Industry-level Output Price Indexes for R&D: An Input-cost Approach with R&D Productivity Adjustment

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Abstract:

The expanding recognition of intangible assets in the production of economic output brings renewed attention to difficult measurement issues. Price and quantity measures are needed to incorporate these components of real investment in the national accounts. This paper describes the construction of industry-specific R&D price indexes that deflate nominal R&D output and investment in the absence of market prices and quantity measures. Building from a standard input cost approach we include a transparent adjustment for the unobserved productivity of the innovator. Our simple model says that the growth rate in R&D can, on average, be best understood by the growth rate in R&D inputs plus the growth rate in productivity in the conduct of R&D. The key question we face is the measure of productivity change in the production of R&D activity. Because we have very limited empirical evidence and the range of informed opinion varies very broadly, this is the most difficult question we face. We choose a broad economy-wide measure of multifactor productivity from the Bureau of Labor Statistics.

Our price indexes are relatively simple to implement for national accounts and capture variations in input types and input prices across industries. The indexes can be implemented and updated with publicly available statistical data, and build on the approach recommended by the OECD for capital intensive intangibles. We estimate that the price index for U.S. business R&D rose by 1.2 percent between 1998 and 2007; this compares to a 2.4 percent growth rate for the GDP price index.

We show experimental price indexes for five industries as well as the resulting growth rates of R&D investment for these industries based on these price indexes. These industries are pharmaceutical manufacturing, semiconductor manufacturing, motor vehicle manufacturing, computer system design and related services, and scientific R&D services. Our results show that the composition and price growth of inputs leads the growth rates of the indexes to differ by more than a percentage point. The alternative method of using a common deflator for R&D investment underestimates the growth in semiconductor-related R&D and overestimates the growth in pharmaceutical-related R&D. However, we also find that aggregate R&D investment and contributions to GDP growth are similar using either a single deflator for all business R&D or using the combined effect of separate industry R&D deflators.

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1. Introduction

R&D and other intangibles are widely understood to make a long-lasting contribution to the creation of economic output and growth. Estimating how big that contribution is, how much of that growth accrues to firms, and how much accrues to consumers are all questions of economic analysis that rely on a quantity measure of R&D output. Translating nominal expenditures into such a quantity measure in turn requires a price index for R&D output. Thus the decision to choose a particular approach to price index measurement has implications for how we understand the role of R&D in the economy. As R&D activity becomes a routinely measured component of the national capital stock, readily updatable price indexes are needed to estimate the quantity of R&D investment in the national economic accounts.

The standard method would be to base an index on the movement in market prices over time for units of R&D output. For R&D this approach is difficult for two reasons. First, prices are unobserved as most business R&D is performed for internal use. Second, the heterogeneous nature of R&D activity makes it difficult to standardize a unit of R&D output. R&D output measurement is further complicated by the different ways that economists and policy analysts define R&D output. For the purpose of measuring investment in the national economic accounts, we define R&D output as additions to the stock of productive knowledge created by systematic R&D expenditures. For businesses, this productive knowledge is used to create further output. R&D expenditures fund both valuable additions to the stock of knowledge and complete flops. The magnitude of each is based on technological opportunity, regulatory influences, demand driven conditions, managerial and entrepreneurial expertise, and innumerable other random influences. Deflated R&D expenditures are therefore broad averages.

Our goal is to estimate a market-based measure of the price of R&D to the firm, given systematic expenditure measures that are industry aggregates. Systematic R&D expenditure as a measure of R&D output is a less specific measure of R&D output than one that could be applied at the firm level for R&D projects. The firm may be able to identify and objectively measure ex post the discounted stream of revenue from a particular successful project and measure R&D output in this way. While less specific than a successful project measure, using systematic R&D expenditure is a measure of a firm's R&D output is also a more limited concept than one that accounts for *outcomes*. In addition to the value of R&D output to the firm, these outcomes could include the value to society of the extra years that a new drug may add to life expectancy, or the enhanced well-being families achieve from cell phone contact.   While these outcomes are arguably some of the most important product of R&D activity, these outcomes are not priced explicitly and are a separate measurement concept. Similarly, although the spillovers from innovative knowledge are widely considered to be important sources of economic growth, national accounts do not, as a rule, explicitly measure externalities. The market-based measure of the price of R&D to the firm is one that allows R&D expenditures to be treated as additions to a quantity of R&D assets for an economic owner rather than the benefit of R&D to the economy as a whole.

This paper describes the construction of industry-specific R&D price indexes. Building from a standard input cost approach we include a transparent adjustment for unobserved productivity of the innovator. Our indexes are straightforward to implement for national accounts and capture variations in input types and input prices across industries. The indexes can be updated with publicly available statistical data, and build on the approach recommended by the Organization for Economic Cooperation and Development (OECD) for intangible capital.

The OECD has two related recommendations with respect to R&D output prices, first, that conceptually, output prices should reflect the difference between input prices and the productivity growth in the production process. Second, they recommend that input prices should be used until a consensus is reached on appropriate "pseudo output" prices.[1] Our proposed method provides both a detailed method for input prices and an example of how to derive productivity-adjusted output prices. The method can also be further simplified with the increasingly available KLEMS data on industry inputs.[2]

The indexes are based on industry cost weights from National Science Foundation (NSF) R&D expenditure data, wages from the Bureau of Labor Statistics (BLS) and intermediate input data from the Bureau of Economic Analysis (BEA). These cost weights are for wages for scientists and engineers, wages for support personnel, materials and supplies, current cost depreciation, and other R&D costs. These resulting input cost indexes are adjusted to account for unobserved productivity in the knowledge-creation process. For this unobserved productivity, we use BLS multifactor productivity for the non-farm business sector. This choice is based on a simple assumption that this productivity measure is a good estimate of the average of innovator productivity. Finally, we compare a data intensive approach that estimates R&D costs separately for industries with an approach that uses a common deflator for R&D performed in different industries.

We find that the weighted average of these productivity-adjusted input cost indexes for R&D grows at an average annual of 1.2 percent between 1998 and 2007. This compares to a growth rate of R&D input costs of 2.7 percent and a growth rate of the gross domestic product

[1] *The Handbook on Deriving Capital Measures of Intellectual Property Products* (2010) recommends that input prices be used until a consensus is reached on appropriate "pseudo output" prices. The *2008 System of National Accounts* defines these pseudo output prices in paragraph 15.117.

[2] *KLEMS* stands for capital, labor, energy, materials, and purchased services.

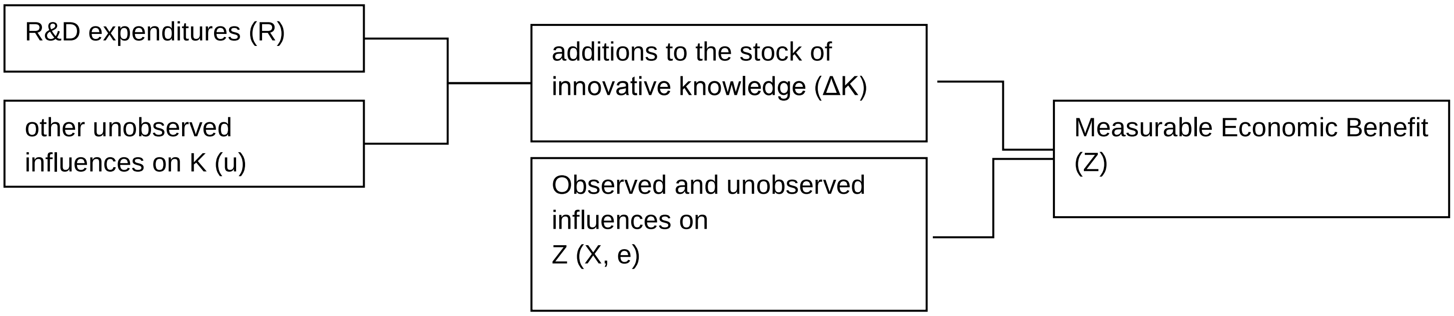
(GDP) price index of 2.4 percent over the same period. We also find that using a common deflator for the R&D of different industries matters primarily at the industry level. Not surprisingly, the use of a common deflator for R&D investment implies more rapid R&D investment growth for industries that have experienced relatively rapid increases input costs compared with an industry-specific deflator.

Sections 2 and 3 provide background information on alternative approaches to R&D price and quantity measurement. Section 4 describes the construction of R&D input cost indexes. Section 5 describes the productivity adjustment. Section 6 describes the results and a comparison to deflation of R&D with a single index. Section 7 concludes. The appendix sections are arranged in the following order: 1) a mathematical appendix on the use of a multifactor productivity adjustment; 2) a series of data tables on the price index results, real R&D investment, and the growth rate of real R&D; 3) a methodological appendix with details on the construction of the input cost indexes.

2. Background

Lacking market prices for units of R&D output or R&D characteristics, we begin with the model of knowledge production presented by Griliches (1984). In this model, research expenditures, R, combine with other unobserved factors, u, to produce an increment to knowledge capital, ΔK, which is also unobserved. This unobserved knowledge capital combines with other influences to produce a measurable benefit, Z (figure 1). The production of additional increments of knowledge capital is what we are trying to measure. However, one of the main difficulties in measuring these increments is that they can be embodied in a number of heterogeneous forms, such as recipes, blueprints, and working plans, where their values are hard to quantify.

Figure 1. The Production of Innovative Knowledge



These relationships can be expressed in the following form:

$$Z = f(\Delta K, X, e).$$

where the increment to knowledge capital, together with other factors (*X*, *e*), provides an economic benefit. This benefit can be narrowly focused, such as profits, or a broadly focused, such as social benefit associated with a higher rate of GDP growth. This benefit is sometimes measured with a proxy variable, such as patents or operating income.

The two approaches most frequently used to measure ΔK are to use upstream inputs, such as R&D expenditures or R&D employment, and to use an indicator of innovative output, such as patents or other downstream outcome measures. However, as Griliches explains, unobserved variables produce measurement errors in both approaches. Additional factors that contribute to the measurement error include uncertainty in the production of innovative knowledge and market structure.

Market structure can affect both the production of innovative knowledge and the production of downstream products. The relationship of market structure and innovation is an unsettled topic: Schumpeter (1946) holds that firms with market power innovate to maintain their dominant position. This view leads to a positive relationship between product market

concentration and innovation (1946). Alternatively, Arrow (1962) holds that competitive firms have a greater incentive to innovate because they do not have an existing product that the innovation would compete with. When the market for R&D is separate from the downstream market (R&D is not internal to the firm), the case is stronger for market power as a central element in the price of R&D. Significant price power should accrue to innovators who can create and sell a unique product.

For R&D that is performed for internal use, market structures as well as public good qualities influence price formation. Hirschleifer's (1956) view is that internal transfers should take place at market prices when a commodity can be sold in a competitive market. When a commodity is sold in an imperfectly competitive market or in a situation where no external market exists, then internal transfers should take place at a price between marginal cost and the market price. For R&D and other intangibles, nonexcludability can make it difficult to control third party use in market transactions, limiting the extent to which a firm can both sell the R&D and use it internally. In this case, the competitive market price provides a benchmark target.

3. Measuring R&D prices

Following the process shown in figure 1, four broad methods to measure R&D prices can be identified. We review them briefly in turn: 1) an output or downstream approach; 2) an input-cost or upstream approach; 3) an approach based on modeling the unobserved production of knowledge; and 4) variants that combine one or more methods.

Observable downstream approach

An implicit approach to price measurement is to use a measurement parameter of downstream output to identify the change in the unobserved quantity of knowledge created with R&D activity. The simplest implementation of this is the change in the price of all downstream

goods and services as a proxy for the unobserved price change of R&D. A quantity measure can then be calculated from nominal expenditures with this implicit price. A GDP price index is one typical measure. This approach is frequently used in international comparisons and is currently used by the National Science Foundation to create constant-dollar measures of R&D expenditures. A variation on this approach is used in the BEA's R&D satellite accounts to deflate R&D outputs. This variation assumes that the unobserved R&D price changes are equal to the price changes for downstream goods produced directly by the industries that perform R&D. Product innovation increases demand for the downstream goods, leading to a rise in the equilibrium price of the firm's downstream products. This follows when the innovator has monopoly power and can capture the price increase for downstream goods in the price of the innovation. [3]

Compared with the movements of a broad GDP price index, this BEA R&D price index falls much faster due to the output price movement of R&D intensive industries. An important component of this faster falling index is the influence of hedonically-deflated semiconductor and electronic equipment industry outputs. These industries have price indexes that fall more than those of many other industries. Two limitations of this particular variation of the output approach are that it is assumes that R&D produces an incremental innovation and that the price change of R&D is the biggest influence on price change in the downstream good.

Downstream operating income is an additional measure that has been used to quantify R&D output. Aboody and Lev (2001) estimate R&D productivity at the firm level for the chemical industry and for the software industry using operating income as an indicator of ΔK. In the context of a deflator for national economic accounting, a limitation of this particular measure is

[3] This approach is discussed in Copeland, Medeiros, and Robbins (2007).

that R&D productivity is calculated as a residual after adjusting for other types of intangible capital. As a result, the implied productivity measures appear to be highly sensitive to unobserved influences.

Patents are another downstream measure used as proxies for the quantity of R&D output. Patent data are used in an extensive literature that investigates the determinants of R&D on productivity measures. However, the value of patents differs widely, with many patents having very little private economic value and a small number having a large value (Lanjouw and Shankerman, 2004). As a result, compared to a simple measure of patent counts several refinements have been made to improve this approach. These refinements include the use of patent renewal data as measured through the payment of maintenance fees (Pakes and Shankerman, 1985, Pakes and Simpson, 1989), the number of claims on the patent document (Tong and Frame, 1994), the number of countries where a patent is filed or granted (OECD 2009), and patent citations (Jaffe and Trajtenberg, 2002). A limitation to this approach for a price index for business R&D in the national accounts is that these indexes are created with data that are released with a substantial lag of several years.

In addition to patents, pharmaceutical-related R&D activity has output measures in the form of new drug applications, biologics license applications, and new drug approvals.[4] By linking the spending for R&D for the development of new drugs to the pace of new drug applications and approvals, these output measures can be used to estimate the cost of developing a new drug. By comparing the growth in R&D spending over time to the growth in these output measures, conclusions can be drawn about the rate of productivity growth for pharmaceutical-related R&D. Based on this type of evidence there has been slowing productivity in pharmaceutical R&D (see

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[4] Papers in this area include Vernon and Gusan (1974) and Berndt, Cockburn, and Grepin (2006).

for example DiMasi, 2003). Reviewing the evidence in this area, Cockburn (2006) concludes that the ratios of new drug counts to R&D expenditures suggest an apparent slowing since 1996 in approval rate for new molecular entities. The issue of quality adjustment for these outputs remains an unresolved issue.

Input-cost approach

For the national economic accounts, the use of input price change as a proxy for output price change is a standard approach when market prices are unobserved or nonexistent. Price changes of R&D inputs have been used since the early 1970s to create price indexes for R&D output. Historically, these price indexes were created to test the robustness of the more common deflator for R&D, a gross national product deflator (GNP), and to improve on it as an indicator of real R&D output. Jaffe's (1972) proposal of a weighted index based on labor compensation and the implicit price index for the nonfinancial corporate sector is early work that was endorsed by Griliches (1984) as the best that could be produced with secondary data sources.

Mansfield, Romeo, and Switzer (1983) extend the input-cost index approach using detailed cost information about company-financed R&D in the U.S. Their indexes all increase more than the GNP deflator, leading them to conclude that the use of the GNP deflator overestimated the growth over time in real R&D output. Jankowski (1990) updates the work of Mansfield, Romeo and Switzer by extending the index to annual measures of price change. Dougherty, Inklaar, McGuckin, and van Ark (2007) extend this approach across countries, finding that cross country variation in labor costs have the largest impact on relative prices for R&D.

Even though input-cost measures are commonly used, they suffer from one major shortcoming. In particular, these indexes do not allow changes in productivity to affect the real

measures of R&D output that should be measured in a set of national economic accounts. Considering the widely held view that R&D expenditures are an important source for increases in productivity, we consider more complex alternatives that model the unobserved knowledge creation process.

