Accounting for R&D in the National Accounts

Dennis Fixler
Bureau of Economic Analysis
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Introduction

There has been a great deal of recent attention directed to the importance of investments in intangibles in the growth of economies. The Bureau of Economic Analysis in 2006 and 2007 released R&D Satellite Accounts that illustrate how the incorporation of R&D as investment affects real GDP growth.[1] Corrado, Hulten and Sichel, CHS, (2006) also provide empirical support to the notion that accounting for investment in intangible assets raises the level of investment in the economy. However, drawing the boundary of the set of intangible assets as well as the measurement of its elements are difficult. As a result much of the attention has been more focused on the intangible asset created by R&D spending. In part, the motivation for the attention to R&D is due to the work of Solow and the identification of an unexplained residual in the growth of output; that is the growth in capital and labor alone cannot explain the growth in output. Implicit in the focus on R&D spending is the idea that technical change is an outcome of firm behavior—firms invest resources in R&D to enhance their growth through both product and process innovations. Schmookler (1965) was one of the early pioneers in this approach and in recent years the works by Jones (1995), Kortum (1997) and others have formed often cited models of endogenous technical change.

One of the main goals of the incorporation of R&D as capital into the national accounts is to determine its contribution to the growth rate of real GDP. But in gauging the contribution of R&D, at least in terms of the national accounts, convention limits the ability to obtain a complete measure of the contribution. More specifically, the convention in the national accounts of excluding externalities, or third party benefits, means that the attention has to focus strictly on the direct effects. Nakamura (2008) posits that the social valuation of R&D, the accounting of externalities, is needed to explain growth and the direct effects, the private valuation, is needed to explain wealth creation. Thus the contribution to the growth rate of real GDP is by definition going to be smaller than it actually is.

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[1] See Okubo et al (2006) for a description of the 2006 R&D satellite account and Robbins and Moylan (2007) for a description of the 2007 update to the satellite account.

Therefore, care must be taken in interpreting the estimates of the contribution in the national accounts as being consistent with the casual empiricism that the impact of R&D technological change is everywhere. The inability to account for externalities may not be the whole story but it is a part. The BLS Office of Productivity and Technology does include the impact of externalities on their measures and they still do not find a significant contribution of R&D to multifactor productivity growth.[2]

There are 4 key measurement questions that must be answered in any incorporation of R&D in the national accounts. They are: What is the output? How long does it last? What is the per-period use? What is its value? These questions are implicitly answered by CHS and in the BEA 2006 and 2007 R&D Satellite Accounts.

Before addressing these questions it is useful to briefly look at how R&D is currently handled in the national accounts.

Current treatment

Currently R&D expenditures are not treated as investment. Instead they were considered current period expenditures. Though it was widely recognized that such a perspective was conceptually incorrect, the measurement hurdles involved in treating R&D as investment were deemed too high to overcome .

That position was tenable until the substantial advances in IT and computer equipment were identified as the main sources of productivity growth in the 1990's. It thus became necessary to come up with a way to incorporate R&D as investment.

Revision to the SNA

The 2008 revision of the SNA now recommends treating R&D as investment. Thus the changes in the treatment of R&D affect the production account and the capital account.

In the production account, the R&D expenditure would now be recorded as the production of an asset instead of an expense. The production can take place for

[2] "Contribution of R&D to Private Nonfarm Business", BLS, August 2008, at www.bls.gov/mfp/rdtable.pdf

sale, for own use or for other non-market purposes. The last concerns largely the production of R&D in the government sector or the non-profit sector—mainly universities.

In the capital account the changes concern recording the additions to the capital stock and the consumption of fixed capital.

The intricacies of how the SNA revision should be implemented is currently being drafted by an OECD task force that is charged with writing a handbook on deriving capital measures for intellectual property.

Measurement Questions

What is the output?

Broadly speaking, the output of R&D is an idea. That is to say, the R&D process can be viewed as the accumulation of knowledge over time and at some point the knowledge is bundled into an idea, which can be sold or transferred. The idea can be embodied in a product, as in the case of pharmaceutical products, embodied in capital equipment, as in computer driven machines, or disembodied as in the case of managerial innovations. The notion of a managerial stock of knowledge that affects the growth of firms was addressed in Penrose (1959) and Marris (1966). One of the main features of innovations in the CHS framework is the attention to the sources of disembodied innovation.

