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8

R&D in the National Income and Product Accounts
A First Look at Its Effect on GDP

Barbara M. Fraumeni and Sumiye Okubo

8.1 Introduction

Research and development (R&D) has long been of interest to researchers and policymakers because of its potential impact on economic growth. However, its impact is difficult to determine from the current measures in the national income and product accounts (NIPAs) and the standard growth-accounting model. The NIPAs and the growth-accounting model do not treat R&D as investment and thus underestimate R&D's contribution to national savings, the country's stock of knowledge, and the economy as a whole. Moreover, with the current measures, the links between R&D and technical changes and between technical changes and growth in gross domestic product are uncertain.

This paper treats R&D as investment rather than current expenditure. This treatment of R&D expenditures is a step toward producing more comprehensive and accurate measures of gross domestic product (GDP), gross domestic income (GDI), and national savings. This treatment also allows for better identification of the variables that are important to a

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sources-of-growth analysis and, therefore, the determination of the contribution of R&D to economic growth.[1]

This paper is a preliminary and exploratory examination of the role of R&D in the U.S. economy. It constructs a partial R&D satellite account (R&DSA) and modifies the NIPA framework by capitalizing R&D.[2] It analyzes the impact of R&D on GDP, national saving, and other macroeconomic aggregates, and identifies the contribution of R&D to economic growth, using a sources-of-growth approach. Accomplishing both objectives entails modifying both the expenditure side and the income side of the accounts. Capitalizing R&D requires modifying the NIPA structure by including R&D expenditures and benefits within the NIPA accounts. R&D expenditures are relatively easy to measure because data are available from the National Science Foundation (NSF). R&D benefits (returns to R&D capital) are much more difficult to measure, yet estimating them is critical to establishing a link between R&D, technical change, and growth in GDP.

Among the measurement topics discussed in this paper are the magnitude of private and spillover returns to R&D, the R&D benefits that are already in the current measure of GDP, the lag with which R&D affects the economy, the rate of depreciation of R&D capital, and the appropriate deflator for R&D expenditures. As these measurement questions cannot be fully resolved here, this paper accordingly is an important, albeit only a first, look at the effect of R&D on the economy. Rates of return to R&D are drawn from past analyses of rates of return, and estimates of the R&D investment and capital stock balance sheet presented in a previously published Bureau of Economic Analysis (BEA) R&DSA are updated (Carson, Grimm, and Moylan 1994).[3]

8.2 Current Treatment of R&D in the NIPAs

The NIPA measures of investment include plant, equipment, and inventories acquired by private businesses, nonprofit institutions, and government, and net foreign investment, and exclude household consumer durables, as well as most intangible capital, such as R&D and, until the 1999 comprehensive NIPA revision, software. R&D expenditures are treated as an intermediate input for businesses and current consumption for nonprofit institutions and general government.[4]

1. In the April 2002 version of this paper, a net return to general government capital was imputed as well as R&D's being treated as investment.

2. For a description of a full R&DSA, see Fraumeni and Okubo (2000, 2001). The current NIPA convention will be described later in the paper.

3. For a description of how the estimates from that project were updated, see appendix C.

4. All R&D activities are allocated to the general government sector in the national accounts. See Bureau of Economic Analysis (1998, p. 5).

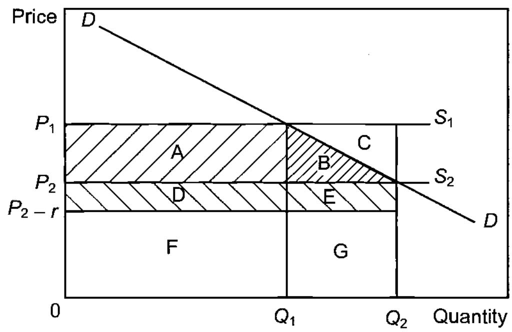

Fig. 8.1 Analysis of a product innovation

8.2.1 What the Current NIPA Includes and Excludes

To identify what is included and what is excluded in current measures of GDP and GDI, we use the graph in figure 8.1.[5] The graph shows the benefits from a product innovation that reduces the cost of an industry using the innovation. The product innovation reduces the price or cost per unit of output of the industry using the innovation from P_1 to P_2 and increases the output of that industry from Q_1 to Q_2.[6] The sum of all hatched areas, A, B, D, and E, shows the economic benefits from the innovation. Area A plus area B shows benefits derived by buyers of the product innovation. Area A is the difference between what buyers paid for $Q_1 \cdot (P_1 \cdot Q_1)$ before the innovation and what they pay for Q_1 after the innovation $(P_2 \cdot Q_1)$. Area B is the difference between the maximum amount consumers would have been willing to pay—as determined by the demand curve—for each marginal unit of the product greater than Q_1 up to Q_2 and what they actually paid $P_2 \cdot (Q_2 - Q_1)$. Area D plus area E shows the gross profit,[7] equal to r dollars per unit, received by the innovator, which is assumed to be transferred from the firm using the innovation to the innovator; thus, potential spillover benefits to the innovation-using firm are appropriated by the innovating firm.[8] The graph assumes that the market structure of the industry using

5. See Mansfield et al. (1977).

6. A similar graph could be used to illustrate the case of product innovation used by households.

7. The term *gross profits* is used because profits include depreciation on the investment in the innovation.

8. $P_2 - r$ is the innovators' per-unit cost of production, and P_2 is the price for the innovation received by the innovator under the assumption that the gross profit is transferred to the innovator.

Griliches distinguishes between two types of spillovers. One is the spillover from purchasing the results of R&D inputs at less than their full quality price. This spillover reflects a problem of measuring improvements in the quality of capital and materials and their prices correctly. The second type is knowledge spillovers and refers to ideas borrowed by research teams in one industry from the research results from another industry. See Griliches (1995, pp. 65–66).

the innovation is competitive and that the supply curve is perfectly horizontal in the relevant range.

Because GDP measures what is actually paid for a product in any given time period, rather than what consumers would have been willing to pay, GDP in any given time period does not measure the consumer surplus gain associated with the innovation but only the resource saving, area D plus area E, which is indistinguishably included in the gross profits of the innovator and in the expenditures of the consumer.

However, when one looks at changes in nominal GDP from one period to next, the resource savings to consumers on the old quantity, area A, will likely be included in the change in GDP as spending on other goods and services.[9] Thus, what will not be measured in nominal GDP will be the triangle area B, the Harberger triangle.[10]

What is included in changes in real GDP is a bit more complicated. A Laspeyres index of changes in real GDP will overestimate the change in real GDP in period two because it will include not only the entire consumer surplus gain—areas A and B—but also the area C. This overestimate occurs because the Laspeyres index values the entire output in period two at period-one prices $(P_1 \cdot Q_2)/(P_1 \cdot Q_1)$. A Pasche index will underestimate the change because it includes none of the consumer surplus gain. The Pasche index values the period-one output at period-two prices and thus includes only the areas D and F for period one in valuing the increase in real GDP in period two $(P_2 \cdot Q_2)/(P_2 \cdot Q_1)$. However, the Fisher, a chain index, which is a geometric mean of a Laspeyres and Pasche index, approximately includes the value of the consumer surplus gain area B excluded from the nominal GDP calculation, and the change in real GDP will be an average of the changes produced by the Pasche and Laspeyres indexes.