Unobserved knowledge creation approach

A third approach to measuring R&D prices and quantities is to model the production of unobserved innovative knowledge. Corrado, Goodridge, and Haskel (2011) do this using a two-sector model to isolate an estimate of total factor productivity (*TFP*) growth in the knowledge creating sector. Using steady state assumptions that the growth in real R&D capital stock is equal to the growth rate of R&D investment assets (τs_Y^N) , they model conventionally-measured TFP into two parts, one unobserved part that is attributable to the downstream industry (*Y*) and a residual that is attributable to the knowledge production process (N) :

$$\Delta lnTFP^{measured} = \Delta lnTFP^{Y} + \tau s_Y^N \Delta lnTFP^{N}$$

Since measured productivity includes the impact of both sectors, the challenge here is to estimate the unobserved productivity of the downstream industry and the capital income share of the innovation assets. With these two measures the residual can be calculated. They do this by assuming that unobserved downstream industry productivity is independent of innovation intensity at the industry level. They can then identify the productivity growth of each sector with a regression of measured productivity on R&D intensity as measured by R&D surveys:

$$\Delta lnTFP^{measured} = a + b \cdot s_{G,i,t}^{N\ \ measured} + e_{i,j}$$

Unobserved downstream industry productivity growth is estimated by *a* and productivity in the knowledge production process is estimated by *b*. As the authors note, these parameters can best be understood as the underlying trends in the two unobservable productivities. After calibrating

their results for a measure of market power in the knowledge-producing sector, their results show that R&D prices in the United Kingdom fall at an average annual rate of seven and a half percent per year from 1981 to 2005.

By this measure conventional methods of deflating R&D output substantially underestimate the growth of real R&D investment. The result is an important contribution to understanding the sources of economic growth in a growth accounting framework. With its assumption of long run equilibrium conditions, it provides a general measure of long range tendencies. However, this approach does not yield a price index that is appropriate for current period deflation in the national accounts. Specifically, a price index for the national accounts needs to account more immediately for changes in prices and productivity. A further concern with this approach is that a large component of the TFP residual is allocated to the unobserved knowledge creation process. Some of this residual clearly is due to the knowledge input used by business. However, there are other factors as well that are part of the TFP residual. In addition to spillovers from other companies' R&D, these factors include both omitted variables and measurement error. For a related discussion of the TFP residual, see Hulten (2012).

Mixed approach

Copeland and Fixler (2012) used a combination of approaches to create a price index for R&D for the specific industry devoted to scientific R&D services, classified by the North American Industrial Classification system as 5417. They used an indicator that combines an output measure in the form of growth in scientific R&D services industry patent counts and an input measure in the form of growth in scientific R&D services industry employment. By incorporating patent counts they improve on a simple input-cost price index by allowing for changes in productivity. The resulting price index rises faster than a traditional R&D input price

index. This faster rise consequently implies slower growth in the quantity of R&D output. A remaining question is whether this single index based on the scientific R&D services industry (NAICS 5417) sufficiently captures industry variation in the R&D process, since this activity can take place in many different industries.

4. Methodology for input cost indexes

Our industry-specific price indexes for R&D activity combine two of the approaches described in section 3. First, in the spirit of Mansfield and Jankowski, we create industry-specific R&D input cost indexes. In our second step, we adjust the input cost indexes to reflect the unobserved productivity changes in R&D activity using the growth rate of a broad multifactor productivity aggregate. Thus at the conceptual level there are similarities between our approach and that of Corrado, Goodridge, and Haskel. However, as we will describe, our results are substantially different.

Five-component input cost indexes

We start by creating and evaluating R&D input cost indexes for scientific R&D services, pharmaceutical manufacturing, semiconductor manufacturing, motor vehicle manufacturing, and computer system design and related services. Each industry input cost index uses a Fisher formula to combine prices and quantities for multiple goods and services into a single index. Fisher indexes are constructed by taking the geometric average of a Laspeyres and a Paasche index. Their general properties are described in more detail in BEA (2011). The particular formula we use is one that combines prices and expenditures from two adjacent time periods and is described in Copeland, Medeiros, and Robbins (2007).

We also create two multi-industry input cost indexes to make economy-wide comparisons that account for all business sector R&D. One is for all-other goods R&D and one

is for all-other services R&D. Further, because there is substantial overlap in the economic output measured as computer software-related R&D and own-account software, we use BEA's price index for custom and own-account software for computer software-related R&D.

Each industry has five cost components with a matching component price sub-index.[5] These cost component weights and price sub-indexes are combined into industry-specific input cost indexes using a Fisher formula. The five cost component weights are based on NSF business R&D data in five basic spending categories: Wages for scientists and engineers; wages for support personnel, materials and supplies; current cost depreciation; and other R&D costs. According to NSF (2006) other R&D costs are composed of utilities, such as telephone, electricity, water, and gas; travel costs and professional dues; property taxes and other taxes (except income taxes); insurance expenses; and company overhead including: personnel, accounting, procurement and inventory, and salaries of research executives not on the payroll of the R&D organization. Table 1 shows the average expenditure shares for each category for our target industries, based on NSF data.

Table 1 Average Cost Component Weights, 1997-2007

Industry	Wages for scientists and engineers	Wages for support personnel	Materials and supplies	Current cost depreciation	Other R&D costs
Scientific R&D Services	26.2	11.8	15.2	5.6	41.2
Computer systems design services	28.4	32.5	4.9	4.8	29.4
Pharmaceutical manufacturing	21.0	11.2	10.6	6.0	51.2
Semiconductor manufacturing	31.6	17.4	12.3	8.6	30.1
Motor vehicle and related parts	20.9	23.9	23.6	3.2	28.4
All other goods	27.1	15.6	15.2	4.7	37.4
All other services	29.8	15.8	13.5	4.6	36.3

Based on National Science Foundation Business R&D survey data and BEA calculations

[5] Appendix table D shows the data sources used for the component price indexes for our approach.

The five sub- indexes that correspond to these five component weights are created with weights and price indexes from BLS and BEA. The wage sub-indexes for scientists and engineers are created using BLS average wages for three occupational categories: Computer and mathematical occupations, architecture and engineering occupations, and life, physical, and social science occupations. The wage sub-index for R&D support personnel is created from BLS average wages for production workers. Integrating the NSF data in table 1 with the BLS wage data requires an additional explanation about these data sources.

Table 2 Industry Sub-Indexes
Wages of Scientists and Engineers and Production Workers
2005 = 100

Industry	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Scientific R&D services	**70.0**	**74.9**	**80.0**	**86.0**	**91.2**	**92.3**	**94.5**	**97.9**	**100.0**	**104.9**	**108.5**
Scientists and engineers (1)	69.3	74.1	79.0	85.0	90.0	91.0	93.0	97.4	100.0	105.0	110.0
Production workers	71.7	76.8	82.2	88.2	94.1	95.2	97.9	99.1	100.0	104.8	105.1
Computer system design services	**80.4**	**84.3**	**88.5**	**92.9**	**97.6**	**92.7**	**96.8**	**97.9**	**100.0**	**103.6**	**106.4**
Scientists and engineers	76.0	80.5	85.1	90.7	95.0	92.8	95.3	98.6	100.0	103.7	108.0
Production workers	84.4	87.7	91.6	94.9	100.0	92.6	98.1	97.2	100.0	103.4	105.0
Pharmaceutical manufacturing	**71.4**	**76.8**	**81.7**	**88.5**	**92.2**	**93.3**	**95.8**	**98.1**	**100.0**	**104.0**	**108.6**
Scientists and engineers	69.7	75.0	79.7	86.6	91.2	93.0	94.3	97.0	100.0	105.1	111.9
Production workers	74.7	80.4	85.6	92.2	94.2	93.7	98.6	100.4	100.0	101.9	102.7
Semiconductor manufacturing	**75.1**	**79.3**	**83.5**	**88.5**	**93.0**	**92.5**	**93.6**	**96.8**	**100.0**	**103.7**	**107.2**
Scientists and engineers	75.0	78.8	82.7	87.5	91.4	91.0	92.3	96.1	100.0	103.9	107.9
Production workers	75.4	80.1	85.0	90.4	95.9	95.3	96.0	98.0	100.0	103.4	105.9
Motor vehicle and related parts	**75.4**	**80.1**	**85.0**	**90.4**	**95.9**	**95.3**	**96.0**	**98.0**	**100.0**	**103.4**	**105.9**
Scientists and engineers	73.8	78.3	82.9	88.6	92.8	93.7	93.9	97.0	100.0	104.5	108.4
Production workers	76.3	81.0	86.0	91.5	96.9	97.8	98.5	99.7	100.0	103.1	105.3

(1) These indexes are created using wages and employment from the broad BLS occupational categories computer and mathematical occupations, architecture and engineering occupations, and life, physical, and social science occupations.

Table 2 shows the variation across industries in the wage sub-indexes created from the BLS data. An important point to keep in mind is that although table 1 (based on NSF data) and table 2 (based on BLS data) both show cross-industry variation in input costs, the industry categories are conceptually different. NSF and BLS use different industry classification standards that are organized either by companies (NSF) or by establishments (BLS). For BLS data along with BEA industry data and much of the Census Bureau data, industries are classified based on the activity of each establishment. The NSF data are generally classified based on the

industry to which the consolidated reporting company is assigned. Thus the cost weights in table 1 represent the combined R&D activity within the reporting firm that can take place in a combination of dedicated R&D establishments, company headquarters establishments, as well as production or testing establishments. To match this in the cost component sub-indexes we use inputs and prices from a combination of establishments.

The price indexes used for the cost components *materials and supplies*, *current cost depreciation*, and *other R&D costs* are based on BEA price indexes and described in more detail in the sections below. The resulting industry-level price indexes shown in the top panel of Appendix Table A (R&D Price Index Comparison) are industry-specific R&D price indexes for scientific R&D services; pharmaceutical manufacturing R&D; semiconductor manufacturing R&D, motor vehicle and related manufacturing R&D; and computer system design-related R&D. Each index shares a core set of sub-inputs specific to R&D activity and also includes industry-specific inputs. The next section describes the construction of the index that contains the core set of sub-inputs specific to R&D services.

Scientific R&D services

Scientific R&D services companies are engaged in conducting original research on a systematic basis to gain new knowledge and create new or significantly improved products or processes (OMB, 2002). They may sell R&D as contracted services to other firms or operate as entrepreneurs to develop, patent, and commercialize innovations. R&D services establishments may perform these activities as well as operate as auxiliaries for other units within the same company, providing specialized R&D services.

For the scientific R&D services input cost index we start with the component weights shown in Table 1 that are based on NSF business R&D survey data.[6] The sub-indexes for each component are based on establishment data. BLS average wage data for establishments classified as scientific R&D services are used for wages for scientists and engineers and for support personnel. For materials and supplies and for other costs we use BEA annual industry data. These BEA data provides both the input expenditures used in scientific R&D services establishments and the movement of matching input prices. The source of the BEA input data on expenditures is the 2002 Business Expenditure Survey (BES) component of the quinquennial Economic Census and the Census Bureau's Annual Services Report for 2005 and beyond. The BEA input prices are based primarily on BLS producer price indexes. For current cost depreciation, a measure of capital services, we use the BEA deflator for consumption of fixed capital services for miscellaneous business and professional services (NAICS 5412OP). This is the broader industry aggregate in BEA's account in which scientific R&D services is a component.

These five components and their matching sub-indexes combine to create an input cost index. Each five-component index may be compared to a labor cost index that combines the wage costs and expenditures for the two types of labor shown in Table 1. Both the five-component Fisher input cost index and the labor cost indexes are shown for four industries in Figures 2 -6.

[6] Scientific R&D services companies are engaged in conducting original research on a systematic basis to gain new knowledge and create new or significantly improved products or processes (OMB, 2002). These companies may sell R&D as contracted services to other firms or operate as entrepreneurs to develop, patent, and commercialize innovations. R&D services establishments can also operate as auxiliaries for other units within the same company, providing specialized R&D services.

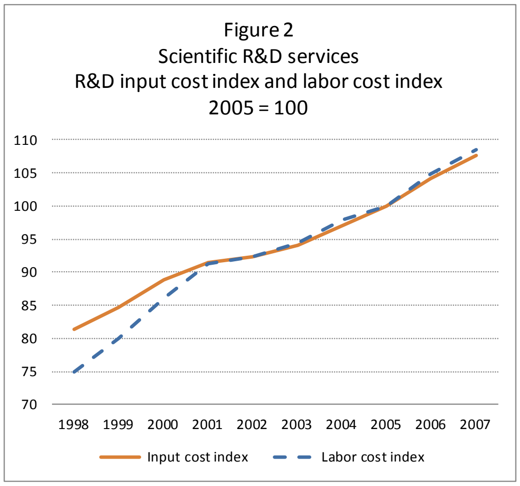
Accounting for other industry costs

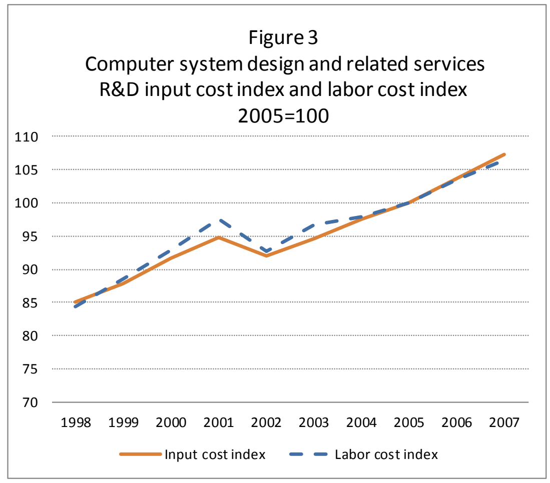
One goal of our work is to understand how much difference accounting for heterogeneity in R&D input costs would make to real measures of R&D investment across industries. For pharmaceutical and medicine manufacturing-related R&D, semiconductor and other component manufacturing R&D, motor vehicles-related R&D, and computer system design and related services R&D we use industry-level information to tailor R&D inputs to costs to that industry. Our approach accounts for differences in both industries and in phases of R&D activity.

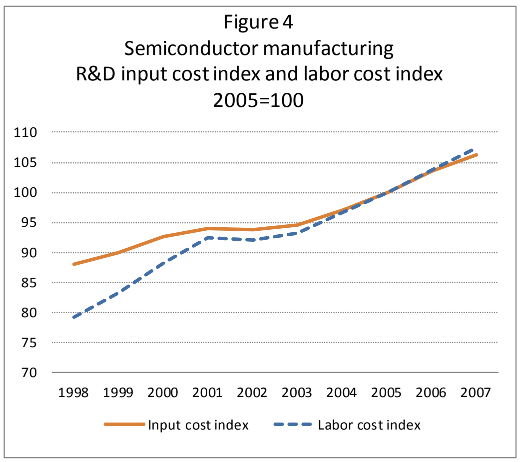
For each industry listed above we use industry-specific cost component weights from the NSF data (Table 1), labor costs from BLS, and input prices from BEA. We add another layer of complexity to the process by using the classification of R&D activity by type from the NSF data to divide each industry's R&D into basic research, applied research and experimental development phases. We vary input costs and prices based on both industry and phase of R&D activity. Basic and applied research phases are constructed with weights that are heavy in R&D and engineering inputs. Experimental development is weighted toward the inputs of the R&D performing industry.

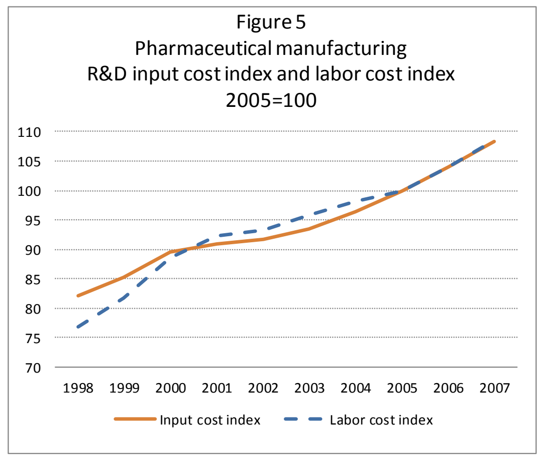
This procedure is described in more detail in the methodology section of the appendix (page 50). The methodology section of the appendix also includes a description of the inputs used for the all other goods and all other services R&D input cost indexes (appendix table E).