Ideas are the epitome of intangibility. Their concrete manifestations, however, can be found in patents, copyrights, and so on. But not all of the output of R&D can be tied to such indicators; one can think of intrafirm R&D or the R&D undertaken by the government.

Because of the inability to count R&D output, it is through the deflation of nominal values that one obtains a quantity measure. Again, it should be noted that the output measure solely focuses on the direct effects of R&D; spillovers are not considered in measuring the output of R&D in the national accounts.

A necessary first step is to determine the nominal amount spent on R&D. But what is the definition of R&D? The Frascatti manual of the OECD sets out three kinds of R&D activity: basic research, applied research and experimental development. Further it delineates what expenditures should be included to support these activities. The National Science Foundation, through the Census Bureau, collects data on the basis of that framework. That framework however focuses on companies and not on establishments, which are the building block of the national accounts. Robbins (2006) sets out how the BEA R&D Satellite Account handles the mapping as well as some other issues concerning the differences in sector definitions. BEA collects data on R&D expenditures of multinational firms. The European Union and the OECD also have data collection efforts to collect the expenditures on R&D.

Within the context of the national accounts, the output measure affects 3 areas. They are: Gross Output, Exports and Imports, and Gross Fixed Capital Formation

The Gross Output measure captures the output of the different sectors that perform R&D. Assigning R&D output to domestic and foreign firms is crucial to determining the domestic production of R&D. It is also crucial to the measurement of the R&D capital stock, which is entailed in Gross Fixed Capital Formation.

<u>How long does it last?</u>

Ideas are replaced by new ideas. This stream of ideas is the heart of Schumpeterian competition: Firms compete with one another to be the first with a new idea. Indeed the innovation race literature is geared to modeling this competition for new ideas.

Practically speaking, several countries have engaged in surveys that attempt to get estimates of duration from performers of R&D. Australia has determined that the average service life is 11 years. Israel is an example of a country that has conducted surveys and has gotten somewhat the same answer.

Some countries have annual patent renewals and these may possibly be used to infer duration of the innovation. The use of these data is based on the idea that firms would not renew patents that were not valuable.

What is the per-period use?

Ideas do not depreciate in the usual sense of wear and tear. As stated above they are replaced by other ideas. In addition, though the idea may continue to exist, its value and thus the value of the per-period use also can be affected by imitation. The competition caused by the dispersion of an idea dissipates the monopoly return to it.

Diewert and Huang (2008) set out the problem of valuing per period use as one of implementing what accountants label as the matching principle. They note that because there is no depreciation in the usual sense, the problem of valuing per period use becomes one of determining an economically sound way of allocating the initial R&D expenditures to the later periods in which the (monopoly) profits are received. The key to their approach is determining an imputation that can be added to period t profit that is actually the imputed cost. Thus the monopoly profit in period t is reduced by the allocation of the initial R&D cost to later periods.

Mead (2007) describes the depreciation rates used by BEA in the 2007 R&D Satellite Account. These rates were determined by literature survey and the rates were industry specific: for transportation equipment the rate was 18%, for computers and electronics, 16.5%, for chemicals, 11% and for all other 15%. In the 2006 BEA satellite account a 15% rate was used throughout and this was treated as the benchmark case.

The assumed level of depreciation, or consumption of fixed capital, CFC, plays a few roles in incorporating R&D in the national accounts. These roles arise because treating R&D expenses as investment instead of as intermediate expenditures affects both the income and expenditure sides of the national accounts. To illustrate, business expenses on R&D would be treated as investment, which thereby boosts the investment component in GDP. At the same time, GDI goes up by the amount of R&D because business profits are no longer reduced by the R&D expenses. But if R&D is to become part of the capital stock then there would have to be a CFC component assigned to it. Thus, the amount of CFC is also raised and so the increase in business income is equal to R&D investment less CFC. There are also similar effects of CFC on Government and non-profit institutions serving households, which is included in PCE. The computation of the CFC in the BEA satellite accounts is discussed in Mataloni and Moylan (2007). The method essentially is based on IRS data on depreciation expenses that are adjusted by BEA.

What is its value?

The BEA satellite accounts showed that the impact of R&D on the growth rate of real GDP is crucially dependent on the choice of the deflator. CHS also noted the importance of selecting the proper deflator. Choosing the right deflator is problematic because there is no clear candidate—the absence of one derives from the fact that the prices for much of the R&D output, the non-traded part, are unobservable and the prices for the traded R&D output are not collected. CHS opt for the non-farm business deflator as a place holder for the deflator. In the BEA satellite accounts several different deflators were used—see Copeland et al (2007) for an in-depth discussion of the deflators used in the 2007 satellite account.

