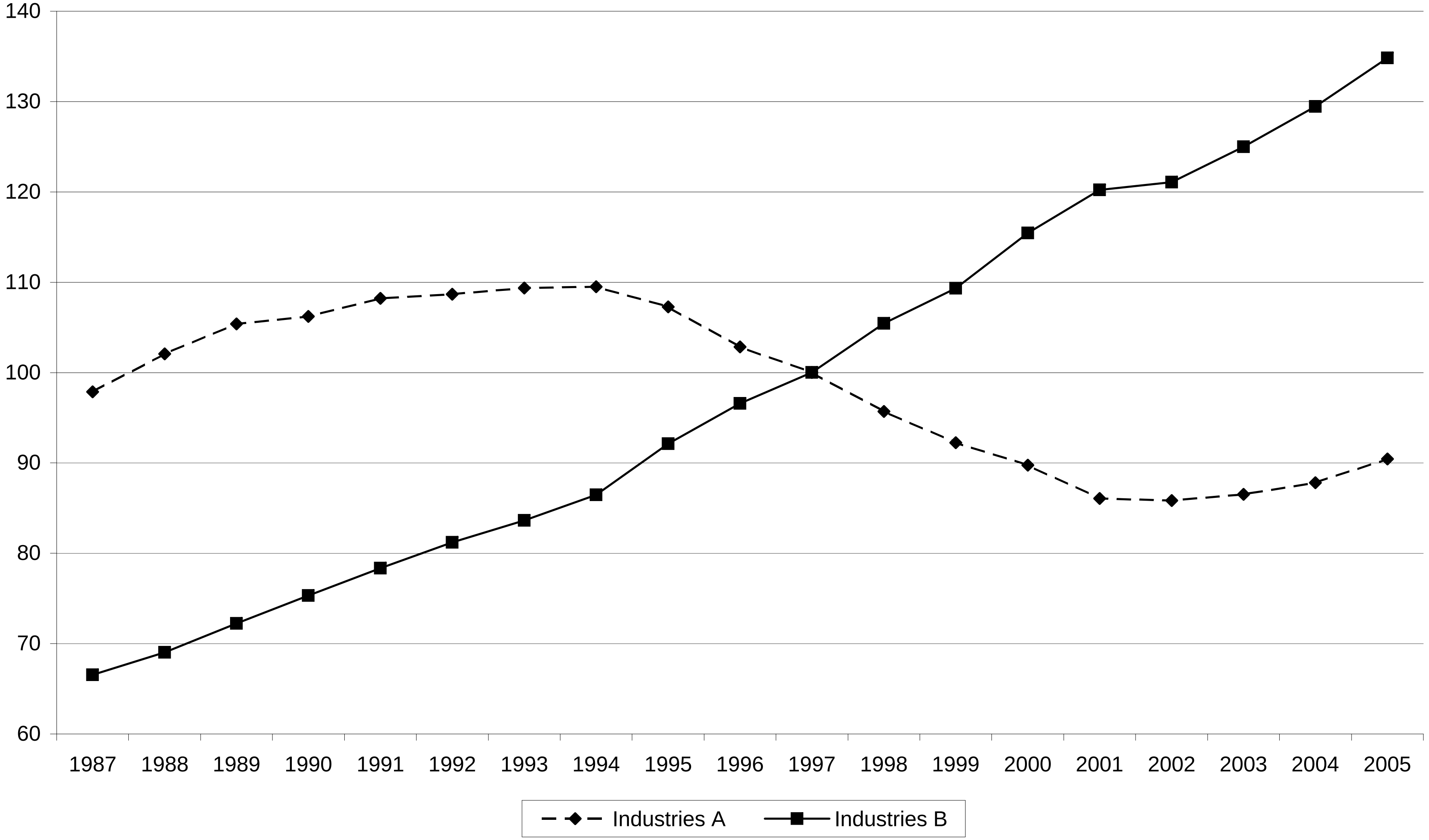


Chart H: Price Index Comparison

(base year is 1997)