The resulting R&D input cost indexes and labor cost indexes are shown in Figures 2 through 5 for scientific R&D services, semiconductor manufacturing, computer system design and related services, and pharmaceutical manufacturing, The motor vehicle R&D cost indexes are presented in the appendix tables, though not shown below.









Source: BLS

Figures 2-5: R&D Labor and Input Cost Indexes, 2005 = 100

The concern that the use of the GDP price index to create constant price measures of R&D expenditures could overestimate real R&D activity was an early motivation for the development of input price indexes for R&D (Griliches, 1984). For the period 1998-2007 our results show more rapid input price growth rates for pharmaceutical-related R&D and for scientific R&D services compared to the GDP price index. For R&D performed by other industries the growth rate of the GDP price index is quite close over the period 1998-2007 (Appendix Table A).

The growth rate of the industry-specific input price indexes ranges from an annual growth rate of 2.1 percentage points for semiconductor-related R&D to 3.2 percent for scientific R&D services. The range for labor costs alone is wider. The industry-specific labor cost index for computer system design and related services grew at an annual rate of 2.6 percentage points over the period while for pharmaceutical-related R&D the growth rate was 3.9 percentage points.

By construction the pharmaceutical-related R&D index is very similar to the scientific R&D services index. For the basic and applied research phases the weights and prices are 50 percent scientific R&D services and 50 percent pharmaceutical manufacturing. For the experimental development component of pharmaceutical and medicine manufacturing-related R&D, where clinical trials play a large role, input weights and prices from the medical and diagnostic laboratories industry are included. The resulting labor costs rise relatively faster than other costs during this period, an average annual rate of 3.8 percent for labor costs compared to 3.1 percent for all inputs.

The two cost indexes shown in Figure 5 for pharmaceutical and medicine manufacturing can be compared to the survey-based Biomedical Research and Development Price Index (BRDPI), an index created specifically to estimate inflation in the inputs to biomedical R&D that is funded by the National Institutes of Health. Between 1998 and 2007 the BRDPI index rises at an average annual rate of 3.8 percent,[7] nearly the same as our pharmaceutical R&D labor cost index, but at a faster rate than our index reflecting all input costs.

Input costs for computer system design-related R&D show the effect of the technology buildup in the late 1990s and the subsequent drop in 2001 associated with the dotcom industries. Compared with other industries the input costs for semiconductor-related R&D are climbing at a

[7] National Institutes of Health, 2012.

more moderate rate. The input cost indexes for motor vehicle related R&D are not shown in the charts but are included in Table A. These costs rise at an average annual rate of 2.5 percent, just above the growth rate of the GDP price index, 2.4 percent.

5. Productivity adjustments

More than thirty years ago Griliches and Mansfield were interested in understanding whether R&D costs were rising faster than the GNP deflator. To understand the magnitude of R&D investment by industry or in an economy as a whole, this issue still has relevance. As Corrado, Goodridge, and Haskell (2011) point out, a conclusion that real R&D effort as a share of GDP is stagnating is partly determined by the deflator used. While the input cost indexes described above provide a constant price measure of R&D *inputs*, the lack of productivity adjustment clearly understates the overall growth of real R&D over time. The constant price measure we are aiming for is the innovative knowledge that is used in the production of other goods and services. We describe the intuition briefly here and in more detail in the mathematical appendix to the paper.

Our model is one of an innovator producing innovative knowledge (*N*) with a Cobb-Douglas production function. The innovator is a price-taker and sells the innovative knowledge at price P^N. With no productivity growth in the production of innovative knowledge the growth rate of P^N can be simply represented as the share-weighted growth rate of input costs, W^N. This W^N is the familiar input cost index combined with a Fisher formula as described in section 4.

With productivity growth in the production of innovative knowledge, the growth rate of input costs will exceed the growth rate in the price of innovative knowledge P^N. On average, this difference can be best understood by the growth rate in R&D input prices less the growth rate in

productivity in the conduct of R&D, A^N. That is to say, a productivity-adjusted input cost index for the innovative knowledge embodied in R&D activity can be calculated as:

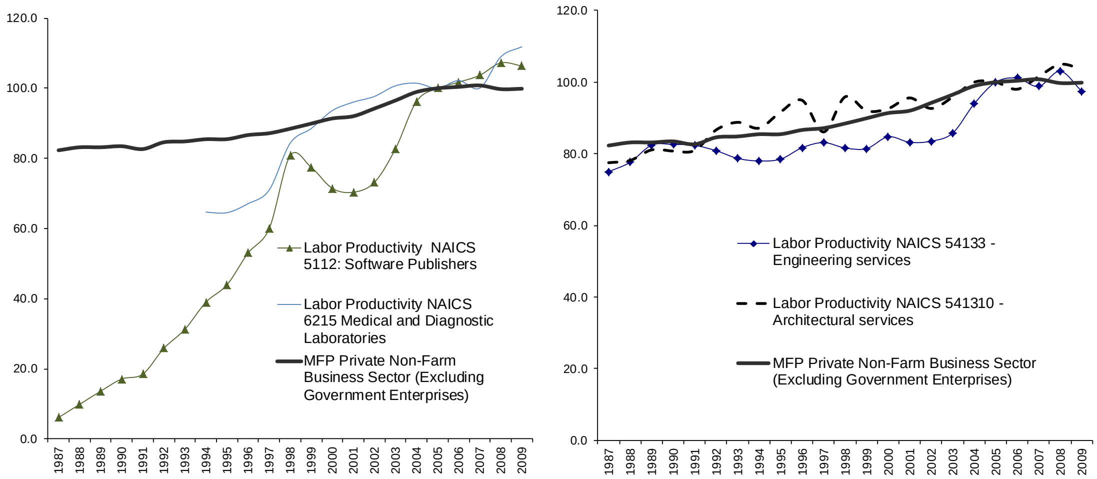
$$\Delta P^N = \Delta W^N - \Delta A^N$$

In the absence of measurable units of output for R&D (innovative knowledge) A^N cannot be calculated directly. What indirect approach best reflects productivity change in the production of R&D activity? Because we have very limited empirical evidence and the range of informed opinion varies very broadly, this is the most difficult question we face.

On one hand, based on recent work by Corrado, Goodridge, and Haskell (2011), the overall price of R&D falls at an average rate of 7.5 percent per year between 1985 and 2005. This implies rapid gains in R&D productivity. On the other hand, based on observable measures of output such as new drug applications and biologics license applications, R&D productivity in pharmaceutical-related R&D has been declining (DiMasi, et al, 2003).

A preferred option for adjusting R&D input costs would be a regularly updated productivity index for the scientific R&D services industry. For all the difficulty measuring appropriate output, the Bureau of Labor Statistics (BLS) does not produce one. The R&D services industry is classified as part of professional and technical services, a broad category wherein BLS produces labor productivity measures (output per hour) for tax preparation services, architectural services, engineering services, advertising agencies, and photography studios. Some of these industries are, like scientific R&D services, knowledge intensive. However, either a “standard” output project or standardized characteristics of output are necessary for prices and productivity measures that can be updated regularly. For architectural services, engineering services, and computer software publishers, these requirements are met. A fourth industry where prices and productivity are measured by BLS is outside of business and

professional services but has some similar activities to R&D. This industry is medical and diagnostic labs.



Source: BLS

Figure 6 Productivity Indexes, 2005 = 100

While the production of innovative knowledge through R&D activity bears similarities to production in these industries, using any of these industries' productivity as a proxy for R&D productivity is a large leap. Because the productivity trends differ across these industries, the choice of any specific industry or group of industries would have a large and potentially arbitrary impact on the result.

Figure 6 shows BLS labor productivity for architectural services and engineering services in the left hand panel and medical and diagnostic laboratory services as well as software publishers in the right hand panel. In each case the industry series are compared to a much broader measure: BLS's multifactor productivity index for the private non-farm business sector. In the absence of a convincing and regularly updated measure of productivity in the knowledge creation, we chose a simple measure: multifactor productivity for the private nonfarm business

sector. We use this economy-wide measure of multifactor productivity as the estimate of unobserved R&D productivity for each industry-specific R&D price index. The use of this broad multifactor productivity adjustment implies that input costs for R&D vary by industry but a single measure reasonably captures the growth of R&D productivity across industries. We view this as a second best solution to industry-specific measures of R&D output and R&D productivity. The change in the price index from the base year is calculated as the change in the labor cost index minus the change in the labor productivity index, shown in Table 3. We use 2005 as the base year, where the index = 100.

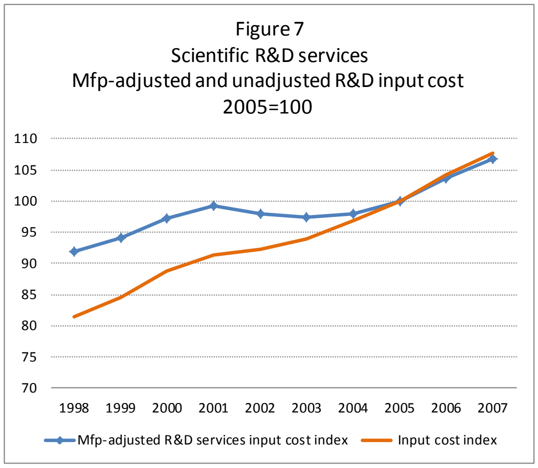
Table 3 Productivity Adjustment Example

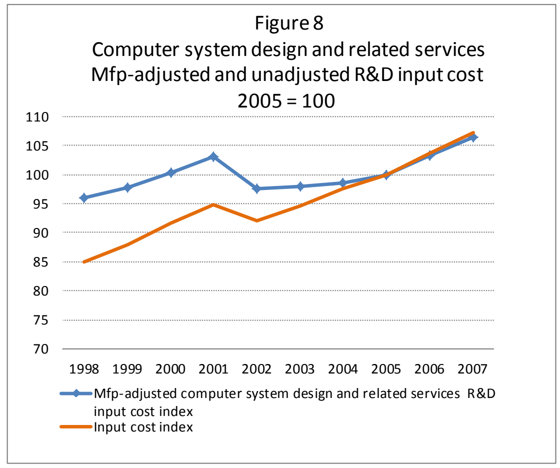
		1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	Input cost index for pharmaceutical-related R&D activity (source: BEA, BLS, and NSF data)	82.1	85.2	89.6	91.0	91.6	93.5	96.5	100.0	104.0	108.2
2	Calculate growth rate of input cost index		3.8%	5.1%	1.6%	0.7%	2.0%	3.2%	3.6%	4.0%	4.1%
3	MFP index (source: BLS private non-farm business sector)		89.9	91.4	92.0	94.2	96.5	98.9	100.0	100.4	100.8
4	Calculate growth rate of multifactor productivity		1.7%	1.6%	0.7%	2.4%	2.4%	2.5%	1.1%	0.4%	0.4%
5	Adjust the growth rate of the input cost index to account for productivity change in the conduct of R&D activity (line 2- line 4)		2.2%	3.5%	0.9%	-1.7%	-0.4%	0.7%	2.6%	3.6%	3.7%
6	Convert to an index where 2005 = 100: Mfp-adjusted pharmaceutical mfg R&D input cost index	92.7	94.7	98.0	98.9	97.2	96.8	97.5	100.0	103.6	107.4

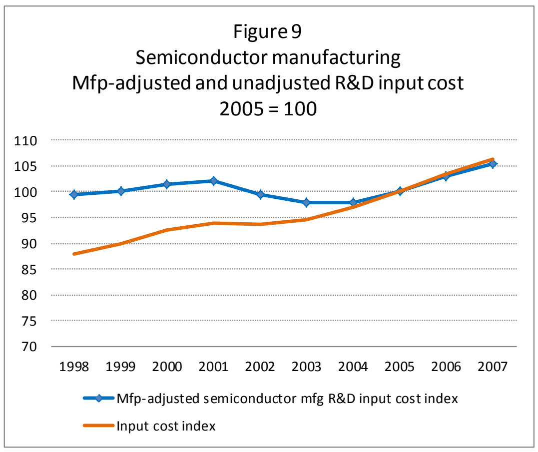
BEA: Bureau of Economic Analysis; BLS: Bureau of Labor Statistics; NSF: National Science Foundation; MFP: Multifactor Productivity

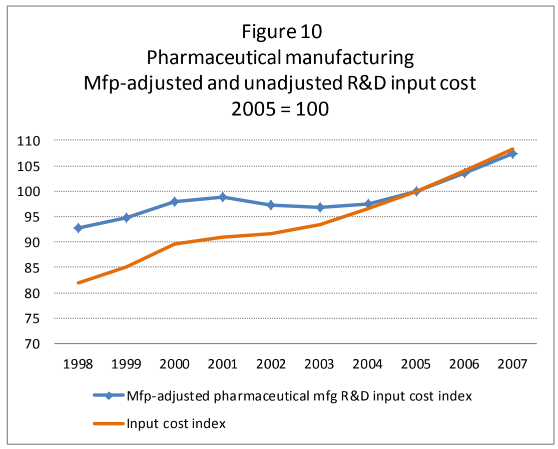
6. Results

The resulting multifactor productivity (mfp)-adjusted indexes use industry-specific input cost information and an economy-wide productivity adjustment factor. They are shown in the third panel of Appendix Table A (page 42). Comparing these to simple input cost indexes (shown in Figures 2-5), we see the impact of the increase in multifactor productivity growth between 1999 and 2004 and slowing of productivity growth thereafter on each of the four indexes in Figures 7 -10.









Source: Authors' calculations

Figures 7-10 Mfp-adjusted and unadjusted R&D input cost indexes

The multifactor productivity adjustment trims the growth rate of the input cost indexes the same amount for each industry. Each of the resulting indexes grows more slowly than the GDP price index, leading to a larger quantity of innovative knowledge than would be implied by the standard procedures of either input costs or the GDP price index.

One industry-specific R&D price index that we can compare to is Copeland and Fixler (2012)'s scientific R&D services price index. Their index is constructed with an output measure that is based on 1) the growth of patent counts in fields where R&D services establishments do research and 2) the growth in scientific R&D services employment. The Copeland-Fixler index

rises at an average annual rate of 2.3 percent compared to 1.7 percent for our multifactor productivity adjusted industry-specific input cost for scientific R&D services. This faster rate of growth for the Copeland-Fixler index implies relatively slower growth of real R&D output.

The area where we view our productivity-adjusted results with caution is pharmaceutical R&D. Our productivity-adjusted input cost index implies modestly increasing productivity growth for pharmaceutical R&D. As noted earlier, analysis based on new drug applications and biologics license applications as measures of R&D output suggest recent declining R&D productivity. The decision to make the adjustment to this industry's input cost index is based on two main considerations. First, in the absence of R&D productivity measures, the single adjustment for all industries is simple and transparent. Second, the measurement of declining productivity in pharmaceutical R&D is still a subject of continued research. Although the ratios of new drug counts to R&D expenditures suggest an apparent slowing since 1996 in approval rate for new molecular entities (NMEs), both quality adjusting these counts moderates the findings (Cockburn 2006) as does the inclusion of supplementary approvals for existing products (Berndt, Cockburn, and Grepin (2006)). A conservative approach to measuring this industry's real R&D output might be to consider the unadjusted input cost index as a lower boundary measure or to take the average of an adjusted and unadjusted index.

To evaluate the impact of different deflators on each industry we calculate the industry's real R&D investment. In Appendix table B (page 43) we compare estimates of R&D investment by industry based on BEA's 2010 R&D satellite account with our indexes well as other deflation approaches. We show the alternative indexes in four categories, output-based indexes that use the price change of downstream goods, input-cost based indexes, productivity adjusted input cost indexes, and the Copeland-Fixler index that uses both patents and employment.