In a recent paper Copeland and Fixler (2009) further expand on one of the indexes examined for use in the 2007 satellite account. More specifically, they develop an index that seeks to estimate the price of R&D from the change in profit arising from its use. Empirically, the attention was directed to the establishments in NAICS 5417, Scientific R&D services. The establishments in this industry can be viewed as independent innovators that sell their R&D output. The price these innovators charge for their output should capture the increase in profit experienced by the buyer. Thus the revenue information for this industry contains information about R&D prices that the paper attempts to tease out. Below, the model for the innovator, located in NAICS 5417, is provided along with some empirics. The 5417 based price index is then compared to other R&D output price indexes used in the BEA satellite accounts.

Model of an independent innovator

Consider a partial-equilibrium industry model in which there are two types of agents. Innovators attempt to generate ideas that improve the current level of technology used by the firms. Once an innovator produces a technology-enhancing idea, it is sold to, and adopted by, a firm. Following the endogenous growth literature and reflecting the nature of innovation, it is assumed that the innovator has market power. Further, firms are assumed to operate in a competitive industry which is a small part of the overall economy.

Turning first to the firm, it is assumed that real 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 and w_Y the wage, then the firm chooses labor in order to maximize

$$AF(L_Y)D(Y,t) - w_Y(t)L_Y ,$$

where t is a time subscript.

The innovator's problem focuses on increasing the technology parameter, A. To capture different types of technological advances, it is assumed that innovators produce drastic or non-drastic types of innovation (Arrow (1959)). Non-drastic innovations are those that are comparable over time. These are relatively 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.[3] 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.[4] In contrast, the invention of the semiconductor represents a drastic innovation. Its introduction transformed multiple markets

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[3] 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 evolutionary implies a quality change of an existing good while revolutionary implies the introduction of a new good.

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

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

A non-drastic innovation is modeled as an increase in the level of A. A represents the current frontier of technology and includes the cumulation of knowledge from *all* relevant sources. Formally, a 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

$$g(x;\varphi,A,l_A)$$

is denoted as the probability of an successful innovation $x\in[1,\varphi]$, where l_A is the innovator's labor input. To capture the idea that more inputs increase the probability of success, it is assumed that g is increasing in l_A, but at a decreasing rate as g approaches one. Further, while there are many innovators in the economy, it is implicitly assume there is zero probability that two innovators successfully produce innovations within the same industry at the same time. Observe that the inclusion of A as an input allows it to influence the probability of producing new innovations.[5]

Drastic innovation is more sparsely modeled. More specifically 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 $h(A,l_D)$, where l_D is the labor input. As with g, it is assumed that h is increasing in l_D.

Let (L_A, L_D) define the total amount of labor used by all innovators working on non-drastic and drastic innovations, respectively. For the industry as a whole, the

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[5] Both Corrado, et.al. (2006) and Jones (2009) emphasize how the current stock of knowledge may be an important factor in the production of new innovations.

probability of a successful non-drastic and drastic innovation occurring is given by $G(A,L_A,\varphi)$ and $H(A,L_D)$ respectively. These industry-level probabilities are built up from the individual-level probabilities, g and h, and so they too are increasing in the labor inputs.

Using this notation, we can write the non-drastic innovator's problem, which is to choose labor, l_A, so as to maximize profits,

$$\begin{aligned}&\int_1^{\varphi} V(xA)g(x;\varphi,A,l_A)dx - w_A(t)l_A \\ &s.t.\ l_A \geq 0\end{aligned}.$$

where V is the nominal price of an idea and w_A is the nominal wage of researchers. The constraint that labor inputs be non-negative emphasizes that innovators can always exit the market by chosing l_A=0, if the benefits from innovation do not exceed the costs. Because it is assumed that innovators have market power and innovation-purchasing firms operate in a competitive market, innovators are able to extract all the gains in profits that the innovation-adopting firm receives.[6] 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 (Lucas (1978)). Similarly, innovations are priced according to the future discounted increases in expected profits the idea will generate for the R&D-adopting firm.

To formally define V, let $\pi(A',A,t)$ be the nominal increase in firm's profits attributable to the adoption of a new innovation, A', in period t. Let $\left(\widehat{L_Y},\hat{Y},\right)$ 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:

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

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

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

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

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

Equation (1) 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 depends primarily upon the expected future stream of profits and the relevant interest rate.[7] Because innovations face an expected obsolescence rate, pricing new ideas entails an extra dimension of difficulty relative to pricing a capital good.