In contrast to the simple example presented, the innovator is often not paid for the spillover benefits to firms using the innovation. This paper, however, assumes that market benefits to business R&D, private and spillover,[11] are included somewhere in current national accounts measures.[12] In the following estimates, they are assumed to appear in GDP and aggregate property income estimates. (Extension of this aggregate analysis to the industry level would have to address this issue.)[13]

9. Unless labor and/or capital supply is reduced.

10. The Harberger triangle is defined as the consumer surplus gain with a decrease in price from P_1 to P_2 excluding the consumer surplus gain that is part of the total amount $P_1 \cdot Q_1$ paid for the product at the higher price.

11. Frequently, private and spillover returns are called *direct effects* and *indirect effects,* respectively. Indirect effects (spillovers) include the benefits from the use of higher-quality or new inputs developed through R&D undertaken by others and benefits from technology transfers. See Bureau of Labor Statistics (BLS; 1989, p. 5).

12. Spillover effects from business can also include unpaid-for benefits from new and improved consumer goods and services.

13. To undertake an industry analysis including spillovers, interindustry technology flow estimates similar to those developed by Scherer (1984) would have to be constructed.

Table 8.1 Estimated rates of return to private R&D (%)

Source	Private	Social
Sveikauskas (1981)	7–25	50
Bernstein and Nadiri (1988)	10–27	11–111
Bernstein and Nadiri (1991)	15–28	20–110
Nadiri (1993)	20–30	50
Mansfield et al. (1977)	25[a]	56[a]
Goto and Suzuki (1989)	26	80
Terleckyj (1974)	29	48–78
Scherer (1982, 1984)	29–43	64–147

[a]These rates are median rates.

A number of researchers have estimated the private and social rates of return to private R&D capital. In general, these returns are gross returns, including both the net return to capital and depreciation (BLS 1989, p. 39). Estimated rates of return to private R&D,[14] arranged by the lowest to the highest private rate-of-return estimates, are summarized in table 8.1. Private rates of return average from 20 to 30 percent. These private rates of return reflect the returns received by the innovator. Social rates of return, which include the spillover benefits, are much higher, ranging from an average lower bound of about 30 percent to an average upper bound of 80 percent. Although researchers have in various ways attempted to include nonmarket benefits, for the most part they reflect spillovers that we assume are already included in GDP.

The private rates of return to R&D based on these studies are considerably higher than the average returns to other types of investments. It can be argued that R&D investments would require a higher rate of return than other investments because of the risk and uncertainty attached to R&D. There are more failures than successes associated with R&D investments—the rule of thumb often used is that for every successful project, ten projects fail. In addition, businesses investing in the R&D must take into account the likelihood of imitation by competitors, and also the uncertainty in the timing of commercialization of the R&D project, especially for basic and applied research. Because of the wide range of estimated rates of return, the assumption made is that the average private rate of return is 25 percent and the average social rate of return, which includes spillovers, is 50 percent.[15]

14. See Council of Economic Advisers (CEA; 1995, p. 5). The CEA table is adapted from Griliches (1992) and Nadiri (1993). Leo Sveikauskas has pointed out in conversations that the rates of return shown in the CEA table represent different types of returns. For example, what is called a private return may be a return not only to the R&D performer but also to all other firms within the industry. However, his conclusion is that the rates of return used by Fraumeni and Okubo are reasonable rates of return, if anything perhaps somewhat too low.

15. A recent Joint Economic Committee Staff Report of the U.S. Congress (1999, p. 12) concluded that it is reasonable to assume that the private rate of return is about 25 percent

In contrast to the returns to private R&D, the returns to nonprofit institutions and general government R&D are less likely to be included in the existing measure of GDP, partly because of the way in which nonprofit institutions and general government are counted in GDP and partly because of the different nature of nonprofit institutions and general government R&D. Because the output of nonprofit institutions and general government is for the most part not sold in markets, it is assumed to be equal to their input costs. And because no input cost is associated with R&D beyond the original investment period and the R&D output is not sold in markets, no direct value is put on the returns to the R&D of nonprofit institutions and general government, and the value of these types of institutions' R&D is understated. Second, because much of the output of nonprofit institutions and general government R&D is likely to be in nonmarket goods and services, such as reduced morbidity and mortality, it is less likely to be included in GDP, which is a measure of market goods and services.

Because nonprofit institutions and general government tend to focus their R&D on nonmarket benefits and do not have to pass the market test that private firms do, their rate of return on R&D is arbitrarily assumed to be one-third smaller than the return to private R&D; that is, the private rate of return for nonprofit institutions and general government is assumed to be 16.7 percent, and the social rate of return, 33.4 percent.

Table 8.2 lists the assumptions made regarding what type of benefits are included in the current NIPA tables and what benefits are included in the estimates in this paper. It also lists the assumptions made about the gross rate of return on R&D capital for all performing sectors, the R&D deflator, the depreciation rate, and the lag structure.

8.2.2 Effects of the Current Treatment

A country's national accounts ideally provide measures of the composition and growth of its economic activity. To the extent that the economic accounts do not include all economic activities or classify some expenditures as intermediate when they actually represent a final use, the accounts are an incomplete basis for measuring a country's growth. In particular, not taking into account R&D investment and other types of intangible capital such as education embodied in human capital, understates investment, net wealth, and national savings.[16] This understatement is larger if intangible capital has risen in importance in the U.S. economy over the past decade, as some have argued.[17]

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and that the social rate of return is about twice as high as the private rate. The Economic Report of the President concludes that the social return to R&D averages about 50 percent (*Economic Report of the President* 1995, box 3–5, p. 122). A recent study of patenting by R&D laboratories of a manufacturing firm conducting R&D estimated the average private rate of return to product R&D to be about 21 percent (Arora, Ceccagnoli, and Cohen 2002).

16. See Eisner (1989, chaps. 1 and 2) and Kendrick (1976, pp. 9–11).

17. See, for example, Nakamura (2001).

Table 8.2 Assumptions

	Benefits		
	Current measures	Adjusted measures (%)	
Return to business R&D capital	Social benefits included	No change: Social benefits included	
Return to nonprofit institutions and general government R&D capital	Spillover benefits included	Private and spillover benefits included	
	Gross rates of return (%)		
Rates of return on:	Private return	Spillover return	Social return
Private R&D	25	25	50
Nonprofit institutions and general government R&D (2/3 of the above rates)	16.7	16.7	33.4
	Other		
Deflator	Depreciation rate (%)	Lag	
Private fixed nonresidential investment	11	One year	

8.3 Proposed Treatment of R&D

R&D uses resources to create products or output for future, rather than current, consumption, and in many cases it provides output and benefits long into the future, especially with seventeen-year—or, more recently, twenty-year—patent protections.[18] In this way, R&D resembles investment more closely than it does intermediate inputs or current consumption. R&D adds to the stock of knowledge or productive capital and wealth, and it provides a flow of services from this stock over time, rather than in one period, depreciating over time like plant and equipment. Accordingly, R&D expenditures should be capitalized and depreciated and treated the same as other NIPA investment.

In this paper, R&D input refers to R&D performance (as opposed to funding) by business, government, and nonprofit institutions.[19] The methodology assumes constant returns to scale and assumes that factors, including R&D capital, are chosen to minimize costs and are hired until the marginal revenue products of these factors are equal to their purchase price.[20]

18. Benefits from R&D continue past the end of patent protection, or, alternatively, they may disappear before the end of patent protection. In addition, R&D benefits may shift toward nonperformers, such as other firms with spillovers, or to consumers.

19. Using a performer basis begs the question of whether it is the performer or the funder, if different from the performer, who receives the private return.