Industry R&D investment

One of the questions this paper aims to answer is how much difference it makes to use industry-specific R&D price indexes compared with one deflator for all R&D. The differences we are interested in include industry-level investment and contributions to GDP growth.

When R&D is deflated with industry-specific productivity-adjusted R&D price indexes, total real R&D investment grew by 4.1 percent annual rate between 1998 and 2007 (page 46). This compares to a rate of 2.8 percent over the same period deflating R&D investment with the input cost index from BEA's R&D satellite account and 5.5 percent with the aggregate output price index of the satellite account.

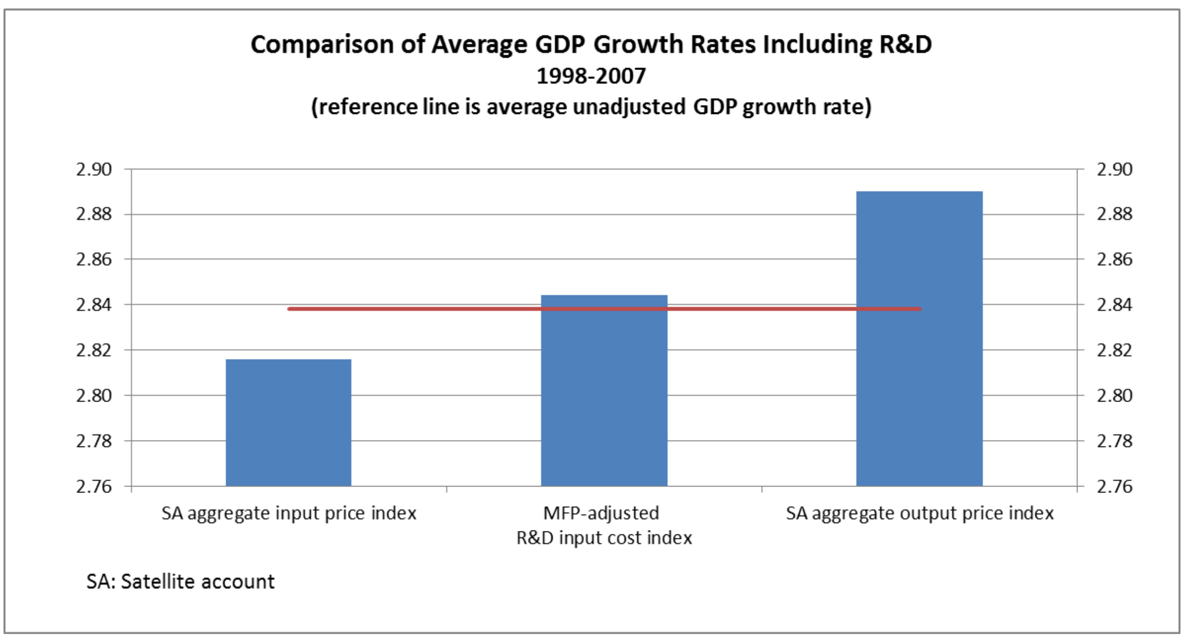
Comparing results across industries, the different impacts are greater. For semiconductor-related R&D, real investment grows at an average annual rate of 7.5 percent between 1998-and 2007 with the industry-specific productivity adjusted index. The comparison rates for the satellite account aggregate input cost and output prices indexes are 4.8 percent and 9.0 percent, respectively.

Contributions to Growth

To calculate contributions to GDP growth using alternative indexes, we deflate all business R&D, including the R&D conducted by industries other than pharmaceutical manufacturing, semiconductor manufacturing, motor vehicle manufacturing, computer system design and related services, and scientific R&D services. For software-related R&D we simply used the BEA price index for custom and own-account software. This is an index that is also based on both input costs and productivity adjustment. For the remainder of private R&D we calculated two aggregates, all-other goods R&D and all-other services R&D. We next calculate

R&D investment and compare the results with two price indexes used in BEA's 2010 R&D satellite account, the aggregate output price index and the aggregate input price index.

Figure 11 compares the GDP growth rate impact of the mfp-adjusted price indexes with the aggregate output price index and the aggregate input cost index from BEA's 2010 update of the R&D satellite account.[8] Using the mfp-adjusted index the average annual growth rate in GDP from 1998 and 2007 would have been 2.84 percentage points, falling between the growth rates estimated using the aggregate output price index and the aggregate input cost index. Capitalized business R&D would have contributed a 2.2 percent share of the average growth rate from 1998 to 2007, compared with 3.5 percent share with the aggregate output price index and 1.0 percent share with the aggregate input cost index. Table 4 shows the annual growth rates and contributions to growth for these indexes.



Source, BEA and authors' calculations.

Figure 11 Average Real GDP Growth Rates Including R&D, 1998-2007

[8] The satellite account input price index is similar but not identical to the input cost index we create in this paper. A comparison is shown in Appendix table D on page 49. For further detail on the satellite account indexes, see Copeland, Medeiros, and Robbins, 2007.

Table 4 Annual Growth Rate of Real GDP, Adjusted for R&D Investment

	Average 1998-2007	1999	2000	2001	2002	2003	2004	2005	2006	2007
Unadjusted real GDP growth rate* [percent change]	2.84	4.83	4.14	1.08	1.81	2.49	3.57	3.05	2.67	1.95
1. SA aggregate output price index										
R&D-adjusted real GDP growth rate [percent change]	2.88	4.89	4.24	1.14	1.73	2.48	3.57	3.11	2.74	2.09
Business R&D contribution to adjusted real GDP [percentage points	0.10	0.18	0.20	0.09	-0.05	0.03	0.06	0.10	0.11	0.17
Business R&D share of adjusted real GDP growth [percent]	3.45	3.70	4.78	7.48	N/A	1.30	1.69	3.29	3.88	8.36
2. SA aggregate input price index										
R&D-adjusted real GDP growth rate	2.81	4.80	4.14	1.04	1.66	2.42	3.52	3.08	2.69	2.00
Business R&D contribution to adjusted real GDP	0.03	0.09	0.10	-0.02	-0.12	-0.03	0.01	0.07	0.06	0.09
Business R&D share of adjusted real GDP growth	0.98	1.81	2.41	N/A	N/A	N/A	0.15	2.42	2.11	4.36
3. MFP-adjusted R&D input cost index										
R&D-adjusted real GDP growth rate	2.84	4.80	4.16	1.06	1.74	2.48	3.57	3.10	2.70	2.04
Business R&D contribution to adjusted real GDP	0.06	0.09	0.12	0.00	-0.04	0.03	0.06	0.09	0.07	0.12
Business R&D share of adjusted real GDP growth	2.18	1.95	2.99	0.37	N/A	1.40	1.60	2.96	2.60	6.01

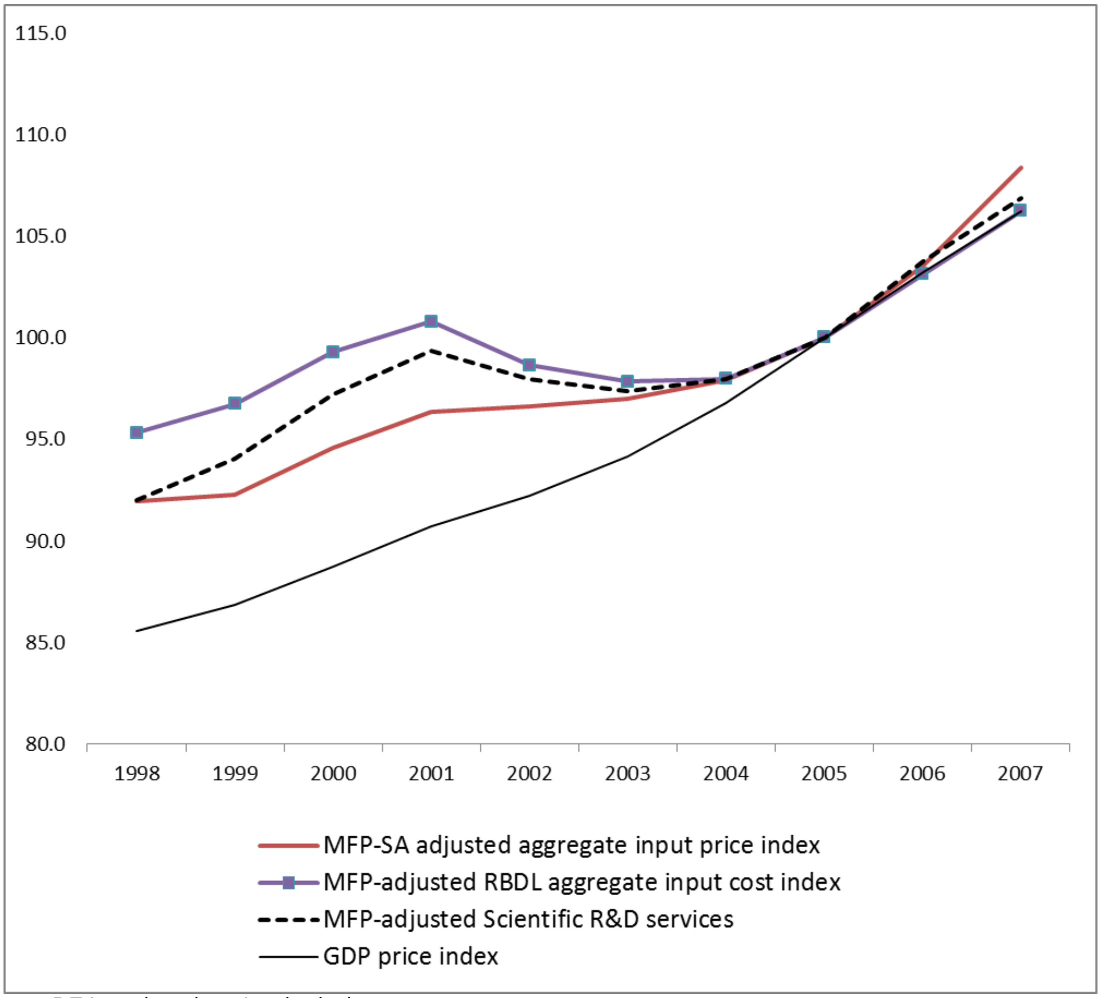
*Unadjusted real GDP growth rate reflects the vintage of the NIPAs published at the time of the 2010 R&D satellite account release, prior to

SA: fron the R&D satellite account

One index to deflate them all?

Data limitations lead to both simplifying assumptions in our index construction and the combination of company and establishment data for industries. A single mfp-adjusted index for all R&D has the obvious benefit of simplicity. We test several alternative constructions of a single index: 1) the aggregate input price index from the R&D satellite account, 2) the index of the industry-specific input cost indexes combined with a Fisher formula (referred to as RBDL to differentiate it from the satellite account index), and 3) the input cost index for scientific R&D services.

Figure 12 shows these three price indexes with the GDP price index. The aggregate input price index from the R&D satellite account and the scientific R&D services index are constructed using similar data.[9]



Source: BEA and authors' calculations

Figure 12: Comparison of Single Deflators for R&D, 2005 = 100

Compared with these two indexes the RBDL index uses a more inclusive set of industry-specific wage and input price data.[10] As Table 2 (page 16) shows, although wages for scientists

[9] The main difference between them is the wage data used. For details, see Appendix table D.

[10] This index differs from the mfp-adjusted input cost index shown in line 3 of Table 4 in the following way. That index is the aggregate of mfp-adjusted industry-specific R&D input cost indexes. The mfp-adjusted RBDL index is a single input cost index with the multifactor productivity adjustment calculated as a last step.

and engineers in the pharmaceutical manufacturing industry rise at a similar pace to that or R&D services, for scientists and engineers in the computer science, semiconductor manufacturing, and motor vehicle manufacturing, wages rise more slowly. This slower growth rate helps to account in part for the slower growth in the aggregate RBDL index shown in Figure 12. The other key difference between the indexes is the inclusion of industry-specific inputs to adjust the cost structure of R&D activity across industries. From an economy-wide perspective using a single mfp-adjusted R&D price index produces very little difference in the growth rate of real GDP across these different indexes. As Table 5 shows, the average annual growth rate of real GDP is 2.84 percentage points for the mfp-adjusted SA aggregate input price index or the mfp-adjusted R&D services index and 2.85 percentage points for the mfp-adjusted RBDL index.

Table 5: Annual Growth Rate of Real GDP, Adjusted for R&D Investment

	Average 1998-2007	1999	2000	2001	2002	2003	2004	2005	2006	2007
Unadjusted real GDP growth rate* [percent change]		4.83	4.14	1.08	1.81	2.49	3.57	3.05	2.67	1.95
Mfp-adjusted SA aggregate input price index										
R&D-adjusted real GDP growth rate [percent change]	2.84	4.83	4.17	1.05	1.70	2.46	3.56	3.10	2.69	2.01
Business R&D contribution to adjusted real GDP [percentage points]	0.05	0.12	0.13	0.00	-0.08	0.02	0.05	0.09	0.06	0.09
Business R&D Share of Adjusted GDP Growth	1.88	2.41	3.10	N/A	N/A	0.62	1.34	2.98	2.36	4.70
Mfp-adjusted aggregate RBDL input cost index										
R&D-adjusted real GDP growth rate [percent change]	2.85	4.81	4.17	1.06	1.75	2.49	3.57	3.10	2.70	2.04
Business R&D contribution to adjusted real GDP [percentage points]	0.06	0.10	0.13	0.00	-0.03	0.04	0.06	0.09	0.07	0.12
Business R&D Share of Adjusted GDP Growth	2.26	1.99	3.04	0.41	N/A	1.47	1.70	3.02	2.64	6.03
Mfp-adjusted Scientific R&D Services input cost index used for all R&D										
R&D-adjusted real GDP growth rate [percent change]	2.84	4.79	4.15	1.05	1.74	2.48	3.56	3.10	2.69	2.04
Business R&D contribution to adjusted real GDP [percentage points]	0.06	0.08	0.11	-0.01	-0.05	0.03	0.05	0.09	0.06	0.12
Business R&D Share of Adjusted GDP Growth	1.98	1.71	2.74	N/A	N/A	1.34	1.47	3.01	2.25	6.05
*Unadjusted real GDP growth rate reflects the vintage of the NIPAs published at the time of the 2010 R&D satellite account release, prior to the 2011 annual revision.										
SA: fron the R&D satellite account										
RBDL: Robbins, Belay, Donohoe and Lee aggregate index from this paper										

More difference exists in the deflation approaches in the level and growth rate of R&D investment. The average growth rate of R&D investment between 1997 and 2007 is 3.7 percent when R&D is deflated with the mfp-adjusted satellite account aggregate input price index and 3.8 percent with the mfp-adjusted industry-specific R&D services index. Using the broader-

based mfp-adjusted RBDL index the growth rate of total R&D investment for the same period is slightly faster, 4.1 percent.[11]

The substantive impact of choosing a single index to deflate R&D activity emerges for industries where labor and other input costs have a different growth rate from the single index chosen. In general, when the industry-specific R&D price index is similar to the scientific R&D services index then deflation with the more broadly-based index will result in a more slowly rising price index for R&D and faster growing real R&D investment. An example of this is pharmaceutical R&D, where the average growth rate of investment between 1998 and 2007 is about a half a percentage point higher with the aggregate RBDL index (16.8 percent) compared to any of the other productivity-adjusted indexes (16.1 to 16.3 percent).

Conversely, when the industry-specific R&D price index is either falling or rising more slowly than the aggregate index used for deflation, an aggregate index will slow the implied rate of real R&D investment. Another way to see these differences is through differences in the price indexes themselves. The table below shows each industry-specific price index relative to the mfp-adjusted RBDL index.