Equation (1) provides a complete picture of the non-drastic innovator's problem. The innovator knows that in equilibrium, a successful innovation $x \in [1,\varphi]$, commands a price $V(xA;A,r,\varphi,L_A,L_D,N)$. Because this price looks forward at the impact an innovation has on the downstream market, it does not depend on the innovators' input choice, l_A. Rather, it depends on macroeconomic conditions (A,r,φ) and aggregate equilibrium labor inputs (L_A,L_D). In particular, as detailed in equation (1), future values of (L_A,L_D) effect the price of an innovation through obsolescence. If there are many innovators, then one innovator's labor choice does not influence the equilibrium aggregate labor input. Instead, the innovator's labor choice effects the probability that the innovator successfully innovates and the probability distribution of potential innovations, a relationship captured by $g(x;\varphi,A,l_A)$.

[7] Service life determination can also be difficult to measure for some capital assets.

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 $\widetilde{A}$, one can write the drastic innovator's profit maximizing problem as choosing labor, l_D, to maximize

$$W(\widetilde{A})h(A,l_D) - w_A(t)l_D .$$

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

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

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

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

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), it is seen 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 is necessarily difficult. 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.

Completing the model, it is assumed that free entry exits in the innovator's market. Hence, in equilibrium the expected profits from both non-drastic and drastic innovation must equal zero, or

$$(3)\quad \int_1^{\varphi} V(xA; A, r, \varphi, L_A, L_D, N)\, g(x; \varphi, A, l_A^*)\, dx = w_A(t) l_A^*$$

$$(4)\quad W(\widetilde{A}; A, r, \varphi, L_A, L_D, M)\, h(A, l_D^*) = w_A(t) l_D^*$$

where l^*_A and l^*_D are equilibrium labor choices for non-drastic and drastic innovators respectively.

The model can be used to connect the costs of the labor inputs to the price of an innovation. This relationship is important, because past research often relies on a fixed, proportional relationship between the change in input costs and the change in the price of R&D to construct R&D price indexes (e.g. Mansfield (1987) and Jankowski (1993)). The link between input costs and price is considered only for the non-drastic innovator's problem, though the results outlined below also hold for the drastic innovator's problem. In the model, changes in the input cost, or wages, have two impacts. The first impact of a change in wages is at an individual level, where innovators alter their optimal labor input, l_A. How this change affects innovator's profits depends upon g, as seen through the first order condition of the non-drastic and drastic innovator's problem,

$$\int_1^{\varphi} V(xA; A, r, \varphi, L_A, L_D, N) \frac{dg(x; \varphi, A, l_A)}{dl_A} dx - w_A = 0\,.$$

As detailed earlier, changes in the labor input effect the probability of an innovation $x \in [1, \varphi]$. The second impact of a change of wages in on the price of innovation, V. Because it is a forward looking measure dependent upon macroeconomic variables, V is not influenced by a single innovator's choice of l_A.

But, the collective actions of all innovators will change the price of R&D output. This second impact manifests through the aggregate labor input, L_A.

Consider the case where wages go up. Given this rise in input costs, some innovators will lower their labor inputs. In the aggregate, this change lowers the equilibrium level of the aggregate labor input. The aggregate labor input reductions affects the price of an idea by lowering the probability of a successful idea's obsolescence, raising the value and price of a successful innovation. Rising wages, then, increase the price of R&D output through the aggregate labor condition, L_A (see equation (1)).

While a positive correlation exists between the input cost of labor and the price of an idea, this is a highly non-linear relationship. First, the changes in wages and aggregate labor inputs are linked through equilibrium conditions, a non-linear relationship. Second, aggregate labor inputs influence price through the non-linear probability function $G(A,L_A,\varphi)$. In this fairly general and simple model, then, there is little hope that changes in input prices will yield reasonable approximations of the change in the price of R&D output, or that an input-cost price index provides a good approximation of the true R&D output price index.

Though equation (1) sets out the conceptual framework for the price of an innovation it is difficult to transform it into a concrete measure. Data on profits and the rate of expected obsolescence are required, figures that are, at the very least, difficult to obtain. While the preferred course of action would be to use such data to directly estimate the parameters in equation (1), the absence of data requires a more indirect course. Using the model's framework, R&D output is considered as a group of ideas or innovations. Then using the Frisch product rule, one can indirectly compute an output price index by decomposing the movement in the innovator's revenues 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))

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

Even taking equation (3) to the data is difficult, because data on prices, quantities and revenues are required, all of which are not readily available. Only a small amount of R&D is licensed or sold in the market place. 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 it has value. To create networks effects, firms may provide innovations to consumers for free.