20. See equation (2) of this paper and annex 3 of OECD (2001), particularly pages 124–26.

8.3.1 Capitalizing R&D

Capitalizing R&D produces several changes in the national accounts, in terms of the composition and level of GDP. These changes are summarized in table 8.3 and described in the following three subsections.

The first change is to treat R&D expenditures by business as investment on the expenditure side and not as an intermediate expense. Because R&D is no longer considered an expense, property-type income[21] increases by an amount equal to the expenditure, reflecting changes in profits and depreciation of R&D capital. The second change is to reclassify R&D expenditures by nonprofit institutions and general government from consumption to investment.[22] Consumption of nonprofit institutions serving persons is part of personal consumption expenditures (PCE) in the accounts, and general government consumption is part of government consumption.[23] Third, capitalizing R&D expenditures of nonprofit institutions and general government increases consumption by an amount equal to private returns to nonprofit institutions and general government R&D. These private returns can also be called imputed services from the R&D capital consumed by nonprofit institutions and general government in the current period, a terminology that highlights the consumption nature of these returns.

On the income side, depreciation and profits (or current surplus of general government) are increased by an amount equal to private returns to nonprofit institutions (or private returns to general government R&D).[24] Spillover returns, regardless of their source, are assumed to be already included in GDP. Thus, on the income side of the national accounts, all returns to R&D capital can be identified—private returns to nonprofit institutions and general government R&D can be added to spillover returns that are already included in GDP: that is, spillover returns from nonprofit institutions and general government R&D and social returns to business capital.

Treating R&D expenditures as investment in the NIPA would make these expenditures fully comparable to other expenditures on intangibles,

21. Property-type income is defined as the sum of corporate profits, proprietors' income, net interest, capital consumption allowances, inventory valuation adjustments, rental income of persons, business transfer payments, and surplus of government enterprises, less subsidies. Alternatively, it is gross domestic income (GDI) less compensation of employees, indirect business tax and nontax liabilities, and the statistical discrepancy.

22. The expenditures include those by federally funded research and development corporations (FFRDCs). Government entities that perform R&D, such as public colleges and universities, are all classified as being part of general government.

23. Some nonprofit institutions serve business, not persons, but this is a quite small percentage of nonprofit institutions' economic activity. Nonprofit institutions serving business are treated as businesses in NIPA.

24. Current surplus for general government is the category comparable to profits for private entities.

Table 8.3 Changes to the national accounts

R&D imputations, R&D performed by:	Gross domestic product			Gross domestic income	
	Treatment in current-measure GDP	Adjusted GDP	Change in current-measure GDP	Adjusted GDI	Capitalizing R&D change in current-measure GDI
Business	Intermediate input	Reallocate to investment	Increase	Increase in profits and depreciation	Increase
Nonprofit institutions	Consumption (PCE)	1) Reallocate to investment 2) Increase in consumption = private R&D returns; spillover returns already in GDP	1) No change 2) Increase	Increase in private returns to R&D capital; spillover returns already in GDI	Increase
General government	Government consumption	1) Reallocate to investment 2) Increase in consumption = private R&D returns; spillover returns already in GDP	1) No change 2) Increase	Increase in private returns to R&D capital; spillover returns already in GDI	Increase

Note: PCE = personal consumption expenditure.

such as software, that are already considered investments.[25] This treatment represents a step toward producing a comprehensive and more accurate measure of investment and savings in the U.S. NIPA, as well as capital stock and depreciation, the value of services from R&D and other fixed capital and net domestic product, and, as a result, improved measures of economic output and growth (Eisner 1989, 14–17). It provides a basis for addressing important macroeconomic, technology, and tax policy concerns and better informs policymakers about the true size of national saving and the nature of choices being made between current and future consumption.

Although this treatment provides conceptually improved estimates of output and growth, R&D is not treated as investment in the NIPAs for several reasons. First, R&D expenditures do not have an easily identifiable set of assets that can be measured or valued in a balance sheet.[26] Unlike plant and equipment and software, R&D capital is not generally sold for a market price. Thus, estimating services from R&D capital cannot be easily imputed from a representative set of market values as can be done, for example, with imputed rents from owner-occupied housing. It is usually measured on a cost basis and does not represent a final demand value. Second, the rate of return to business R&D is included in the returns to all fixed capital—plant, equipment, and R&D; separating out the returns to R&D is as thorny a problem as estimating services of R&D capital. A third and related problem is one of appropriability: other private producers may also benefit from the R&D, either as imitators or as buyers of the new product incorporating the new technology. Also difficult to determine are spillover benefits from nonprofit institutions' and government R&D investments, as well as those spillovers, such as pollution reduction R&D, from which society as a whole benefits and for which no market exists. Other problems in measuring R&D capital and R&D services include the choice of deflators, service lives, depreciation, the rates of return, and the lag structure, or the length of time before the benefits from R&D are realized.

These problems create uncertainty with estimates of R&D capital and its rate of return, but they can be addressed by using a supplemental or satellite account. Satellite accounts provide a means of experimenting with methods of estimating R&D capital and alternative scenarios of R&D returns to get a picture of the order of magnitude of the size and impact of R&D capital on GDP, without reducing the usefulness of the main accounts. The R&D satellite account tests the sensitivity of the estimates us-

25. Software was capitalized beginning with the 1999 comprehensive NIPA revision. For a description of the methodology and quantitative impacts, see Bureau of Economic Analysis (2000).

26. See *System of National Accounts 1993* (Commission of the European Communities et al. 1993) for discussion of treatment of R&D in the national accounts (pp. 9–10, para. 1.51).

ing alternative assumptions about the R&D deflator, depreciation rates, and the lag structure.[27]

8.3.2 Adjusted National Account Tables

Treating R&D as investment and computing rates of return to R&D change the estimates of GDP and the components of the accounts. Tables 8.4, 8.5, and 8.6 show revised NIPA tables incorporating these changes and expanding the detail for R&D. The tables highlight the changes and show data in 1996 dollars for selected years: 1961, 1966, 1973, 1995, and 2000. These estimates are discussed in section 8.4.1.[28] Tables 8.4 and 8.6 show the changes to the national accounts by providing a numerical link between current-measure GDP and adjusted GDP for these selected years. Table 8.4 focuses on expenditure components (GDP); table 8.6 focuses on income components (GDI). The difference between GDP and GDI is the statistical discrepancy, which is unaffected by the innovations in the R&DSA. Table 8.5 shows adjusted measures for several other NIPA aggregates.

In the adjusted-GDP table (table 8.4), which is based on NIPA tables 1.1 and 1.2, estimates of the private return to R&D capital, broken out by net return and depreciation, are included under consumption for nonprofit institutions and general government. Under all investment categories, "Completed research and development" and "Change in R&D-in-progress" are added. The sum of these two categories is equal to R&D expenditures. These two subcategories of investment exist because we assume that R&D expenditures enter the capital stock and benefits from R&D are realized with a one-year lag. Accordingly, completed R&D is equal to expenditures in the previous year, and the change in R&D-in-progress is equal to the difference in expenditures between year t and $t - 1$.[29]

The addenda to table 8.4 show how the current measure of GDP changes when R&D is capitalized, and show separately a R&D component and a net return component in the adjusted GDP. First, R&D investment is listed as an addition, but a significant portion of R&D expenditures is subtracted because it is included in current-measure GDP. This portion includes R&D expenditures of most nonprofit institutions and of general government.[30] The largest component of R&D expenditures excluded from

27. Alternative assumptions are discussed in appendix C, and the effect of alternative assumptions on the results is presented in appendix A.

28. This paper does not consider international activities, and therefore there are no data for the bolded entries under net exports of goods and services.