Table 6: Index Numbers Comparison: Aggregate v Industry-specific percentage point difference compared to a common index

Mfp-adjusted aggregate RBDL* input cost index	95.3	96.7	99.3	100.8	98.7	97.8	98.0	100.0	103.1	106.2
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Pharmaceutical and medicine manufacturing	-2.7	-2.1	-1.3	-1.9	-1.5	-1.0	-0.5	0.0	0.5	1.2
Semiconductor and other electronic component manufacturing	4.2	3.3	2.2	1.3	0.9	0.1	0.0	0.0	0.0	-0.8
Motor vehicles, bodies and trailers, and parts manufacturing	0.7	0.5	0.4	0.7	1.4	0.7	0.5	0.0	0.1	-0.5
Computer systems design and related services	-3.3	-2.7	-2.1	-1.4	-0.7	-0.5	0.0	0.0	0.6	0.6
Software publishers**	-5.0	-3.5	-2.1	-2.0	-0.5	0.9	0.7	0.0	-0.9	-2.1
Scientific R&D services	-3.3	-2.7	-2.1	-1.4	-0.7	-0.5	0.0	0.0	0.6	0.6
All other goods industries	-1.0	-1.0	-0.8	-0.6	-0.3	-0.5	-0.2	0.0	0.3	0.0
All other service industries	-0.6	-1.0	-1.4	-1.6	-1.0	-0.3	-0.4	0.0	-1.2	0.1

Note: percentage point difference between an mfp-adjusted aggregate index and industry-specific indexes, where 2005 is the base year

*RBDL is the Robbins, Belay, Donahoe, Lee index that is a Fisher of industry-specific Fisher indexes.

** Software index is BEA's price index for custom and own-account software.

[11] The annual level of real R&D investment and the growth rates are shown in Appendix Tables B and C.

7. Conclusions

For real measures of R&D as investment in national economic accounts, internationally comparable alternatives for deflating R&D activity include either the GDP price index or an input cost index that is specific to R&D activity. Neither alternative is entirely satisfying. The use of the GDP price index does not account for industry variation in R&D performance. While the input cost index captures the impact of industry-specific increasing costs, it does not allow for any productivity change in the conduct of R&D. Our approach is to adjust industry-specific R&D input costs for the unobserved productivity in the conduct of R&D-- the productivity of the innovator.

The approach that we use is a conventional perfect competition framework. While this approach enables us account for both input costs and an average measure of productivity growth, it does not allow us to incorporate the impact of increasing returns to scale and industry-level externalities. Further work developing quality-adjusted measures of R&D output will be required for these improvements.

In this paper we have done several things: constructed industry-specific input cost indexes, adjusted these indexes for productivity in the conduct of R&D, and compared the resulting growth in real R&D investment across different approaches to R&D deflators. We then compare our more complicated approach of using different deflators for industry-specific R&D with a common deflator for all R&D. While there are tradeoffs at the industry level a common deflator for all business R&D makes the estimation of the real impacts of R&D significantly simpler to estimate and integrate into measures of real investment. Additional simplifications to evaluate include the use of simple KLEMS data on inputs instead of the more complex procedure used here.

In sum, we find that at the macro level the impact on R&D investment and GDP is not substantially affected by the choice of industry-specific or aggregate deflators. Given the tradeoff between computational complexity and precision, an aggregate deflator for business R&D had substantial appeal.

The impact of choosing industry-specific or aggregate deflators shows up at the level of each industry. Since we use a single productivity adjustment for all industries, the variation across industries in the price indexes is a function of input cost variation. This variation in input costs is substantial: Our input cost index for semiconductor-related R&D rises at an average annual rate of 2.1 percent between 1997 and 2007 while our input cost index for scientific R&D services rises at a rate of 3.1 percent. The greatest difference between industry-specific and aggregate deflators shows up in industries where labor and other input costs have a different growth rate from the single index chosen. For example, when compared with an aggregate deflator constructed with inputs from many R&D performing industries, an aggregate deflator constructed with inputs costs that are similar to those of scientific R&D services (an industry with relatively rapidly rising input costs) will tend to *underestimate* real R&D for semiconductor-related R&D. Conversely, deflating scientific R&D services activity with an aggregate deflator constructed with inputs from many R&D performing industries will tend to *overestimate* real R&D for scientific R&D services.

A. Mathematical Appendix

This section provides a theoretical justification for the input-cost based estimate used in the text. We introduce a simplified model of innovation, and show that if innovators are price-takers, then the growth in the price of the innovator's output can be derived from the growth in input costs and the marginal productivity of the inputs. We confront two measurement issues: first, the marginal productivity of inputs are usually not measured, and only average measures of productivity are available. Second, if the growth rate in prices is measured using an average of the costs of several inputs, the average of the marginal productivities must be used; however, we may only have a multifactor productivity measure available. If the innovator's production function is Cobb-Douglas, then we show that average measures of productivity may be used in place of marginal measures, and that multifactor productivity may be used in place of average marginal productivity.

Simple Model of an Innovator

Suppose we have a price-taking innovator who sells innovations at a price *p*. Assume he uses two inputs, *K* and *L*, and that the quantity of innovations produced, Q_T, has production function

$$Q_T = F(A, K, L) \tag{0.1}$$

A represents total factor productivity in the R&D producing industry - anything that impacts output in this industry which is not attributable to input changes. Assuming that the innovator is a price-taker, the optimal choices of *K* and *L* will be those that maximize his profits function,

$$\max_{K,L} \left\{ pF(A, K, L) - rK - wL \right\},$$

where w is the wage rate and r is the rental rate for capital. Taking first order conditions, the innovator's optimal choices of K and L will satisfy the following two equations:

$$pF_K(A, K, L) \tag{0.2}$$

$$pF_L(A, K, L), \tag{0.3}$$

where F_K and F_L are the marginal productivities of capital and labor, respectively (equivalently, the partial derivatives of the production function with respect to capital and labor). By expressing equations (0.2) and (0.3) as growth rates, and taking the growth rate of the marginal product of capital and labor to the right side of the equation, the growth rate in the price of R&D must satisfy the following 2 equations:

$$\Delta \ln(p) = \Delta \ln(r) - \Delta \ln(F_K(A, K, L)) \tag{0.4}$$

$$\Delta \ln(p) = \Delta \ln(w) - \Delta \ln(F_L(A, K, L)). \tag{0.5}$$

Equations (0.4) and (0.5) provide two ways to estimate the growth rate in the R&D price: we can use the growth rate in the capital cost, and subtract off the growth in the marginal productivity of capital, or we can use the growth rate in wages, and subtract off the marginal productivity of labor. In order to use this approach, we need to observe the growth rate of the cost of at least one input, as well as the growth rate of the marginal productivity of at least one input. If the marginal productivities of the inputs are unavailable, one might try to proxy for the missing measure using the productivity growth of a different industry, or the productivity growth of a downstream industry.

Alternatively, we may also use some average of equations (0.4) and (0.5) to estimate the growth in the R&D price:

$$\Delta\ln(p) = \omega\Delta\ln(r) + (1-\omega)\Delta\ln(w) - (\omega\Delta\ln(F_K(A,K,L)) + (1-\omega)\Delta\ln(F_L(A,K,L))) \qquad (0.6)$$

Equation (0.6) is the weighted average of equations (0.4) and (0.5), where $\omega \in [0,1]$ is the weight applied to equation (0.4). Equation (0.6) says that the growth rate in the price of R&D can be expressed as the average growth in input prices, minus the average growth in the marginal productivities of the inputs. In practice, we might choose ω to be the cost share of capital used in R&D production.

Using Average Productivity as a Substitute for Marginal Productivity

One problem that immediately arises is that the marginal productivity of capital and labor, $F_K(A,K,L)$ and $F_L(A,K,L)$, are usually unobserved. The Bureau of Labor Statistics produces indexes that reflect the average productivity of inputs, which for labor is $F(A,K,L)/L$. In order to substitute average productivity for marginal productivity into equation (3), it must be the case that

$$\begin{aligned}\Delta\ln(F_K(A,K,L)) &= \Delta\ln\left(\frac{F(A,K,L)}{K}\right) \\ \Delta\ln(F_L(A,K,L)) &= \Delta\ln\left(\frac{F(A,K,L)}{L}\right)\end{aligned}.$$

That is, the growth rate in the marginal product of an input must equal the growth rate of the average product. One production function that guarantees this is Cobb-Douglas. If we assume that

$$F(A,K,L) = AK^{\alpha}L^{\beta} \tag{0.7}$$

where α and β measure the output elasticities of capital and labor, then

$$\begin{aligned} F_L(A,K,L) &= \beta AK^{\alpha}L^{(\beta-1)} \\ \frac{F(A,K,L)}{L} &= AK^{\alpha}L^{(\beta-1)} \end{aligned} .$$

We assume that α and β are constant over time. Since the average productivity and the marginal productivity only differ by a constant β, the growth rate in the average productivity equals the growth rate in the marginal productivity.

Using Multifactor Productivity of the Innovator

In order to use equation (0.6) to estimate the growth in the price of R&D, we need to observe both capital and labor productivity. The BLS produces labor productivity for many industries, but capital productivity is not as readily available. In this case, we might consider using multifactor productivity of the innovator as a substitute for the average productivity. This approach is viable if production is Cobb-Douglas. To see this, we first note that the definition of multifactor productivity growth used by the BLS is a Tornqvist index:[1]

$$\Delta \ln(MFP^T) = \Delta \ln(Q^T) - \Delta \ln(I^T) . \tag{0.8}$$

$\Delta \ln(I^T)$ is weighted average of Tornqvist indexes for capital and labor

$$\Delta \ln(I^T) = s\Delta \ln(K) + (1-s)\Delta \ln(L) ,$$

[1] The Bureau of Labor Statistics' technical report located at http://www.bls.gov/mfp/mprtech.pdf explains how the agency constructs productivity indexes.

where s is the cost share of capital.

Using the fact that $Q^T = F(A,K,L)$ and the preceding equation, we can rewrite the index for MFP in equation (0.8) as

$$\Delta \ln(MFP^T) = \Delta \ln(F(A,K,L)) - s\Delta \ln(K) - (1-s)\Delta \ln(L). \tag{0.9}$$

If $\omega = s$, then the average growth in marginal productivity, which is the last term in brackets in equation (0.6), is

$$s\Delta \ln(F_K(A,K,L)) + (1-s)\Delta \ln(F_L(A,K,L)). \tag{0.10}$$

In general, equations (0.9) and (0.10) will not be equal. However, if the production function is Cobb-Douglas as in equation (0.7), then the two equations will be the same. To see this, notice that plugging equation (0.7) for $F(A,K,L)$ into (0.9) gives us

$$\begin{aligned}
\Delta \ln(F(A,K,L)) - s\Delta \ln(K) - (1-s)\Delta \ln(L) &= \Delta \ln(AK^{\alpha}L^{\beta}) - s\Delta \ln(K) - (1-s)\Delta \ln(L) \\
&= \Delta \ln(A) + \alpha\Delta \ln(K) + \beta\Delta \ln(L) - s\Delta \ln(K) - (1-s)\Delta \ln(L) \\
&= \Delta \ln(A) + (\alpha - s)\Delta \ln(K) + (\beta - (1-s))\Delta \ln(L).
\end{aligned}$$

We can do something similar with equation (0.10). Noting that (0.7) implies that

$$\begin{aligned}
F_K(A,K,L) &= \alpha AK^{(\alpha-1)}L^{\beta} \\
F_L(A,K,L) &= \beta AK^{\alpha}L^{(\beta-1)}
\end{aligned}$$

we can rewrite equation (0.10) as

$$
\begin{aligned}
s\Delta\ln(F_K(A,K,L))+(1-s)\Delta\ln(F_L(A,K,L)) &= s\Delta\ln(\alpha AK^{(\alpha-1)}L^{\beta})+(1-s)\Delta\ln(\beta AK^{\alpha}L^{(\beta-1)}) \\
&= s\Delta\ln(A)+s(\alpha-1)\Delta\ln(K)+s\beta\Delta\ln(L)+ \\
&\quad (1-s)\Delta\ln(A)+(1-s)\alpha\Delta\ln(K)+(1-s)(1-\beta)\Delta\ln(L) \\
&= \Delta\ln(A)+(\alpha-s)\Delta\ln(K)+(\beta-(1-s))\Delta\ln(L).
\end{aligned}
$$

To summarize, under Cobb-Douglas equations (0.9) and (0.10) are both equal to

$$\Delta\ln(A)+(\alpha-s)\Delta\ln(K)+(\beta-(1-s))\Delta\ln(L).$$

meaning that we can rewrite the price growth of R&D in equation (0.6) as

$$\Delta\ln(p)=s\Delta\ln(K)+(1-s)\Delta\ln(L)-\Delta\ln(MFP^{T}). \tag{0.11}$$

Appendix Table A: R&D Price Index Comparison, 2005 = 100

Industry-specific input cost indexes for R&D	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	1998-2007 growth rate
Pharmaceutical and medicine manufacturing	82.1	85.2	89.6	91.0	91.6	93.5	96.5	100.0	104.0	108.2	3.1
Semiconductor and other electronic component manufacturing	88.0	89.9	92.6	93.9	93.7	94.5	97.0	100.0	103.5	106.3	2.1
Motor vehicles, bodies and trailers, and parts manufacturing	85.0	87.5	91.0	93.4	94.2	95.1	97.5	100.0	103.6	106.6	2.5
Computer systems design and related services	85.0	87.9	91.7	94.8	92.0	94.7	97.5	100.0	103.6	107.2	2.6
Scientific R&D services	81.5	84.6	88.8	91.4	92.3	94.0	97.0	100.0	104.1	107.7	3.2
All other goods industries	83.5	86.2	90.0	92.1	92.7	94.0	96.8	100.0	103.8	107.1	2.8
All other service industries	83.8	86.2	89.4	91.3	92.0	94.1	96.6	100.0	102.3	107.2	2.8

Industry-specific labor cost indexes for R&D	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	1998-2007 growth rate
Pharmaceutical and medicine manufacturing	76.8	81.7	88.5	92.2	93.3	95.8	98.1	100.0	104.0	108.6	3.9
Semiconductor and other electronic component manufacturing	79.1	83.3	88.2	92.5	92.0	93.1	96.6	100.0	103.8	107.4	3.5
Motor vehicles, bodies and trailers, and parts manufacturing	79.8	84.5	90.2	95.0	95.9	96.3	98.4	100.0	103.7	106.7	3.3
Computer systems design and related services	84.3	88.5	92.9	97.6	92.7	96.8	97.9	100.0	103.6	106.4	2.6
Scientific R&D services	74.9	80.0	86.0	91.2	92.3	94.5	97.9	100.0	104.9	108.5	4.2
All other goods industries	78.4	83.1	88.7	93.5	94.0	94.8	97.3	100.0	103.9	107.4	3.6
All other service industries	83.2	86.4	90.3	93.0	93.4	95.8	97.4	100.0	100.8	107.0	2.8

Mfp-adjusted industry-specific input cost indexes for R&D	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	1998-2007 growth rate
Pharmaceutical and medicine manufacturing	92.7	94.7	98.0	98.9	97.2	96.8	97.5	100.0	103.6	107.4	1.7
Semiconductor and other electronic component manufacturing	99.5	100.1	101.4	102.1	99.5	97.9	98.0	100.0	103.1	105.4	0.6
Motor vehicles, bodies and trailers, and parts manufacturing	96.1	97.3	99.7	101.5	100.0	98.5	98.5	100.0	103.2	105.7	1.1
Computer systems design and related services	92.0	94.1	97.2	99.3	98.0	97.4	98.0	100.0	103.7	106.9	1.7
Software publishers*	90.3	93.2	97.2	98.8	98.2	98.7	98.7	100.0	102.2	104.2	1.6
Scientific R&D services	92.0	94.1	97.2	99.3	98.0	97.4	98.0	100.0	103.7	106.9	1.7
All other goods industries	94.3	95.8	98.5	100.1	98.4	97.3	97.8	100.0	103.4	106.3	1.3
All other service industries	94.7	95.8	97.8	99.2	97.6	97.5	97.6	100.0	101.9	106.4	1.3

Aggregate price indexes for R&D	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	1998-2007 growth rate
Aggregate of mfp-adjusted industry-specific indexes	94.2	95.7	98.4	99.9	98.2	97.5	97.9	100.0	103.2	106.3	1.3
Aggregate of industry-specific input cost indexes	84.4	87.0	90.7	92.7	93.0	94.5	97.0	100.0	103.5	107.1	2.7
SA aggregate output price index	107.7	104.3	102.8	99.9	98.9	98.3	98.5	100.0	101.1	101.2	-0.7
SA aggregate input price index	81.4	83.1	86.5	88.7	91.1	93.7	96.9	100.0	104.0	109.2	3.3
Mfp-adjusted SA aggregate input price index	92.0	92.3	94.6	96.4	96.6	97.0	97.9	100.0	103.6	108.4	1.8
Mfp-adjusted RBDL aggregate input cost index	95.3	96.7	99.3	100.8	98.7	97.8	98.0	100.0	103.1	106.2	1.2
GDP price index	85.6	86.8	88.7	90.7	92.2	94.1	96.8	100.0	103.2	106.2	
Copeland-Fixler price index	85.1	88.9	92.1	93.0	94.2	93.8	96.4	100.0	99.9	104.8	2.3

* Software index is BEA's price index for custom and own-account software.