The 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. Two different quantity measures are tried: the change in the number of successful patents for NAICS 5417-related R&D and the change in the number of employees in NAICS 5417 establishments. The patent data come from the US Patent and Trademark Office (USPTO). Using a mapping of patents to industries provided by the USPTO, the number of successful patents attributed to industries to the following industries was selected: Chemical & Allied Products, Rubber & Miscellaneous Plastic Products, Electrical & Electronic Machinery Equipment, Transportation Equipment, and Professional & Scientific Instruments.[8]

The 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 employees in the industry. The data come from the Bureau of Labor Statistics. This broad measure of labor is chosen over the commonly used scientist and engineers because it captures substitution between different professions.[9] Technical

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[8] The USPTO categorizes patents into industries based upon information claimed and disclosed in the patent. Patent counts data 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.

[9] The National Science Foundation collects employment data on the number of scientists and engineers, but only has data for NAICS 5417 from 1998 onwards. In addition to the employment data we use in this paper, the BLS also publishes

assistants and other occupations not deemed to be scientists or engineers are likely to be important in the production of R&D.

With the caveats about the quality of the data in mind, chart B illustrates the two price indexes for R&D output corresponding to the two types of quantity indexes. These two price indexes provide different contours to R&D output price-change. The patent-based price index exhibits steady growth over our sample period of 1987 to 2006, with an average annual growth rate of 4.5 percent. In contrast, the employment-based price index exhibits faster, but slowing growth rates. Over the sample period, the employment-based price index has an average annual growth rate of 6.6 percent. Before 1997, however, prices grew 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 (chart A). In particular, the employment-based price index results in a much flatter stream of real NAICS 5417 revenue. Real revenue computed using the employment-based price index grows 20 percent from 1990 to 2006. In contrast, real revenue computed using the patent-based price index grows 90 percent over the same time period.

Because it is not clear whether patents or the number of employees is the better indicator of R&D output quantity, the geometric mean of the indexes' growth rates is used.[10] This average is hereafter called the 5417 output price index.

In the 2006 and 2007 BEA R&D satellite accounts several R&D output price measures were used. One was an aggregate input cost index that focuses on the expenditures on inputs on R&D by the private sector, government and non-profit institutions serving households (Scenario A). The use of input cost is a standard method in the national accounts for measuring the value of output that does not have an observable price. In the U.S. national accounts, this approach is used for computing the real value of the output of governments and nonprofits institutions serving households. A limitation of this approach is that it necessarily implies that real inputs grow at the same rate as real output and thus produces zero productivity growth (e.g. real output cannot grow faster than real inputs).

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employment figures by occupation and industry. Unfortunately, for NAICS 5417 these occupation data are only available from 2002 onwards.

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

BEA in 2006 experimented with an input cost index adjusted for multifactor productivity growth in manufacturing, Scenario B. This scenario assumes that the real value of R&D output is higher than the real value of R&D inputs by the amount of productivity growth recorded in higher-performing industries in the U.S. economy; the industries used varied from year to year but "electronic and other electrical equipment, except computer equipment," and "industrial and commercial machinery and computer equipment" consistently appeared in the top. This adjustment was implemented by subtracting average multifactor productivity (MFP) growth, estimated for a group of manufacturing industries with the highest MFP growth, from the increase in the cost-based price index from scenario A.

Instead of looking at input costs, one could also examine whether R&D output prices could be proxied by the output prices of downstream users of R&D. One variant of this approach focused on service industries, Scenario C. This scenario assumes that R&D, which is most similar to a service industry, is valued at the output prices of the most productive service industries. Though service industries have traditionally had lower productivity growth and higher inflation than the industries in the goods sector, key industries have a good record in producing high-productivity, declining relative prices, and ever increasing real output per unit of input. In this scenario, the R&D output price index is estimated using a weighted average of BEA's GDP by industry value-added price indexes of these high-productivity service industries. These industries are air transportation, broadcasting and telecommunications, securities and commodity brokers, and information and data processing services. A limitation of this approach is that it may not reflect the scope of the R&D performed in the economy.