29. Lags are discussed in appendix C, and alternative lag scenarios are presented in appendix A.

30. Some government R&D investment is already capitalized in the current national accounts measures. Adjustments are made to deduct what can be specifically identified: R&D software defense expenditures, from the estimates of other than R&D investment, capital stock, and depreciation.

Table 8.4 **Estimated components for adjusted gross domestic product (in billions of 1996 dollars)**

	1961	1966	1973	1995	2000
Adjusted GDP	*2,446*	*3,254*	*4,169*	*7,705*	*9,475*
Personal consumption expenditures	1,541	2,008	2,681	5,087	6,271
Households					
Durable goods					
Nondurable goods					
Services					
Nonprofit institutions					
Durable goods					
Nondurable goods					
Services					
Private returns to R&D capital	*2*	*4*	*7*	*17*	*22*
Net return	1	1	2	6	7
Depreciation	1	2	5	11	14
Other services					
Gross private domestic investment	304	483	652	1,286	2,001
Business fixed investment					
Nonresidential					
Structures					
Equipment and software					
Residential					
Completed R&D	**33**	**43**	**47**	**121**	**195**
Change in R&D-in-progress	**1**	**4**	**2**	**12**	**18**
Change in business inventories					
Nonprofit institutions fixed investment					
Nonresidential					
Structures					
Equipment and software					
Residential					
Completed R&D	**3**	**5**	**6**	**16**	**21**
Change in R&D-in-progress	**1**	**0**	**0**	**1**	**1**
Net exports of goods and services	(18)	(40)	(62)	(78)	(399)
Exports					
Goods					
Services					
R&D expenditures					
Other services					
Imports					
Goods					
Services					
R&D expenditures					
Other services					
Government consumption expenditures and gross investment	673	834	901	1,411	1,584
Consumption expenditures					
Goods					
Services					
Private returns to R&D capital	*7*	*10*	*17*	*39*	*49*

Table 8.4 (continued)

	1961	1966	1973	1995	2000
Net return	2	4	6	13	17
Depreciation	5	7	11	26	32
Other services					
Fixed investment					
Nonresidential					
Structures					
Equipment and software					
Residential					
Completed R&D	**7**	**13**	**16**	**35**	**47**
Change in R&D-in-progress	**1**	**1**	**1**	**2**	**3**
Addenda					
Current measure GDP	2,432	3,228	4,123	7,544	9,224
R&D	23	36	55	161	253
R&D fixed investment	45	67	73	187	285
Business fixed investment	34	47	49	133	213
Nonprofits institutions fixed investment	3	6	6	16	22
General government fixed investment	8	14	17	37	50
Private returns to R&D[a]	9	14	24	56	71
Nonprofits institutions returns to R&D	2	4	7	17	22
General government returns to R&D	7	10	17	39	49
Less R&D expenditures in current measure GDP	30	45	42	81	103
Adjusted GDP	2,446	3,254	4,169	7,705	9,475

Notes: The value of some entries is affected by rounding. Italic numbers appear as listed in the addenda to the table. The sum of the bold numbers for completed R&D and change in R&D-in-progress appear in the addenda to the table. Bold italic titles show R&D components.

[a]The returns to R&D listed here are only returns to R&D performed by nonprofit institutions and general government (private returns) as other returns to R&D, specifically spillovers which are all assumed to fall to business, and returns to business performers, are assumed to be already included in the current measure of GDP. See table 8.2, the addenda to table 8.6, and the text section "What the Current NIPA Includes and Excludes."

current-measure GDP is expenditures for R&D performed and funded by business.[31] The subtractions are a smaller part of R&D fixed investment in 2000 than they are in 1961 and reflect the larger share of R&D performed and funded by business in all R&D in 2000.[32] Of total returns to R&D, only

31. General government funds R&D performed by business and nonprofit institutions, business funds R&D performed by nonprofit institutions and general government, and nonprofit institutions fund R&D performed by general government. Of these five cross-funding categories, only general government funding represents more than 1 percent of total R&D expenditures. According to our estimates, from 1961 to 2000 general government funding of business represented on average 34 percent of total R&D expenditures, while general government funding of nonprofit institutions represented 7 percent. The treatment of all cross-funding, except in the case of general government funding business, depends on whether the funding is a transfer or a contract.

32. See the discussion in appendix B comparing 1995–2000 to 1961–1966.

Table 8.5 **Estimated components for relation of adjusted gross domestic product, adjusted gross national product, adjusted net national product, adjusted national income, and adjusted personal income (in billions of 1996 dollars)**

	1961	1966	1973	1995	2000
Adjusted GDP	2,446	3,254	4,169	7,705	9,475
(+) Plus: Income receipts from the rest of the world and less income payments to the rest of the world					
(=) Equals: Adjusted GNP	2,462	3,274	4,205	7,725	9,469
(–) Less: Consumption of fixed capital					
Business					
Consumption of R&D capital	16	26	39	96	125
Consumption of other fixed capital					
Capital consumption allowances for other fixed capital					
(–) Less: Capital consumption adjustment for other fixed capital					
Nonprofit Institutions					
Consumption of R&D capital	1	2	5	11	14
Consumption of other fixed capital					
Capital consumption allowances for other fixed capital					
(–) Less: Capital consumption adjustment for other fixed capital					
Government					
General government					
Consumption of R&D capital	5	7	11	26	32
Consumption of other fixed capital					
Government enterprises					
(=) Equals: Adjusted net national product	2,239	2,993	3,805	6,675	8,060
Addenda					
Adjusted gross domestic income[a]	2,447	3,228	4,145	7,678	9,597
Adjusted gross national income[b]	2,463	3,248	4,182	7,698	9,591
Adjusted net domestic product	1,846	2,525	3,315	6,620	8,367

Note: Bold italic titles show R&D components.

[a]Adjusted gross domestic income deflated by the implicit price deflator for adjusted GDP.

[b]Adjusted gross national income deflated by the implicit deflator for adjusted GNP.

returns to the performer are a net addition to GDP, for the reasons outlined previously.

Table 8.5 is based on NIPA tables 1.9 and 1.10.[33] Including R&D in the accounts requires estimates of "consumption of R&D capital" and its subcategories "capital consumption allowances" and "capital consumption adjustment" for all performing sectors when relevant. "Capital consumption allowances" refers to tax-return-based depreciation, and "consumption of fixed capital" refers to economic depreciation as estimated by the

33. Table 1.10 in NIPA, the 1996 dollar table, has significantly fewer entries than table 1.9.

Table 8.6 **Estimated adjusted components for components of gross domestic product, by industry group (in billions of 1996 dollars)**

	1961	1966	1973	1995	2000
Adjusted GDP	*2,446*	*3,254*	*4,169*	*7,705*	*9,475*
Private industries					
Compensation of employees					
Indirect business tax and nontax liability					
Adjusted property-type income					
Returns to business capital					
Returns to R&D capital	*73*	*120*	*178*	*438*	*567*
Net return	57	94	139	341	442
Depreciation	16	26	39	96	125
Returns to other capital					
Net return					
Depreciation					
Returns to nonprofit institutions capital					
Returns to R&D capital	*3*	*7*	*14*	*34*	*44*
Net return	2	5	9	23	29
Depreciation	1	2	5	11	14
Returns to other capital					
Net return					
Depreciation					
Statistical discrepancy					
Government					
Compensation of employees					
Indirect business tax and nontax liability					
Adjusted property-type income					
Returns to general government capital					
Private returns to R&D capital	*14*	*21*	*35*	*78*	*98*
Net return	9	14	23	52	66
Depreciation	5	7	11	26	32
Addenda					
Current measure GDP	2,432	3,228	4,123	7,544	9,224
Returns to R&D capital[a]	91	148	226	549	709
Returns to business capital	73	120	178	438	567
Returns to nonprofit institutions capital	3	7	14	34	44
Returns to general government capital	14	21	35	78	98
(–) Less: Returns to R&D capital included in current measure GDP	82	134	202	493	638
All returns to business capital	73	120	178	438	567
Spillover returns to nonprofits institutions capital	2	4	7	17	22
Spillover returns to general government capital	7	10	17	39	49
Net increase in R&D expenditures in GDP	14	22	30	106	182
R&D fixed investment (Table 8.4)	45	67	73	187	285
(–) Less: R&D expenditures in current measure GDP (Table 8.4)	30	45	42	81	103
Adjusted GDP	2,446	3,254	4,169	7,705	9,475

Note: The value of some entries is affected by rounding. Italic numbers appear as listed in the addenda to the table. Bold italic titles show R&D components.