**RBDL is the Robbins, Belay, Donahoe, Lee index that is a Fisher of industry-specific Fisher indexes.

Appendix Table B: Real R&D Investment by Industry (continues)

Total R&D investment, including government and non-profit R&D*	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Output-price based indexes										
Down-stream product output price index	256,903	278,991	300,533	313,104	311,478	322,405	331,665	345,313	363,127	389,518
SA aggregate output price index	243,748	267,880	292,110	307,091	306,261	318,799	329,913	345,313	364,854	393,577
Input-cost based indexes										
SA aggregate input price index	293,226	311,349	327,163	331,582	322,735	328,711	333,337	345,313	358,298	374,600
Industry specific R&D input cost index	286,569	302,035	317,090	322,240	318,599	327,007	333,172	345,313	359,313	379,478
Industry specific R&D labor cost index	296,388	308,085	319,377	319,682	316,480	324,621	331,652	345,313	359,442	378,951
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	266,578	283,758	300,830	307,126	307,562	320,457	331,225	345,313	360,079	381,212
Mfp-adjusted SA aggregate input price index	270,889	290,738	308,754	314,411	310,795	321,491	331,149	345,313	359,195	376,503
Mfp-adjusted aggregate RBDL R&D input cost index	264,587	281,843	299,034	305,341	306,716	319,785	330,983	345,313	360,217	381,427
Mfp-adjusted Scientific R&D services input cost index	270,897	287,159	303,263	308,204	308,063	320,788	331,002	345,313	358,797	379,992
Copeland-Fixler Price Index	284,895	297,684	313,954	321,685	315,889	328,447	334,527	345,313	367,614	384,569

Pharmaceutical and Medicine Manufacturing (3254)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Output-price based indexes					**Levels in Millions of 2005 Dollars**					
Down-stream product output price index	18,527	23,196	25,366	27,824	32,968	37,848	44,513	45,199	48,445	62,198
SA aggregate output price index	13,893	18,360	20,794	23,981	29,404	35,184	42,934	45,199	50,270	66,620
Input-cost based indexes										
SA aggregate input price index	18,380	23,045	24,708	27,003	31,915	36,919	43,636	45,199	48,878	61,765
Industry specific R&D input cost index	18,244	22,467	23,860	26,328	31,738	36,996	43,818	45,199	48,874	62,313
Industry specific R&D labor cost index	19,483	23,437	24,141	25,977	31,172	36,115	43,087	45,199	48,857	62,117
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	16,154	20,217	21,806	24,231	29,915	35,727	43,369	45,199	49,063	62,802
Mfp-adjusted SA aggregate input price index	16,280	20,749	22,598	24,869	30,088	35,652	43,187	45,199	49,067	62,247
Mfp-adjusted aggregate RBDL R&D input cost index	15,704	19,787	21,520	23,778	29,474	35,355	43,153	45,199	49,284	63,495
Mfp-adjusted Scientific R&D services input cost index	16,273	20,351	21,982	24,122	29,677	35,530	43,157	45,199	48,983	63,124
Copeland-Fixler Price Index	17,596	21,527	23,206	25,772	30,870	36,872	43,881	45,199	50,861	64,330

Semiconductor and Other Electronic Component Manufacturing (3344)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Output-price based indexes					**Levels in Millions of 2005 Dollars**					
Down-stream product output price index	4,250	5,983	8,599	12,554	13,526	15,614	17,527	19,211	20,286	22,226
SA aggregate output price index	8,852	10,566	12,339	14,791	15,712	17,194	18,306	19,211	19,244	19,199
Input-cost based indexes										
SA aggregate input price index	11,712	13,263	14,662	16,655	17,054	18,042	18,605	19,211	18,711	17,800
Industry specific R&D input cost index	10,843	12,249	13,687	15,741	16,574	17,881	18,589	19,211	18,798	18,295
Industry specific R&D labor cost index	12,056	13,230	14,376	15,987	16,883	18,146	18,669	19,211	18,742	18,094
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	9,589	11,011	12,499	14,477	15,614	17,263	18,398	19,211	18,871	18,439
Mfp-adjusted SA aggregate input price index	10,373	11,941	13,410	15,339	16,077	17,423	18,413	19,211	18,783	17,939
Mfp-adjusted aggregate RBDL R&D input cost index	10,007	11,387	12,770	14,666	15,749	17,278	18,399	19,211	18,866	18,299
Mfp-adjusted Scientific R&D services input cost index	10,369	11,712	13,045	14,878	15,858	17,363	18,401	19,211	18,751	18,192
Copeland-Fixler Price Index	11,212	12,389	13,771	15,896	16,495	18,019	18,709	19,211	19,470	18,539

Motor Vehicles, Bodies and Trailers, and Parts Manufacturing (336MV)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Output-price based indexes					**Levels in Millions of 2005 Dollars**					
Down-stream product output price index	14,688	19,166	19,518	17,612	17,126	19,380	17,538	17,942	18,642	18,157
SA aggregate output price index	13,628	18,419	19,103	17,647	17,117	19,442	17,746	17,942	18,409	18,092
Input-cost based indexes										
SA aggregate input price index	18,030	23,120	22,699	19,870	18,579	20,401	18,036	17,942	17,899	16,773
Industry specific R&D input cost index	17,276	21,948	21,562	18,885	17,964	20,099	17,924	17,942	17,964	17,187
Industry specific R&D labor cost index	18,407	22,721	21,772	18,567	17,649	19,843	17,760	17,942	17,936	17,164
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	15,286	19,738	19,697	17,373	16,923	19,404	17,738	17,942	18,034	17,323
Mfp-adjusted SA aggregate input price index	15,970	20,816	20,760	18,300	17,515	19,701	17,851	17,942	17,968	16,904
Mfp-adjusted aggregate RBDL R&D input cost index	15,405	19,851	19,770	17,497	17,158	19,537	17,837	17,942	18,047	17,243
Mfp-adjusted Scientific R&D services input cost index	15,963	20,417	20,195	17,750	17,276	19,633	17,838	17,942	17,937	17,143
Copeland-Fixler Price Index	17,261	21,597	21,319	18,964	17,970	20,375	18,138	17,942	18,625	17,470

SA: BEA Satellite Account
RBDL: Robbins, Belay, Donahoe, and Lee version
* Government and non-profit R&D deflated with input cost index

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Output-price based indexes					**Levels in Millions of 2005 Dollars**					
Down-stream product output price index	18,527	23,196	25,366	27,824	32,968	37,848	44,513	45,199	48,445	62,198
SA aggregate output price index	13,893	18,360	20,794	23,981	29,404	35,184	42,934	45,199	50,270	66,620
Input-cost based indexes										
SA aggregate input price index	18,380	23,045	24,708	27,003	31,915	36,919	43,636	45,199	48,878	61,765
Industry specific R&D input cost index	18,244	22,467	23,860	26,328	31,738	36,996	43,818	45,199	48,874	62,313
Industry specific R&D labor cost index	19,483	23,437	24,141	25,977	31,172	36,115	43,087	45,199	48,857	62,117
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	16,154	20,217	21,806	24,231	29,915	35,727	43,369	45,199	49,063	62,802
Mfp-adjusted SA aggregate input price index	16,280	20,749	22,598	24,869	30,088	35,652	43,187	45,199	49,067	62,247
Mfp-adjusted aggregate RBDL R&D input cost index	15,704	19,787	21,520	23,778	29,474	35,355	43,153	45,199	49,284	63,495
Mfp-adjusted Scientific R&D services input cost index	16,273	20,351	21,982	24,122	29,677	35,530	43,157	45,199	48,983	63,124
Copeland-Fixler Price Index	17,596	21,527	23,206	25,772	30,870	36,872	43,881	45,199	50,861	64,330

Semiconductor and Other Electronic Component Manufacturing (3344)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Output-price based indexes					**Levels in Millions of 2005 Dollars**					
Down-stream product output price index	4,250	5,983	8,599	12,554	13,526	15,614	17,527	19,211	20,286	22,226
SA aggregate output price index	8,852	10,566	12,339	14,791	15,712	17,194	18,306	19,211	19,244	19,199
Input-cost based indexes										
SA aggregate input price index	11,712	13,263	14,662	16,655	17,054	18,042	18,605	19,211	18,711	17,800
Industry specific R&D input cost index	10,843	12,249	13,687	15,741	16,574	17,881	18,589	19,211	18,798	18,295
Industry specific R&D labor cost index	12,056	13,230	14,376	15,987	16,883	18,146	18,669	19,211	18,742	18,094
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	9,589	11,011	12,499	14,477	15,614	17,263	18,398	19,211	18,871	18,439
Mfp-adjusted SA aggregate input price index	10,373	11,941	13,410	15,339	16,077	17,423	18,413	19,211	18,783	17,939
Mfp-adjusted aggregate RBDL R&D input cost index	10,007	11,387	12,770	14,666	15,749	17,278	18,399	19,211	18,866	18,299
Mfp-adjusted Scientific R&D services input cost index	10,369	11,712	13,045	14,878	15,858	17,363	18,401	19,211	18,751	18,192
Copeland-Fixler Price Index	11,212	12,389	13,771	15,896	16,495	18,019	18,709	19,211	19,470	18,539

Motor Vehicles, Bodies and Trailers, and Parts Manufacturing (336MV)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Output-price based indexes					**Levels in Millions of 2005 Dollars**					
Down-stream product output price index	14,688	19,166	19,518	17,612	17,126	19,380	17,538	17,942	18,642	18,157
SA aggregate output price index	13,628	18,419	19,103	17,647	17,117	19,442	17,746	17,942	18,409	18,092
Input-cost based indexes										
SA aggregate input price index	18,030	23,120	22,699	19,870	18,579	20,401	18,036	17,942	17,899	16,773
Industry specific R&D input cost index	17,276	21,948	21,562	18,885	17,964	20,099	17,924	17,942	17,964	17,187
Industry specific R&D labor cost index	18,407	22,721	21,772	18,567	17,649	19,843	17,760	17,942	17,936	17,164
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	15,286	19,738	19,697	17,373	16,923	19,404	17,738	17,942	18,034	17,323
Mfp-adjusted SA aggregate input price index	15,970	20,816	20,760	18,300	17,515	19,701	17,851	17,942	17,968	16,904
Mfp-adjusted aggregate RBDL R&D input cost index	15,405	19,851	19,770	17,497	17,158	19,537	17,837	17,942	18,047	17,243
Mfp-adjusted Scientific R&D services input cost index	15,963	20,417	20,195	17,750	17,276	19,633	17,838	17,942	17,937	17,143
Copeland-Fixler Price Index	17,261	21,597	21,319	18,964	17,970	20,375	18,138	17,942	18,625	17,470

SA: BEA Satellite Account
RBDL: Robbins, Belay, Donahoe, and Lee version
*government and non-profit R&D deflated with input cost indexes

Appendix Table B: Real R&D Investment by Industry (continues)

Computer Systems Design and Related Services (5415)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Output-price based indexes					Levels in Millions of 2005 Dollars					
Down-stream product output price index	2,970	4,035	5,625	11,202	15,467	14,312	11,402	13,524	14,166	14,559
SA aggregate output price index	2,773	3,962	5,777	11,900	16,355	14,918	11,612	13,524	14,188	14,642
Input-cost based indexes										
SA aggregate input price index	3,668	4,973	6,864	13,400	17,751	15,654	11,802	13,524	13,794	13,575
Industry specific R&D input cost index	3,515	4,702	6,476	12,541	17,572	15,490	11,728	13,524	13,838	13,826
Industry specific R&D labor cost index	3,544	4,668	6,387	12,180	17,449	15,155	11,682	13,524	13,850	13,930
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	3,248	4,392	6,107	11,970	16,506	15,065	11,673	13,524	13,824	13,874
Mfp-adjusted SA aggregate input price index	3,249	4,478	6,278	12,341	16,735	15,117	11,681	13,524	13,848	13,681
Mfp-adjusted aggregate RBDL R&D input cost index	3,134	4,270	5,978	11,799	16,393	14,991	11,672	13,524	13,909	13,955
Mfp-adjusted Scientific R&D services input cost index	3,248	4,392	6,107	11,970	16,506	15,065	11,673	13,524	13,824	13,874
Copeland-Fixler Price Index	3,512	4,646	6,447	12,788	17,169	15,634	11,868	13,524	14,354	14,138

Computer Software Publishers (5112)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Output-price based indexes					Levels in Millions of 2005 Dollars					
Down-stream product output price index	8,542	10,014	11,343	11,956	12,437	15,211	16,089	16,497	18,396	18,944
SA aggregate output price index	8,513	10,336	12,156	13,250	13,664	16,228	16,494	16,497	18,405	18,943
Input-cost based indexes										
SA aggregate input price index	11,263	12,974	14,444	14,920	14,831	17,029	16,764	16,497	17,895	17,563
Productivity-adjusted indexes										
BEA index for custom and own account software	10,158	11,563	12,851	13,401	13,760	16,164	16,458	16,497	18,204	18,412
Mfp-adjusted SA aggregate input price index	9,976	11,681	13,210	13,741	13,982	16,444	16,592	16,497	17,965	17,700
Mfp-adjusted aggregate RBDL R&D input cost index	9,623	11,140	12,580	13,138	13,696	16,307	16,578	16,497	18,044	18,055
Mfp-adjusted Scientific R&D services input cost index	9,972	11,457	12,851	13,328	13,791	16,388	16,580	16,497	17,934	17,949
Copeland-Fixler Price Index	10,782	12,119	13,566	14,240	14,345	17,007	16,858	16,497	18,621	18,292

Scientific R&D Services (5417)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Output-price based indexes					Levels in Millions of 2005 Dollars					
Down-stream product output price index	7,725	8,329	10,420	10,594	8,850	7,508	8,346	8,517	8,549	9,344
SA aggregate output price index	5,653	6,470	8,683	9,308	7,976	7,022	8,080	8,517	8,630	9,803
Input-cost based indexes										
SA aggregate input price index	7,479	8,121	10,317	10,481	8,658	7,368	8,212	8,517	8,391	9,088
Industry specific R&D input cost index	7,478	7,970	10,043	10,173	8,542	7,344	8,207	8,517	8,376	9,216
Industry specific R&D labor cost index	8,130	8,436	10,374	10,196	8,547	7,305	8,125	8,517	8,315	9,151
Productivity-adjusted indexes										
Mfp-adjusted SA aggregate input price index	6,624	7,312	9,436	9,653	8,162	7,116	8,128	8,517	8,423	9,159
Mfp-adjusted aggregate RBDL R&D input cost index	6,390	6,973	8,986	9,229	7,995	7,056	8,122	8,517	8,460	9,343
Mfp-adjusted Scientific R&D services input cost index	6,621	7,172	9,179	9,362	8,050	7,091	8,122	8,517	8,409	9,289
Copeland-Fixler Price Index	7,160	7,586	9,690	10,003	8,374	7,359	8,259	8,517	8,731	9,466