Another variant of the downstream approach is to look at the industries that use R&D. In 2006 satellite account, this index focused on the four manufacturing industries that performed the most R&D and the price indexes that were used varied by industry—one was a gross output price index, two were valued added price indexes and one was a personal consumption price index. In the 2007 satellite this index focused on the top 13 industries performing R&D and notably added software publishers. Furthermore, the 2007 version used the corresponding industry producer price indexes as published by the BLS. The 2007 version of this index will be the featured index here. A limitation of the downstream price approach is that it assumes that all of the movement in the downstream output price is attributable to R&D. Furthermore, it combines the effects of product and process innovations which have contrasting effects on price; ceteris paribus, product innovations raise demand and thereby increase the price of the using good and process innovations lower costs and thereby reduce the price of the using good.

The table below provides a comparison of the various price indexes.

Comparison in Changes in Average Real GDP Growth

	1995-2002	1987-1994	1994-2004	1987-2004
W/O R&D, published	3.25	2.76	3.14	2.98
With R&D				
Scenario A; input cost	3.21	2.74	3.10	2.96
Scenario B; adj. input cost	6.80	na		
Scenario C; high productivity service.	6.30			
Scenario D; aggregate output price (2007)	3.40*	2.81	3.27	3.08
Scenario E; 5417 output price	3.08	2.66	2.98	2.85

*The 2006 version of Scenario D price index yielded an average growth rate of 6.7.

As can be seen from the table, the magnitudes of all the rates of growth are similar for scenarios A, D and E. The results in scenarios B and C are likely due to the fact that the set of industries used varied from year to year. Furthermore the prices in scenario C were value added prices produced from BEA's industry accounts and not BLS Producer Prices as were used in scenario D.

CHS use the non-farm business deflator as its measure of the R&D output price, though this is deemed a placeholder pending the determination of an appropriate deflator. Chart C compares that deflator with the input cost index and the 5417 output price index.[11] Given the similarity between the input cost index and the non-farm business deflator the comparisons above likely apply. However, it should be noted that from 2000 the non-farm deflator rises even less than the input cost index.

[11] At first blush, the years for which the input price index is above the output price index might strike one as yielding the untenable inference that innovator productivity growth is negative. Such is not the case. As shown in Appendix B in Fixler and Copeland (2008), the recognition of the uncertainty that is part of the innovation process as well as the non-competitive market structure for innovations makes inapplicable the textbook linear relationship between the growth rate of marginal productivity and the input and output price indexes.

The above table also illustrates the impact of incorporating R&D in the post-1994 time period. Observe that relative to the 1987-1994 period, scenarios A, D, and E show higher rates of growth in the 1994-2004 period, as does the real GDP growth rates without the incorporation of R&D. In the period 1994-2004, Scenario A has a rate of growth about the same (rounding to 1 decimal place) as the no R&D case, Scenario D higher and Scenario E lower. The lower growth rates for Scenario E likely results from the rising price trend for R&D illustrated in chart B; though it should be noted that for the period 1987-2004 the average annual growth of nominal R&D expenditures is less than the growth of nominal GDP without R&D. Without incorporating R&D there is a 0.38 percentage point increase in the rate of real GDP growth. The input cost index yields a 0.36 percentage point increase and the 5417 output price index a 0.32 percentage point increase. These values are approximately the same and thereby consistent with the CHS finding that when one expands the definition of capital to include many kinds of intangible capital, the increase in productivity growth in 1995 is not explained. On the other hand, the aggregate output price that is featured by BEA yields a 0.46 percentage point increase and so can be viewed as partly explaining the 1995 increase in productivity. This finding reinforces the point that the choice of the R&D output price index is crucial to gauging its role in the economy.

Other related issues

There are several other issues on which further research work is needed in order to incorporate R&D in the national accounts; two are prominent. One issue concerns the assignment of R&D to different parts of a company which is related to the more general issue of ownership and the identifying the beneficiary. This is an important feature of dealing with multinational firms. It also effects how one looks at regional issues—the headquarters of a company can undertake R&D whose results can be shared with all of the establishments of the company scattered throughout the company. A related issue is how to determine the related transfer price of the asset between the organizational units.