[a]Returns to R&D capital listed here include all returns to R&D capital (e.g., both private and spillover returns).

BEA.[34] Estimates are also needed for "subsidies less current surplus of government" and "current surplus of general government," as the surplus will change because of the R&D capital imputation.

Table 8.6 shows changes needed in the table "Components of GDP by Industry Group"[35] to reflect returns to R&D capital for all performing sectors. As before, net return and depreciation are shown separately. For government property-type income, returns to R&D capital are estimated for general government.

The addenda to table 8.6 present a comparison similar to that shown in the addenda to table 8.4. The total of all returns to R&D capital is shown in the first block of entries after the entry for current-measure GDP. The main body of the table separates these returns by sector—that is, private or government—and breaks them out into net return and depreciation. All (social) returns to business R&D and spillover returns to nonprofit institutions and general government are subtracted because they are included in current-measure GDP. As is required by a double-entry national accounts system such as the NIPA, GDP from the expenditure (product) side is exactly equal to GDP from the income side.[36]

8.3.3 Equations Comparing Current-Measure GDP with Adjusted GDP

Another way to look at the relationship between current-measure GDP and adjusted-measure GDP is through equations. The expenditure equation in nominal dollars is

$$\text{(1)} \qquad \text{GDP} = P_C C + P_I I + P_{NE} NE + P_G G,$$

where $P_C C$ is consumption, $P_I I$ is investment, $P_{NE} NE$ is net exports, and $P_G G$ is government expenditures. Looking at the expenditure components of GDP to compare current measures to adjusted measures is useful:

$$\text{(2)} \qquad \text{Current-measure } P_C C = P_{CH} C_H + P_{C,N} C_N,$$

where $P_{C,H} C_H$ is personal consumption expenditures (PCE) by households and $P_{C,N} C_N$ is PCE by nonprofit institutions that serve persons.

$$\text{(3)} \qquad \text{Adjusted-measure } P_C C = \text{current-measure } P_C C + P_{PR,N} PR_N - P_{C,R\&D} R_{C,R\&D},$$

where $P_{PR,N} PR_N$ is private returns to R&D performed by nonprofit institutions and $P_{C,R\&D} R_{C,R\&D}$ is R&D expenditures in current-measure GDP,

34. Some activities of nonprofit institutions are taxable; therefore, capital consumption adjustment for nonprofit institutions may be nonzero.

35. Table 6 is modeled after table 3 from Lum and Moyer (2001, p. 27).

36. The statistical discrepancy, which is the difference between GDP on the expenditure (product) side and GDI on the income side, is not shown, as it is unchanged and has no impact on the estimates or the analysis.

which are reclassified from consumption to investment. The R&D expenditures in consumption in current-measure GDP include nonprofit institutions and general government funding of R&D performed by others, and business funding of R&D performed by nonprofit institutions and general government.

$$(4) \qquad \text{Current-measure } P_I I = P_{I,B} I_B + P_{I,N} I_N,$$

where $P_{I,B}I_B$ is business fixed investment and $P_{I,N}I_N$ is nonprofit institutions' fixed investment.

$$(5) \qquad \text{Adjusted-measure } P_I I = \text{current-measure } P_I I + P_{R\&D,B}\, R\&D_B + P_{R\&D,N}\, R\&D_N,$$

where $P_{R\&D,B}R\&D_B$ is expenditures for R&D performed by business and $P_{R\&D,N}R\&D_N$ is expenditures for R&D performed by nonprofit institutions.

$$(6) \qquad \text{Current-measure } P_{NE}\, NE = \text{adjusted-measure } P_{NE}\, NE,$$

as there is no change in the net exports measure as a result of the innovations.

$$(7) \qquad \text{Current-measure } P_G G = P_{C,G} C_G + P_{L,G} G,$$

where $P_{C,G}C_G$ is government consumption expenditures and $P_{I,G}G$ is government fixed investment.

$$(8) \qquad \text{Adjusted-measure } P_G G = \text{current-measure } P_G G + P_{PR,G} PR_G + P_{R\&D,G}\, R\&D_G - P_{I,R\&D} R_{I,R\&D},$$

where $P_{PR,G}PR_G$ is private returns to R&D performed by general government, $P_{R\&D,G}R\&D_G$ is expenditures for R&D performed by general government, and $P_{I,R\&D}R_{I,R\&D}$ is R&D expenditures for R&D funded by general government and performed by business contractors. The R&D funded by general government and performed by business that is included in the current measure of government consumption is reallocated to expenditures for R&D performed by business, $P_{R\&D,B}R\&D_B$, and included in adjusted measure $P_I I$.

The magnitude of the additions to investment exceed the magnitude of the additions to consumption, whether including or excluding government consumption and investment in the totals. Capitalizing R&D decreases consumption, on net, as the increase in consumption from $P_{PR,N}PR_N$ and $P_{PR,G}PR_G$, private returns to R&D performed by nonprofit institutions and general government, respectively, is less than the reduction in consumption from $P_{C,R\&D}R_{C,R\&D}$, expenditures in current-measure GDP, which are reclassified from consumption to investment. Investment unambiguously goes up as $P_{R\&D,B}R\&D_B$, $P_{R\&D,N}R\&D_N$, and $P_{R\&D,G}R\&D_G$, expenditures for

R&D performed by business, nonprofit institutions, and general government, respectively, are all added to GDP.[37]

The income equation in nominal dollars is

$$(9) \qquad GDP = GDI + SD = wH + rS + IBT + SD,$$

where SD is the statistical discrepancy,[38] wH is employee compensation, rS is property-type income, IBT is indirect business and nontax liability, and income-side current measure GDP is equal to expenditure- (product-) side GDP as guaranteed by equation (9).[39] Looking at the details, this time on the income side, and comparing current measures to adjusted measures are again useful:

$$(10) \qquad \text{Current-measure } wH = \text{adjusted-measure } wH,$$

$$(11) \qquad \text{Current-measure } IBT = \text{adjusted-measure } IBT,$$

$$(12) \qquad \text{Current-measure } SD = \text{adjusted-measure } SD,$$

because the innovations have no effect on employee compensation, indirect business taxes, or the statistical discrepancy.