All Other Goods (AOG)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Output-price based indexes					Levels in Millions of 2005 Dollars					
Down-stream product output price index	71,041	72,560	80,348	80,788	72,787	72,487	72,559	77,343	85,930	92,232
SA aggregate output price index	66,093	68,105	77,178	78,648	70,355	70,627	71,715	77,343	86,310	93,262
Input-cost based indexes										
SA aggregate input price index	87,443	85,485	91,705	88,559	76,362	74,109	72,887	77,343	83,919	86,465
Industry specific R&D input cost index	85,202	82,357	88,193	85,415	75,156	73,853	73,006	77,343	84,259	88,144
Industry specific R&D labor cost index	89,562	84,626	88,985	84,066	74,064	73,061	72,581	77,343	84,388	87,995
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	75,411	74,086	80,585	78,594	70,823	71,311	72,256	77,343	84,587	88,839
Mfp-adjusted SA aggregate input price index	77,449	76,968	83,871	81,560	71,990	71,566	72,137	77,343	84,245	87,140
Mfp-adjusted aggregate RBDL R&D input cost index	74,711	73,397	79,871	77,981	70,521	70,970	72,080	77,343	84,616	88,886
Mfp-adjusted Scientific R&D services input cost index	77,418	75,491	81,588	79,108	71,007	71,320	72,087	77,343	84,100	88,368
Copeland-Fixler Price Index	83,712	79,853	86,130	84,520	73,861	74,015	73,296	77,343	87,324	90,055

All Other Services (AOS)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Output-price based indexes				Levels in Millions of 2005 Dollars						
Down-stream product output price index	28,258	31,832	34,083	29,248	22,959	19,857	20,459	22,835	23,040	24,129
SA aggregate output price index	21,549	25,524	28,740	25,710	20,500	18,411	19,778	22,835	23,747	25,791
Input-cost based indexes										
SA aggregate input price index	28,510	32,037	34,149	28,950	22,250	19,319	20,102	22,835	23,089	23,912
Industry specific R&D input cost index	27,757	30,882	32,940	28,029	21,969	19,241	20,145	22,835	23,285	24,375
Industry specific R&D labor cost index	28,592	31,287	32,925	27,551	21,649	18,967	20,011	22,835	23,441	24,378
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	24,568	27,781	30,100	25,793	20,704	18,578	19,938	22,835	23,376	24,567
Mfp-adjusted SA aggregate input price index	25,252	28,845	31,232	26,662	20,976	18,656	19,895	22,835	23,179	24,099
Mfp-adjusted aggregate RBDL R&D input cost index	24,359	27,507	29,743	25,492	20,548	18,501	19,879	22,835	23,281	24,581
Mfp-adjusted Scientific R&D services input cost index	25,242	28,292	30,382	25,860	20,690	18,592	19,881	22,835	23,139	24,438
Copeland-Fixler Price Index	27,294	29,926	32,073	27,629	21,521	19,295	20,214	22,835	24,026	24,905

SA: BEA Satellite Account
RBDL: Robbins, Belay, Donahoe, and Lee version

Appendix Table C: Growth Rate of Real R&D Investment by Industry (continues)

Total R&D investment, including government and non-profit R&D*	1999	2000	2001	2002	2003	2004	2005	2006	2007	1998-2007 growth rate
Output-price based indexes				annual growth rate						
Down-stream product output price index	8.6	7.7	4.2	-0.5	3.5	2.9	4.1	5.2	7.3	4.7
SA aggregate output price index	9.9	9.0	5.1	-0.3	4.1	3.5	4.7	5.7	7.9	5.5
Input-cost based indexes										
SA aggregate input price index	6.2	5.1	1.4	-2.7	1.9	1.4	3.6	3.8	4.5	2.8
Industry specific R&D input cost index	5.4	5.0	1.6	-1.1	2.6	1.9	3.6	4.1	5.6	3.2
Industry specific R&D labor cost index	3.9	3.7	0.1	-1.0	2.6	2.2	4.1	4.1	5.4	2.8
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	6.4	6.0	2.1	0.1	4.2	3.4	4.3	4.3	5.9	4.1
Mfp-adjusted SA aggregate input price index	7.3	6.2	1.8	-1.1	3.4	3.0	4.3	4.0	4.8	3.7
Mfp-adjusted aggregate RBDL R&D input cost index	6.5	6.1	2.1	0.5	4.3	3.5	4.3	4.3	5.9	4.1
Mfp-adjusted Scientific R&D services input cost index	6.0	5.6	1.6	0.0	4.1	3.2	4.3	3.9	5.9	3.8
Copeland-Fixler Price Index	4.5	5.5	2.5	-1.8	4.0	1.9	3.2	6.5	4.6	3.4

Pharmaceutical and Medicine Manufacturing (3254)	1999	2000	2001	2002	2003	2004	2005	2006	2007	1998-2007 growth rate
Output-price based indexes				annual growth rate						
Down-stream product output price index	25.2	9.4	9.7	18.5	14.8	17.6	1.5	7.2	28.4	14.4
SA aggregate output price index	32.2	13.3	15.3	22.6	19.7	22.0	5.3	11.2	32.5	19.0
Input-cost based indexes										
SA aggregate input price index	25.4	7.2	9.3	18.2	15.7	18.2	3.6	8.1	26.4	14.4
Industry specific R&D input cost index	23.2	6.2	10.3	20.5	16.6	18.4	3.2	8.1	27.5	14.6
Industry specific R&D labor cost index	20.3	3.0	7.6	20.0	15.9	19.3	4.9	8.1	27.1	13.7
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	25.2	7.9	11.1	23.5	19.4	21.4	4.2	8.5	28.0	16.3
Mfp-adjusted SA aggregate input price index	27.5	8.9	10.1	21.0	18.5	21.1	4.7	8.6	26.9	16.1
Mfp-adjusted aggregate RBDL R&D input cost index	26.0	8.8	10.5	24.0	20.0	22.1	4.7	9.0	28.8	16.8
Mfp-adjusted Scientific R&D services input cost index	25.1	8.0	9.7	23.0	19.7	21.5	4.7	8.4	28.9	16.3
Copeland-Fixler Price Index	22.3	7.8	11.1	19.8	19.4	19.0	3.0	12.5	26.5	15.5

Semiconductor and Other Electronic Component Manufacturing (3344)	1999	2000	2001	2002	2003	2004	2005	2006	2007	1998-2007 growth rate
Output-price based indexes				annual growth rate						
Down-stream product output price index	40.8	43.7	46.0	7.7	15.4	12.3	9.6	5.6	9.6	20.2
SA aggregate output price index	19.4	16.8	19.9	6.2	9.4	6.5	4.9	0.2	-0.2	9.0
Input-cost based indexes										
SA aggregate input price index	13.2	10.6	13.6	2.4	5.8	3.1	3.3	-2.6	-4.9	4.8
Industry specific R&D input cost index	13.0	11.7	15.0	5.3	7.9	4.0	3.3	-2.1	-2.7	6.0
Industry specific R&D labor cost index	9.7	8.7	11.2	5.6	7.5	2.9	2.9	-2.4	-3.5	4.6
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	14.8	13.5	15.8	7.9	10.6	6.6	4.4	-1.8	-2.3	7.5
Mfp-adjusted SA aggregate input price index	15.1	12.3	14.4	4.8	8.4	5.7	4.3	-2.2	-4.5	6.3
Mfp-adjusted aggregate RBDL R&D input cost index	13.8	12.1	14.8	7.4	9.7	6.5	4.4	-1.8	-3.0	6.9
Mfp-adjusted Scientific R&D services input cost index	13.0	11.4	14.1	6.6	9.5	6.0	4.4	-2.4	-3.0	6.4
Copeland-Fixler Price Index	10.5	11.2	15.4	3.8	9.2	3.8	2.7	1.3	-4.8	5.7

Motor Vehicles, Bodies and Trailers, and Parts Manufacturing (336MV)	1999	2000	2001	2002	2003	2004	2005	2006	2007	1998-2007 growth rate
Output-price based indexes				annual growth rate						
Down-stream product output price index	30.5	1.8	-9.8	-2.8	13.2	-9.5	2.3	3.9	-2.6	2.4
SA aggregate output price index	35.2	3.7	-7.6	-3.0	13.6	-8.7	1.1	2.6	-1.7	3.2
Input-cost based indexes										
SA aggregate input price index	28.2	-1.8	-12.5	-6.5	9.8	-11.6	-0.5	-0.2	-6.3	-0.8
Industry specific R&D input cost index	27.0	-1.8	-12.4	-4.9	11.9	-10.8	0.1	0.1	-4.3	-0.1
Industry specific R&D labor cost index	23.4	-4.2	-14.7	-4.9	12.4	-10.5	1.0	0.0	-4.3	-0.8
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	29.1	-0.2	-11.8	-2.6	14.7	-8.6	1.1	0.5	-3.9	1.4
Mfp-adjusted SA aggregate input price index	30.3	-0.3	-11.8	-4.3	12.5	-9.4	0.5	0.1	-5.9	0.6
Mfp-adjusted aggregate RBDL R&D input cost index	28.9	-0.4	-11.5	-1.9	13.9	-8.7	0.6	0.6	-4.5	1.3
Mfp-adjusted Scientific R&D services input cost index	27.9	-1.1	-12.1	-2.7	13.6	-9.1	0.6	0.0	-4.4	0.8
Copeland-Fixler Price Index	25.1	-1.3	-11.0	-5.2	13.4	-11.0	-1.1	3.8	-6.2	0.1

SA: BEA Satellite Account
RBDL: Robbins, Belay, Donahoe, and Lee version
*government and non-profit R&D deflated with input cost indexes

Appendix Table C: Growth Rate of Real R&D Investment by Industry (continues)

Computer Systems Design and Related Services (5415)	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**1998-2007 growth rate**
Output-price based indexes				**annual growth rate**						
Down-stream product output price index	35.9	39.4	99.2	38.1	-7.5	-20.3	18.6	4.8	2.8	19.3
SA aggregate output price index	42.9	45.8	106.0	37.4	-8.8	-22.2	16.5	4.9	3.2	20.3
Input-cost based indexes										
SA aggregate input price index	35.6	38.0	95.2	32.5	-11.8	-24.6	14.6	2.0	-1.6	15.6
Industry specific R&D input cost index	33.8	37.7	93.7	40.1	-11.9	-24.3	15.3	2.3	-0.1	16.4
Industry specific R&D labor cost index	31.7	36.8	90.7	43.3	-13.1	-22.9	15.8	2.4	0.6	16.4
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	35.2	39.0	96.0	37.9	-8.7	-22.5	15.9	2.2	0.4	17.5
Mfp-adjusted SA aggregate input price index	37.8	40.2	96.6	35.6	-9.7	-22.7	15.8	2.4	-1.2	17.3
Mfp-adjusted aggregate RBDL R&D input cost index	36.2	40.0	97.4	38.9	-8.6	-22.1	15.9	2.8	0.3	18.0
Mfp-adjusted Scientific R&D services input cost index	35.2	39.0	96.0	37.9	-8.7	-22.5	15.9	2.2	0.4	17.5
Copeland-Fixler Price Index	32.3	38.8	98.4	34.3	-8.9	-24.1	13.9	6.1	-1.5	16.7

Computer Software Publishers (5112)	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**1998-2007 growth rate**
Output-price based indexes				**annual growth rate**						
Down-stream product output price index	17.2	13.3	5.4	4.0	22.3	5.8	2.5	11.5	3.0	9.3
SA aggregate output price index	21.4	17.6	9.0	3.1	18.8	1.6	0.0	11.6	2.9	9.3
Input-cost based indexes										
SA aggregate input price index	15.2	11.3	3.3	-0.6	14.8	-1.6	-1.6	8.5	-1.9	5.1
Productivity-adjusted indexes										
BEA index for custom and own account software	13.8	11.1	4.3	2.7	17.5	1.8	0.2	10.4	1.1	6.8
Mfp-adjusted SA aggregate input price index	17.1	13.1	4.0	1.8	17.6	0.9	-0.6	8.9	-1.5	6.6
Mfp-adjusted aggregate RBDL R&D input cost index	15.8	12.9	4.4	4.3	19.1	1.7	-0.5	9.4	0.1	7.2
Mfp-adjusted Scientific R&D services input cost index	14.9	12.2	3.7	3.5	18.8	1.2	-0.5	8.7	0.1	6.7
Copeland-Fixler Price Index	12.4	11.9	5.0	0.7	18.6	-0.9	-2.1	12.9	-1.8	6.0

Scientific R&D Services (5417)	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**1998-2007 growth rate**
Output-price based indexes				**annual growth rate**						
Down-stream product output price index	7.8	25.1	1.7	-16.5	-15.2	11.2	2.0	0.4	9.3	2.1
SA aggregate output price index	14.5	34.2	7.2	-14.3	-12.0	15.1	5.4	1.3	13.6	6.3
Input-cost based indexes										
SA aggregate input price index	8.6	27.0	1.6	-17.4	-14.9	11.5	3.7	-1.5	8.3	2.2
Industry specific R&D input cost index	6.6	26.0	1.3	-16.0	-14.0	11.8	3.8	-1.7	10.0	2.3
Industry specific R&D labor cost index	3.8	23.0	-1.7	-16.2	-14.5	11.2	4.8	-2.4	10.1	1.3
Productivity-adjusted indexes										
Mfp-adjusted SA aggregate input price index	10.4	29.0	2.3	-15.4	-12.8	14.2	4.8	-1.1	8.7	3.7
Mfp-adjusted aggregate RBDL R&D input cost index	9.1	28.9	2.7	-13.4	-11.7	15.1	4.9	-0.7	10.4	4.3
Mfp-adjusted Scientific R&D services input cost index	8.3	28.0	2.0	-14.0	-11.9	14.5	4.9	-1.3	10.5	3.8
Copeland-Fixler Price Index	6.0	27.7	3.2	-16.3	-12.1	12.2	3.1	2.5	8.4	3.2

All Other Goods (AOG)	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**1998-2007 growth rate**
Output-price based indexes				**annual growth rate**						
Down-stream product output price index	2.1	10.7	0.5	-9.9	-0.4	0.1	6.6	11.1	7.3	2.9
SA aggregate output price index	3.0	13.3	1.9	-10.5	0.4	1.5	7.8	11.6	8.1	3.9
Input-cost based indexes										
SA aggregate input price index	-2.2	7.3	-3.4	-13.8	-3.0	-1.6	6.1	8.5	3.0	-0.1
Industry specific R&D input cost index	-3.3	7.1	-3.1	-12.0	-1.7	-1.1	5.9	8.9	4.6	0.4
Industry specific R&D labor cost index	-5.5	5.2	-5.5	-11.9	-1.4	-0.7	6.6	9.1	4.3	-0.2
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	-1.8	8.8	-2.5	-9.9	0.7	1.3	7.0	9.4	5.0	1.8
Mfp-adjusted SA aggregate input price index	-0.6	9.0	-2.8	-11.7	-0.6	0.8	7.2	8.9	3.4	1.3
Mfp-adjusted aggregate RBDL R&D input cost index	-1.8	8.8	-2.4	-9.6	0.6	1.6	7.3	9.4	5.0	1.9
Mfp-adjusted Scientific R&D services input cost index	-2.5	8.1	-3.0	-10.2	0.4	1.1	7.3	8.7	5.1	1.5
Copeland-Fixler Price Index	-4.6	7.9	-1.9	-12.6	0.2	-1.0	5.5	12.9	3.1	0.8

SA: BEA Satellite Account

RBDL: Robbins, Belay, Donahoe, and Lee version

Appendix Table C: Growth Rate of Real R&D Investment by Industry (continued)

All Other Services (AOS)	1999	2000	2001	2002	2003	2004	2005	2006	2007	1998-2007 growth rate
Output-price based indexes				annual growth rate						
Down-stream product output price index	12.6	7.1	-14.2	-21.5	-13.5	3.0	11.6	0.9	4.7	-1.7
SA aggregate output price index	18.4	12.6	-10.5	-20.3	-10.2	7.4	15.5	4.0	8.6	2.0
Input-cost based indexes										
SA aggregate input price index	12.4	6.6	-15.2	-23.1	-13.2	4.0	13.6	1.1	3.6	-1.9
Industry specific R&D input cost index	11.3	6.7	-14.9	-21.6	-12.4	4.7	13.4	2.0	4.7	-1.4
Industry specific R&D labor cost index	9.4	5.2	-16.3	-21.4	-12.4	5.5	14.1	2.7	4.0	-1.8
Productivity-adjusted indexes										
Mfp-adjusted industry specific input cost index for R&D activity	13.1	8.3	-14.3	-19.7	-10.3	7.3	14.5	2.4	5.1	0.0
Mfp-adjusted SA aggregate input price index	14.2	8.3	-14.6	-21.3	-11.1	6.6	14.8	1.5	4.0	-0.5
Mfp-adjusted aggregate RBDL R&D input cost index	12.9	8.1	-14.3	-19.4	-10.0	7.4	14.9	2.0	5.6	0.1
Mfp-adjusted Scientific R&D services input cost index	12.1	7.4	-14.9	-20.0	-10.1	6.9	14.9	1.3	5.6	-0.4
Copeland-Fixler Price Index	9.6	7.2	-13.9	-22.1	-10.3	4.8	13.0	5.2	3.7	-1.0