Another issue is how to measure productivity. There are two kinds of productivity that one can examine with R&D. The first concerns the measurement of productivity for the user of the R&D output. The second concerns the measurement of the productivity for the producers of R&D. The first kind requires the measurement of the R&D capital stock. Both BEA and BLS provide estimates of this stock. BLS estimates of the stock of R&D differ from those of BEA for a couple of reasons. One, the BLS focuses only on the private business stock while BEA includes government and non-profit. Two, the BLS estimates contain estimates of the impact of spillovers, which BEA does not consider. These estimates cause the BLS stocks to greatly exceed those of BEA--For example, the BEA reported that in 2002 the R&D stock was $931 billion, of which R&D financed by private firms was $581 billion. In contrast, in 2002 the BLS R&D stock, limited to the R&D of private firms, was $1295 billion.

The second kind requires an estimation of the production function and a particular issue is timing. Namely in the R&D production process inputs and outputs are not necessarily contemporaneous. Usually for measures of productivity one considers the output and inflows from the same time period. One could consider the output in each period as knowledge and the increase in knowledge over the period arises from the use of inputs. However, there would then be a problem of defining what the output is that is transferred to the user/buyer; a what point does the accumulated knowledge constitute a good?

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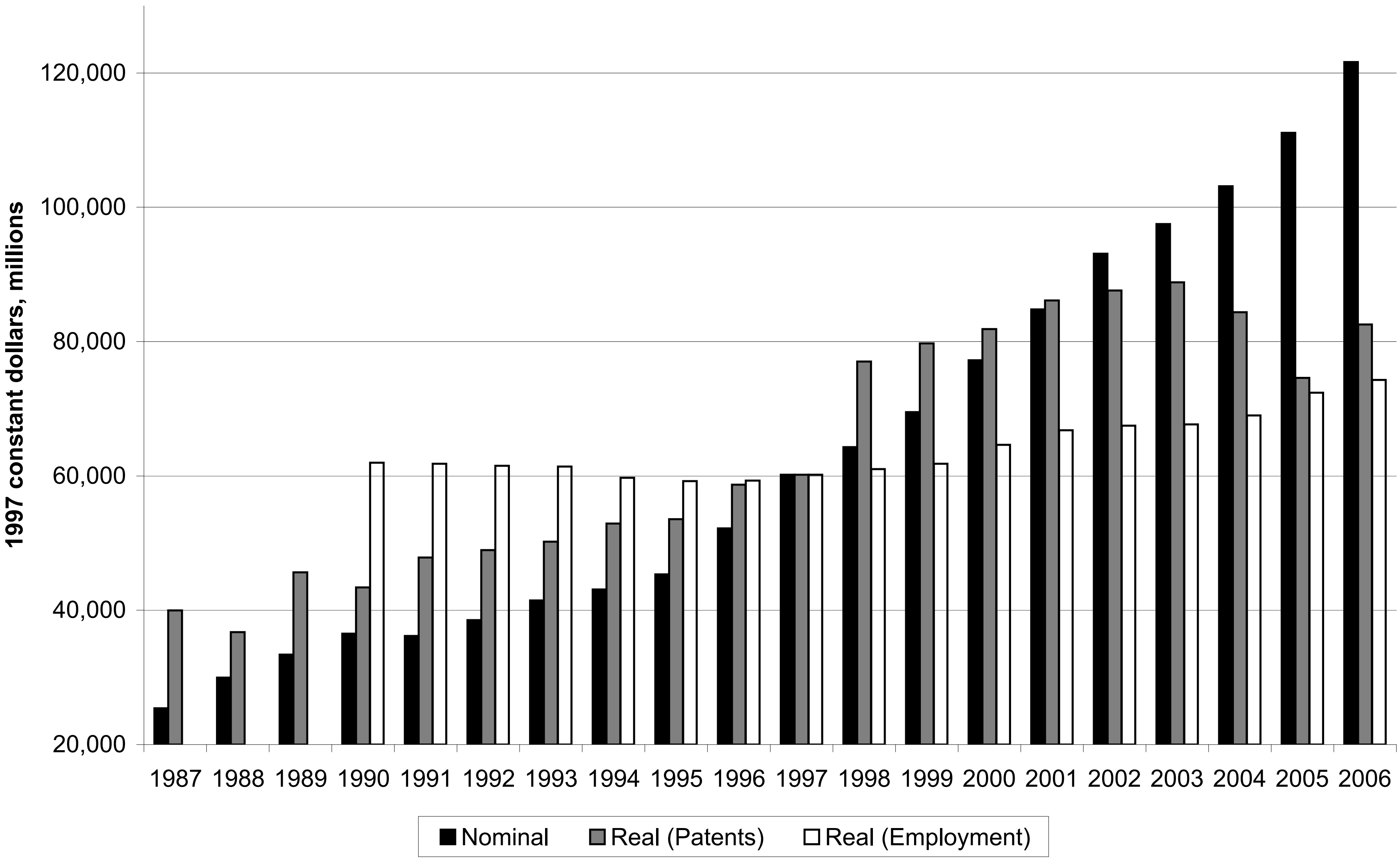
Chart A: NAICS 5417 Nominal and Real Revenues