Property-type income is the only component of GDI that changes with the innovation.

$$(13) \quad \text{Current-measure } rS = r_P S_P + r_G S_G = r_{P,B} S_{P,B} + r_{P,N} S_{P,N} + r_G S_G,$$

where $r_P S_P$ is private property-type income, $r_G S_G$ is government property-type income, $r_{P,B} S_{P,B}$ is business private property income, and $r_{P,N} S_{P,N}$ is nonprofit institutions' private property income. The adjusted measure of private property-type income increases by the private returns to R&D to private nonprofit institutions and to government.

$$(14) \quad \text{Adjusted-measure } rS = r_{O,B} S_{O,B} + r_{O,N} S_{O,N} + r_{O,G} S_{O,G} + r_{R\&D,B} S_{R\&D,B} + r_{R\&D,N} S_{R\&D,N} + r_{R\&D,G} S_{R\&D,G},$$

where property-type income is separated into a component for "other than R&D capital," indicated by the subscript 'O,' and an R&D component, indicated by the subscript 'R&D.' Equation (9) holds for adjusted measures as it did for current measures.

37. The difference between current-measure GDP and adjusted GDP is shown in 1996 dollars in the addenda to table 4. The two entries for R&D expenditures in current-measure GDP—$P_{C,R\&D} R_{C,R\&D}$, the portion already in consumption, and $P_{I,R\&D} R_{I,R\&D}$, the portion already in investment—are combined into one line.

38. Gross domestic product does not equal GDI because their components are estimated using largely independent and less-than-perfect source data; the difference between the two measures is the statistical discrepancy. See Parker and Seskin (1997, p. 19).

39. This paper will not discuss the estimation of property-type income, employee compensation, or the component parts, as this is not the primary purpose of this paper.

8.4 Effects of the Proposed Changes in Estimates

Capitalizing R&D increases the level of real and nominal GDP and affects the components of the accounts. It has a very small effect on the rate of growth of real GDP, but a significant effect on the composition of GDP and on our understanding of the sources of economic growth. Capitalizing R&D also raises investment and therefore savings and GDP. Specifically, over the 1961–2000 period, the following phenomena occurred:

- The rate of growth of real GDP is increased by less than 0.1 percentage point, and the nominal level of GDP is increased by 2 percentage points.
- The distribution of consumption and investment in the economy is changed, and the national savings rate is raised by 2 percentage points, from 19 to 21 percent.
- The analysis shows that R&D is a significant contributor to economic and productivity growth, in the base case scenario with the contribution of R&D investment accounting for 4 percent of overall GDP growth and the contribution of returns to R&D capital accounting for 11 percent of GDP growth.
- R&D investment is on average 13 percent of current fixed investment; R&D fixed capital stock adds 6 percent of current fixed capital stock.
- The share of property-type income in GDI rises by 1 percentage point compared to current-measure estimates.
- Returns to R&D capital represent 20 percent of property-type income.
- Regardless of the alternative assumptions made about R&D service lives, depreciation, lag in benefits, or deflators, R&D is a significant contributor to economic growth, with the contribution of R&D investment ranging from 2 to 7 percent of GDP growth and the contribution of returns to R&D capital ranging from 4 to 15 percent of GDP growth.[40]

8.4.1 Adjusted NIPA Tables

In this section the estimates for selected years in tables 8.4, 8.5, and 8.6 are discussed.

Table 8.4 shows adjusted GDP, relevant R&D estimates, and the impact of capitalizing R&D on major subaggregates of GDP. The biggest addition to GDP is R&D business fixed investment. Business R&D investment is 11 to 12 percent of gross private domestic investment (GPDI) except in 1973, when it is only 8 percent of GPDI. In 1973 government R&D investment

40. Rates of growth are computed throughout this paper from endpoint to endpoint. For example, the 1961–2000 rate of growth of adjusted GDP is calculated as ([1996 dollar-adjusted GDP_{2000}/1996 dollar-adjusted GDP_{1961}] raised to the power [1/{2000-1961}] – 1) × 100.

increased in relative terms and private R&D investment decreased. Government R&D investment is no greater than 25 percent of private R&D investment except in 1973, when it is 31 percent of private R&D investment. Private returns to R&D capital of nonprofit institutions and general government have a small impact on GDP. They amount to less than 1 percent of current-measure GDP. Depreciation, one component of private returns to R&D capital, is commonly larger than the net return, the other component.[41] The net return is to the performer only (excludes spillovers), but depreciation is on the total R&D capital stock. The magnitudes for private R&D investment are larger than those for private returns to R&D performed by nonprofit institutions and general government.

Table 8.5 shows consumption of R&D capital (depreciation) as well as a number of adjusted aggregates. The magnitudes of adjusted GDP, adjusted gross national product (GNP), adjusted GDI, and adjusted gross national income (GNI) are very similar. Adjusted net national product (NNP) and adjusted net domestic product (NDP) are smaller than the other aggregates, but similar in size to each other as both deduct consumption of fixed capital.[42] As GNP is the market value of goods and services produced by labor and property supplied by U.S. residents, regardless of where they are located, adjusted GNP is equal to GDP plus net income from the rest of the world. As previously noted, the difference between GDP and GDI is the statistical discrepancy. Similarly, NNP is equal to NDP and GNI is equal to GDI, both plus net income from the rest of the world. Consumption of R&D capital is an increasing share of GDP for the years shown, doubling from slightly less than 1 percent to almost 2 percent between 1961 and 2000.

Table 8.6 focuses on components of GDI. The rates of growth of the 1996 dollar estimates for returns to R&D capital are inputs to the contribution calculations, along with current dollar shares. The share of all returns to R&D in GDP doubled between 1961 and 2000, rising from less than 4 percent to over 7 percent. Returns to business R&D consistently represent the largest component of R&D, averaging close to 80 percent of total returns to R&D in all years shown.

8.4.2 Effects on GDP, GDI, and National Savings

Capitalizing R&D affects both the product (GDP) and income (GDI) sides of the national accounts in a double-entry system. It affects estimates

41. The estimation of depreciation is discussed in appendices A and C. A geometric rate of depreciation is employed.

42. In table 8.5 the term "consumption of R&D capital" refers to economic depreciation. In NIPA table 1.9, "consumption of fixed capital" also refers to economic depreciation (ignoring the complication of adjustments for disasters), "capital consumption allowances" refers to tax-based depreciation, and the capital consumption adjustment is equal to the consumption of fixed capital less capital consumption allowances.

Table 8.7 **National savings rate (%)**

Period	Adjusted measure	Impact of capitalizing R&D	Current measure
1961–66	23.7	2.4	21.3
1967–73	21.9	2.2	19.7
1974–95	20.2	2.0	18.1
1996–2000	20.3	2.1	18.1
1961–2000	21.0	2.1	18.9

Note: Totals may be off by ± .1 because of rounding.

of savings, investment, capital stock, and the returns to R&D and property-type income.

Savings, Investment, and Wealth

Capitalizing R&D has a significant effect on measures of savings, investment, and wealth. It raises the estimate of investment and, therefore, the estimate of national savings, as well as capital stock. R&D investment and R&D fixed capital stock, the latter of which is an important component of wealth, are large relative to current measures of investment and stock. Business performers account for more than two-thirds of R&D investment and capital stock. Notable period-by-period differences in the growth rate of R&D investment by performing sector may have had, and may continue to have, an effect on economic growth.

Table 8.7 shows that capitalizing R&D raises the national savings rate around 2 percentage points. As defined in NIPA table 5.1, the national savings rate is equal to gross investment (the sum of gross private domestic, gross government, and net foreign investment) less the statistical discrepancy, divided by GNP.