SA: BEA Satellite Account

RBDL: Robbins, Belay, Donahoe, and Lee version

Appendix Table D: Comparison of Data Sources for R&D Input Cost Indexes

	Mansfield, Romeo, and Switzer, 1983	Mansfield, 1987	Jankowski 1990	1994 R&D Satellite Account	2007 BEA R&D Satellite Account	2012 Experimental Estimates
Years covered by index	1979 relative to 1969	1969 - 1981	1969 -1988	1960-1992	1987-2006	1997-2007
Industries covered	Chemicals, Petroleum, Electrical Equipment, Primary Metals, Fabricated Metal Products, Rubber, Stone, Clay, and Glass, Textiles	Chemicals, Petroleum, Electrical Equipment, Primary Metals, Fabricated Metal Products, Rubber, Stone, Clay, and Glass, Textiles Aircraft, Food, Machinery, Automobiles, Instruments, Other	Food, Chemicals, Petroleum, Rubber, Stone, clay, and glass, Primary Metals, Fabricated Metals, Machinery, Electrical Equipment, Automobiles, Aircraft, Professional and Scientific Instruments	Food and kindred products, Chemicals and allied products, Petroleum refining and extraction, Rubber and miscellaneous plastics products, Stone, clay, and glass products, Primary metal industries, Fabricated metal products, Industrial machinery and equipment, Electronic and other electric equipment, Aircraft and missiles, Other transportation equipment, Instruments and related products, Other manufacturing industries, Nonmanufacturing industries	All-industry aggregate	Pharmaceutical manufacturing, Semiconductor manufacturing, Scientific R&D services, Computer System Design All other goods producing industries, All other service producing industries
Scientists and Engineers	Firm survey conducted by authors	Bureau of Labor Statistics mean pay for engineers and scientists	Bureau of Labor Statistics mean pay for engineers and scientists to 1983, thereafter industry specific data from American Association of Engineering Societies Engineering Manpower Commission survey.	Industry specific American Association of Engineering Societies Engineering Manpower Commission survey.	For 2000-06, judgmental estimates based on salaries for R&D scientists and engineers from R&D Magazine salary surveys and BEA's unpublished chain-type Laspeyres salary index based on engineer salaries in R&D organizations from the American Association of Engineering Societies (AAES) annual salary surveys. For 1987-99, BEA's unpublished chain-type Laspeyres salary index based on AAES data.	BLS wages for scientists and engineers, identified by the following occupations: computer and mathematical occupations, architecture and engineering occupations, and life, physical, and social science occupations. Weights for each industry are based on the proportions shown in Appendix Table E
Other Support Personnel		Industry specific average hourly earnings of production workers	Industry specific average hourly earnings of production workers	Industry specific average hourly earnings of production workers	BLS average hourly earnings of production workers in research and testing services.	BLS average hourly earnings of production workers
Materials and Supplies		BEA index of cost of materials, tabulated until 1983	NBER productivity data indexes for materials and energy	Producer price index for industrial commodities less fuel	BEA unpublished composite index for materials in the scientific R&D services industry (NAICS industry 5417) from the KLEMS data	BEA intermediate inputs and supplies, weights are based on the proportions shown in Appendix Table E .
Services of R&D Plant and Equipment		Weighted average of BEA prices for producers durable equipment (2/3) and industrial nonresidential structures (1/3)	BEA prices for producers durable equipment and nonresidential structures	Implicit price deflator for private purchases of new industrial nonresidential structures and producers durable equipment	NIPA implicit price deflator for depreciation in NAICS industry 5412OP.	NIPA implicit price deflator for depreciation, weights are based on proportions in Appendix Table E
Other inputs		Median weekly salary of managers and administrators	Median weekly earnings for executives, administrators, and managers	Median weekly salaries of managers and administrators	BEA unpublished composite index for overhead in the scientific R&D services industry (NAICS industry 5417)	BEA intermediate inputs and supplies, weights are based on the proportions shown in Appendix Table E.

Methodological Appendix: industry-specific R&D inputs

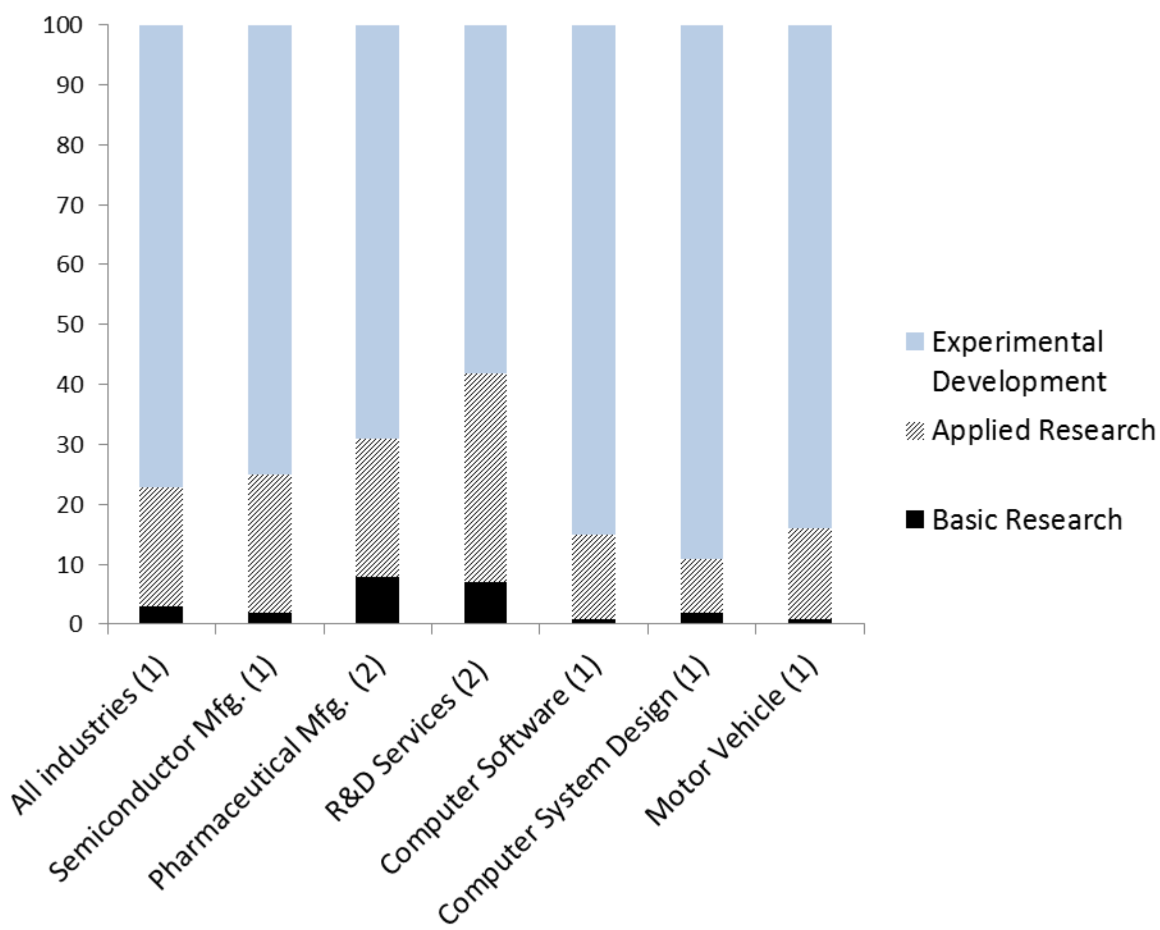
Each industry-specific input cost index shares a core set of sub-inputs specific to R&D activity, described in Section 4, and a sub-set of industry-specific inputs. This section describes the selection of the industry-specific inputs. The weight selection is primarily judgmental; for pharmaceutical R&D supplemental information provides support for choice of weights.[2] The split between basic research, applied research, and experimental development is shown in Appendix Figure A. The selection of weights by R&D performing industry is shown in Appendix Table E.

For R&D performed by manufacturing industries we assume that the basic and applied phases of R&D are activities that are more similar to scientific R&D services than the later phase of R&D activity, experimental development. Accordingly, basic and applied research inputs for pharmaceutical-related R&D are assumed to be half scientific R&D services and half industry-specific. For motor vehicle manufacturing inputs from industrial design services are included in the basic and applied research phases. We include inputs from testing laboratories in the experimental development phase of semiconductor-related R&D and all other goods R&D. For pharmaceutical R&D we include inputs from medical and diagnostic testing in the experimental development phase.

For R&D performed by the computer system design industry we assume that the inputs to R&D are similar to those of the industry itself, we simply include a one-fifth weight of scientific

[2] NSF data for 2004 shows that 31 percent of expenditures are in basic and applied research and 69 percent are in experimental development (Appendix Figure A.). As described by Scherer (2007), pharmaceutical R&D activity has two main phases. First is a preclinical phase, where new compounds or molecules are developed and tested for efficacy and safety on difference species of animals. Second is a clinical trials phase, where these drugs are tested on humans after the Food and Drug Administration issues an investigation of a new drugs permit. Accordingly, we use the classification of R&D activity by type from the NSF data to treat the basic and applied research expenditures as the preclinical phase of R&D activity and experimental development as the clinical trials phase. We assume that the inputs used in basic and applied research are different from those used in experimental development. This division corresponds closely to the functional distribution of US R&D for 2003 in Moses, et al (2005), where 32 percent of expenditures are for pre-human and preclinical activity.

R&D services. For all other services we simply make a fifty-fifty split between the industry – specific inputs and the inputs of scientific R&D services. For computer software R&D we use BEA's custom software index. This is an input cost index for software that already includes a productivity adjustment. Its use is recognition that there is substantial overlap between software and R&D.



Source: National Science Foundation/Division of Science Resource Statistics, Survey of Industrial R&D, data not available for all years for each industry
(1) 2003-2006
(2) 2004

Appendix Figure A Basic Research, Applied Research, and Experimental Development, 2003-2006.

Appendix Table E: Industry Combination Weights

Performing Industry	Composition of R&D Inputs for Cost Weights		
Same weight pattern for all R&D expenditures			
Scientific R&D services	100% Scientific R&D services (NAICS 5417)		
Computer system design R&D	80% Computer system design (NAICS 5415) 20% scientific R&D services (NAICS 5417)		
Computer software R&D	100% Custom software		
All other services R&D	50% industry-specific inputs 50% R&D services (NAICS 5417)		
Weight basic and applied research differently from experimental development			
	Basic and Applied Research		Experimental Development
Pharmaceutical manufacturing R&D	50% Pharmaceutical manufacturing (NAICS 3254) 50% Scientific R&D services (NAICS 5417)		33% Pharmaceutical manufacturing (NAICS 3254) 33% Scientific R&D services (NAICS 5417) 33% Medical and diagnostic testing (NAICS 6215)
	Basic and Applied Research		Experimental Development
Motor vehicle manufacturing R&D	33% Motor vehicle and related parts manufacturing (NAICS 3361-3) 33% Industrial design services (NAICS 54142) 33% Scientific R&D services (NAICS 5417)		25% Motor vehicle and related parts manufacturing (NAICS 3361-3) 25% Scientific R&D services (NAICS 5417) 25% Engineering services (NAICS 54133) 25% Industrial design services (NAICS 54142)
Weight each type of R&D by a different weight			
	Basic Research	Applied Research	Experimental Development
Semiconductor manufacturing R&D	50% Semiconductor manufacturing (NAICS 3344) 50% Scientific R&D services (NAICS 5417)	33% Semiconductor manufacturing (NAICS 3344) 33% Scientific R&D services (NAICS 5417) 33% Engineering services (NAICS 54133)	50% Semiconductor manufacturing (NAICS 3344) 40% Engineering services (NAICS 54133) 10% Testing laboratories (NAICS 54138)
	Basic Research	Applied Research	Experimental Development
All other goods R&D	50% industry-specific inputs 50% Scientific R&D services (NAICS 5417)	33% industry-specific inputs 33% R&D Services (NAICS 5417) 33% Industrial design services (NAICS 54142)	25% industry-specific inputs 25% Scientific R&D services (NAICS 5417) 25% Engineering services (NAICS 54133) 25% Testing laboratories (NAICS 5418)

Table F shows the resulting input proportions for our input-cost structure for each industry specific category of R&D. For example, based on the ratios shown in Table E, the price index for pharmaceutical R&D is calculated using the intermediate input percentages show in the second column of Table F. Farm products make up 0.3 percent of intermediate inputs, mining products make up 0.4 percent, and utilities make up 1.4 percent.

Appendix Table F. Composition of Intermediate Inputs by R&D Industry

Type of Intermediate Input	Pharmaceutical R&D	Semiconductor R&D	Motor Vehicles R&D	All Other Goods R&D	R&D Services	Computer System Design R&D	Computer Softw are	All Other Services R&D
Farm Products	0.3%	0.0%	0.2%	0.5%	0.7%	0.1%	0.0%	0.4%
Mining	0.4%	0.4%	0.8%	1.0%	0.6%	0.1%	0.0%	0.8%
Utilities	1.4%	1.7%	1.7%	1.9%	1.9%	0.7%	0.4%	1.7%
Construction	2.2%	1.1%	1.7%	1.8%	4.6%	1.1%	0.3%	3.0%
Apparel, Food, and other Non-durable Products	0.9%	0.1%	0.8%	0.8%	1.4%	0.3%	0.0%	1.3%
Chemicals, Plastic, Rubber, Paper, Wood, and Petroleum Products	27.0%	8.5%	8.0%	9.3%	7.9%	3.0%	1.8%	7.2%
Machinery, Fabricated Metal, and other Durable Products	3.5%	26.7%	24.0%	17.8%	5.9%	6.2%	4.2%	6.1%
Transportation and Warehousing Services	3.1%	2.2%	3.0%	3.1%	4.7%	4.1%	2.9%	4.6%
Information Services	2.6%	2.5%	3.0%	3.9%	4.2%	5.7%	6.8%	9.6%
Finance and Insurance Services	4.0%	5.9%	6.5%	6.6%	6.2%	8.0%	7.2%	8.3%
Real Estate and Rental and Leasing Services	8.8%	7.9%	9.5%	10.3%	11.8%	13.6%	13.4%	11.8%
Professional, Scientific, and Technical Services	22.6%	22.3%	21.2%	22.6%	27.8%	27.0%	26.3%	24.4%
Management of Companies and Enterprises	7.6%	6.0%	3.0%	3.7%	2.4%	2.6%	6.4%	2.4%
Administrative and Support and Waste Management and Remediation Services	7.8%	6.8%	7.9%	8.3%	13.1%	14.4%	22.9%	10.6%
Educational Services	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%
Arts, Entertainment, and Recreation	0.2%	0.3%	0.3%	0.3%	0.3%	0.9%	0.6%	1.0%
Accommodation and Food Services	1.3%	3.4%	3.1%	3.1%	2.5%	6.9%	4.0%	2.8%
Other Services (except Public Administration)	2.4%	3.4%	4.6%	4.3%	2.8%	1.9%	1.1%	2.6%
Non-Comparable Imports	3.8%	0.6%	0.6%	0.4%	0.7%	3.1%	1.8%	1.0%
State and Local Government	0.2%	0.1%	0.1%	0.1%	0.4%	0.2%	0.1%	0.2%

Source: BEA Annual Industry database and author’s calculations

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