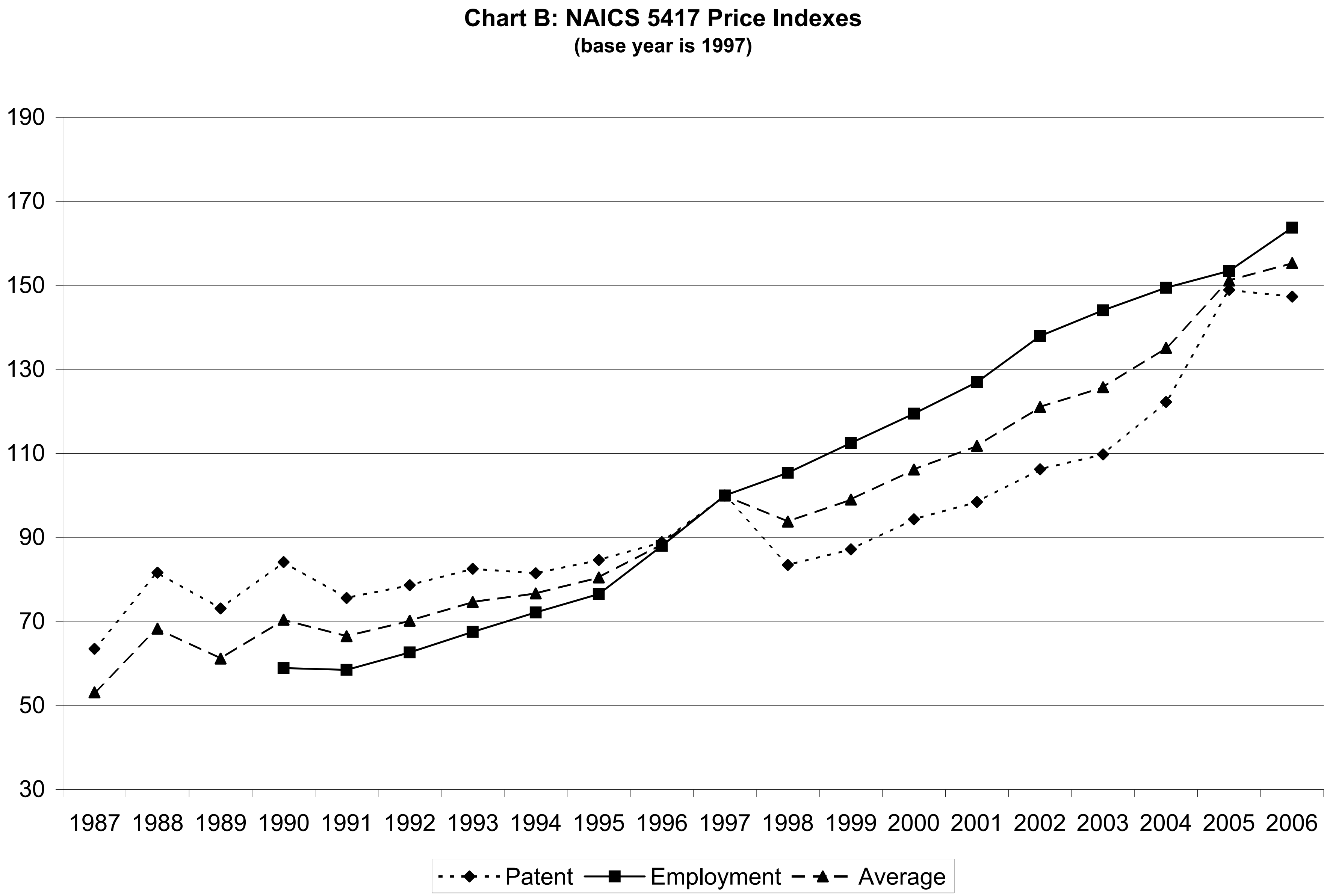


Chart B: NAICS 5417 Price Indexes
(base year is 1997)
190
170
150
130
110
90
70
50
30
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
Patent
Employment
Average

Chart C: Nonfarm business, 5417 output and aggregate input cost price indexes
2000=100