Although the 1961–2000 rates of growth for real R&D investment and fixed capital stock are similar across all performing categories, growth rates for investment show much more fluctuation by periods than those for fixed capital stocks (see tables 8.8 and 8.9). Other things held equal, stocks will change much more slowly than investment, as current stocks are large relative to investment. Accordingly, it is not surprising that there is less variation in the composition of R&D fixed capital stocks than for R&D investment. For the last three periods—1967–73, 1974–95, and 1996–2000—the average share of R&D fixed capital stocks for business, nonprofit institutions, and general government is almost constant.[43] In all but the first period shown (1953–60), the sum of the shares for business and nonprofit

43. When growth rates are calculated, the periods are 1953–61, 1961–66, 1966–73, 1973–95, and 1995–2000; when shares or contributions are calculated, the periods are 1953–60, 1961–66, 1967–73, 1974–95, and 1996–2000.

Table 8.8 **Rates of growth of real R&D investment and current measure real gross domestic product (%)**

	Real R&D Investment				
Period	Total	Business	Nonprofit institutions	General government	Current measure real GDP
1953–61	11	12	16	6	3
1961–66	8	7	14	12	6
1966–73	1	1	1	3	4
1973–95	4	5	4	4	3
1995–2000	9	10	7	6	4
1961–2000	5	5	5	5	3
1953–2000	6	6	7	5	3

Table 8.9 **Rates of growth of real R&D fixed capital stock and current measure real gross domestic product (%)**

	Real R&D fixed capital stock				
Period	Total	Business	Nonprofit institutions	General government	Current measure real GDP
1961–66	10	10	17	9	6
1966–73	6	5	8	7	4
1973–95	4	4	4	4	3
1995–2000	6	6	5	5	4
1961–2000	5	5	7	5	3

institutions is approximately 80 percent in all periods.[44] Only the 1953–60 period shows a significant difference from the typical pattern. The share of the total for business is close to or above 70 percent for both the R&D investment share and the R&D fixed capital stocks share.

Returns to R&D and Property-Type Income

In the previous section, the focus was on an asset flow (investment and savings) and balance sheet (stock and wealth) account. This section describes the effect of capitalizing R&D on the income side of the accounts.

Gross domestic income rises by the same amount as the increase in GDP, as capitalizing R&D increases property-type income.[45] The returns to

44. The first year of R&D expenditures data from the NSF R&D database is 1953; see NSF (2001a) or the NSF website at http:www.nsf.gov/sbe/srs/indus/start.htm.

45. Property-type income is defined as the sum of corporate profits, proprietors' income, net interest, capital consumption allowances, inventory valuation adjustments, rental income of persons, business transfer payments, and surplus of government enterprises, less subsidies.

Table 8.10 **Share of property-type income in gross domestic income (GDI) and share of returns to R&D in property-type income (%)**

Period	Share of property-type income in adjusted GDI	Difference adjusted and current measure GDI	Share of property-type income in current measure GDI	Share of returns to R&D in adjusted property-type income
1961–66	36	1	35	16
1967–73	34	1	32	21
1974–95	35	1	34	20
1996–2000	37	1	36	19
1961–2000	35	1	34	20

Notes: Totals may be off by ± 1 because of rounding. Shares are average current dollar shares.

R&D capital can be separated out from other types of capital, and its share of property-type income can be identified.[46]

The share of property-type income in GDI increases on average by 1 percentage point per year (see table 8.10) due to capitalizing R&D. The share of returns to R&D in adjusted property-type income is significant, averaging 20 percent. Except for 1961–66, when the share of property-type income in GDI is relatively high, there is little variation in the share of R&D returns in property-type income.

8.4.3 Effects on Variables Used in Growth Analysis: Property-Type Income and Gross Returns to Capital

The growth-accounting model provides the basis for estimating the returns to R&D capital and the contribution of R&D to economic growth on the income (supply) side.[47] By typically excluding R&D capital, past analyses of sources of economic growth have attributed property-type income to fixed assets other than R&D capital. Accordingly, the rate of return to fixed assets and the contribution of those assets to GDP growth on the income (supply) side have been overstated. Distinguishing the return to R&D capital, from returns to other types of capital, provides a means of determining its size relative to other types of traditionally measured returns to capital and, therefore, R&D's relative contribution to economic growth.

The basic growth accounting model equation is

Alternatively, it is GDI less compensation of employees, indirect business tax and nontax liabilities, and the statistical discrepancy.

46. See the "Returns to R&D Capital" section of appendix C for a discussion of how net returns to R&D are estimated.

47. Two types of contributions are estimated in this paper, one for the product (demand) side and the other from the income (supply) side. The contribution from the product (demand) side looks at the contribution of R&D investment to GDP growth. The contribution from the income (supply) side looks at the contribution of returns to R&D to GDP growth.

(15) $$\text{ROG of } Q = \alpha_K \cdot \text{ROG of } K + \alpha_L \cdot \text{ROG of } L + \lambda, \text{ where}$$

$$\alpha_K = \text{nominal dollar property-type income share} = \text{rS}/\text{p}_\text{Q}Q,$$

$$\alpha_L = \text{nominal dollar labor income share} = \text{wH}/\text{p}_\text{Q}Q,$$

ROG is the abbreviation for rate of growth, Q is real output, K is real capital input, L is real labor input, $\text{p}_\text{Q}\text{Q}$ is nominal dollar output, and λ is the rate of productivity change.

Equation (15) is revised to include R&D capital as follows:

(16) $$\text{ROG of } Q = \alpha_{\text{R\&D}} \cdot \text{ROG of } K_{\text{R\&D}} + \alpha_\text{O} \cdot \text{ROG of } K_\text{O} + \alpha_L \cdot \text{ROG of } L + \lambda,$$

where the subscript R&D refers to R&D capital and O refers to all other capital. The contribution of R&D to economic growth on the income (supply) side is equal to $\alpha_{\text{R\&D}} \cdot \text{ROG of } K_{\text{R\&D}}/\text{ROG of } Q$; the contribution of other assets is $\alpha_\text{O} \cdot \text{ROG of } K_\text{O}/\text{ROG of } Q$.

Equation (16) of this paper shows the revisions needed in the basic growth accounting model to allow for incorporation of R&D capital. Gross return to capital is defined as property-type income divided by fixed capital stock. Distinguishing R&D fixed capital stock and property-type income from fixed capital stock, other than R&D, and the related property-type income allows for the estimation of gross rates of return for R&D capital, as distinct from all other capital. Property-type income is the same as what would be used in the construction of the alphas, the income shares, in equations (15) and (16).

In the current NIPAs, rates of return on capital tend to be overstated because R&D stock is not included in the capital stock denominator, yet most of the return to R&D capital is included in the property-type income numerator. The returns to R&D additions to GDP amount to 1 percent of current-measure GDP, yet R&D fixed capital stock averages 6 percent of current-measure fixed capital stock (tables 8.11 and 8.12). However, the effect on the gross return to total fixed capital stock is small, as the changes are a relatively small percent of the current measure totals.[48]

8.4.4 Sources of Growth Analysis: Contributions of R&D to Growth

Contributions of R&D to growth can be estimated on the product (demand) side and on the income (supply) side. The contribution of R&D investment to growth in adjusted GDP is the product-side number, and the contribution of return on R&D capital to adjusted GDP growth is the income-side number.[49] National account estimates using the product-side

48. If inventories and land (including subsoil minerals) were included in the estimate of capital stock, both the current and the adjusted measures of the gross rate of return would be lower.

49. Annual approximate contributions are calculated in this paper as a weighted growth rate, where the weights are the average share in the preceding period and the current period.

Table 8.11 **Net additions to gross domestic product and R&D totals (as a percent of current dollar, current measure GDP)**

	Net additions to GDP			R&D totals	
Period	Total	R&D funded and performed by business	Private returns to NP&GG from R&D performed by NP&GG	R&D investment	Returns to R&D
1961–66	1	1	1	3	6
1967–73	2	1	1	3	7
1974–95	2	1	1	2	7
1996–2000	2	2	1	3	7
1961–2000	2	1	1	3	7

Notes: Totals may be off by ± 1 because of rounding. NP&GG is an abbreviation for non-profit institutions and general government.

Table 8.12 **R&D investment and wealth share of existing measures (%)**

Period	Share R&D fixed investment is of current measure investment	Share R&D fixed capital stock is of current measure fixed capital stock
1961–66	14	5
1967–73	13	6
1974–95	13	6
1996–2000	13	6
1961–2000	13	6

Note: Shares are average current dollar shares.

approach are reported in NIPA tables S.2 and 8.2. Income-side estimates follow the sources of economic growth approach discussed earlier. The contributions are presented in two formats (see table 8.13). The first corresponds to the presentation in the NIPA tables, where the sum of all contributions sum to the rate of growth of GDP. The second takes these same contribution estimates and presents them as a percentage of the rate of growth of GDP, where the sum of all contributions so calculated is 100 percent.

The significant contribution of R&D to economic growth should be recognized, whether viewed from the product side or the income side. In the base case scenario, for 1961–2000, the contribution of R&D investment to

For example, the contribution of R&D investment to growth in adjusted GDP is calculated as .5 × (nominal dollar R&D investment$_{t-1}$/nominal dollar-adjusted GDP$_{t-1}$ + nominal dollar R&D investment$_t$/nominal dollar-adjusted GDP$_t$) × ([real R&D investment$_t$/real R&D investment$_{t-1}$] – 1) × 100. An average of the annual contributions is then calculated and reported in table 8.13.

Table 8.13 **Contribution of R&D investment and return to R&D capital to growth in GDP (%)**

	R&D investment		Return on R&D capital	
Period	Summing to GDP growth rate	As a percentage of GDP growth rate	Summing to GDP growth rate	As a percentage of GDP growth rate
1961–66	.22	4	.62	11
1967–73	.03	1	.43	12
1974–95	.11	4	.29	10
1996–2000	.22	5	.37	9
1961–2000	.12	4	.38	11

growth in adjusted GDP averages 4 percent, and the contribution of return on R&D capital to growth in adjusted GDP averages 11 percent (table 8.13).[50] In the alternative scenarios presented and discussed in appendix A, for 1961–2000, the contribution of R&D investment to growth in adjusted GDP averages from a low of 2 percent to a high of 7 percent (table 8A.1), and the contribution of return on R&D capital to growth in adjusted GDP averages from a low of 4 percent to a high of 15 percent (table 8A.6). The period-to-period fluctuation in the contribution of R&D investment reflects mainly the variation in the growth rate of R&D investment (see table 8.8), rather than variation in the rate of growth of adjusted GDP. The lesser period-to-period fluctuation in the contribution of returns to R&D capital reflects the smaller variation in the rate of growth of R&D fixed capital stock (compare estimates in table 8.8 to those in table 8.9).

8.5 Conclusions and Future Research

Construction of the partial R&DSA within a NIPA framework allows for the estimation of the impact of R&D on GDP and other macroeconomic aggregates as well as the estimation of the contribution of R&D to economic growth using a sources-of-economic-growth approach. The sources of economic growth approach is based on growth-accounting models, which have been used to analyze the relationship between output and inputs in production and to determine the contribution of inputs, including R&D.[51] They are part of a rich tradition of examining the sources of economic growth, including productivity growth, as epitomized by the work of Edward F. Denison, John W. Kendrick, Dale W. Jorgenson and his

50. Griliches (1973, p. 78) estimates the product-side contribution of R&D to GDP growth to be .34 percent as of 1966, probably considerably less. Our estimate of this contribution is .22 for the 1961–66 period (see table 8.13).

51. See op cit., Solow (1957), and OECD (2001, annex 3).

coauthors, and others such as Stephen D. Oliner and Daniel E. Sichel.[52] R&D expenditures have been listed as a possible cause of productivity growth in the attempts to identify the factors behind the so-called Solow residual.[53]

Substantial additional work is needed to determine the effect of R&D on GDP. Estimates provided in this paper depend on assumptions made about the rates of return, depreciation rates, service lives, deflators, gestation, and application lags. The reasonableness of these assumptions needs to be assessed. Each of these factors may have varied over time as the composition of R&D expenditures by performers has changed and the nature of technical change itself has changed. Also, further work is needed to determine whether the pattern of returns to R&D, both private and spillover, has varied over time or has remained constant. The pattern of returns may vary over the lifetime of a specific asset, may certainly vary from one investment to another, and may vary over time, for different vintages of R&D investment. Without a means of gauging these kinds of changes, assessing the effect of R&D on GDP is difficult. In addition, rates of return that may be appropriate for private R&D may not be appropriate for government R&D.

Despite these remaining questions, this exploratory paper is a first step in improving our understanding of the contribution of R&D to growth. It shows how a national income accounting methodology can be used to examine the role of R&D and how capitalization of R&D expenditures might affect GDP. When the *System of National Accounts* (1993) was revised, one of the last decisions made was not to capitalize R&D expenditures. This decision is being revisited by a number of national income accountants and is an area in which the BEA could again demonstrate that it is a world leader in statistical innovations. One only needs to look as far as the adoption of a quality adjusted computer price index and chain indexes and, most recently, the capitalization of software to understand the important role that the BEA has played.

Appendix A

Alternative Scenarios

Since much is unknown about R&D, such as the appropriate deflators, depreciation rates, lengths of gestation and application lags, and spillover

52. See Denison (1985), Kendrick (1973), Jorgenson, Gollop, and Fraumeni (1987), Jorgenson and Stiroh (2000), Oliner and Sichel (2000), and Jorgenson (2001).
53. See Denison (1979, pp. 122–27) and Kendrick and Grossman (1980, pp. 10, 16–18, and chap. 6, pp. 100–111).

gross rates of return, a number of alternative scenario is analyzed using different assumptions about the deflators, depreciation rates, lag structure, and the spillover gross rates of returns. The estimates under these alternative scenarios are compared to the results in the main part of the paper to gauge the significance of the contribution of R&D. These estimates highlight their preliminary nature because of the uncertainty about many aspects of R&D.

In the tables and discussion that follow, two alternative deflators are employed. The deflator used in the main body of the paper is the private fixed nonresidential investment chain-type price index from NIPA table 7.6. The alternative deflators are the overall R&D deflator used in the previous BEA R&D study (Carson, Grimm, and Moylan 1994) extended beyond 1992 with a GDP deflator and the information processing equipment and software chain-type price index from NIPA table 7.6.[54]

Two alternative depreciation rates are employed for business R&D. The geometric depreciation rate used in the main body of the paper for all R&D from the 1994 BEA study is 11 percent. The alternative geometric depreciation rates for business R&D are 20 percent in all years and a rate that increases gradually from 10 percent in 1961 to 20 percent in 2000.[55] The latter rates take into account the rise in the R&D in information technology (IT) relative to other industries[56] and the increased pace of technological change in information technologies that has reduced the life of R&D capital, especially semiconductor technology. Semiconductor technology is an important component of IT and many other products, and has experienced increasingly rapid rates of obsolescence, as reflected in the steeply falling prices of semiconductor devices.

The declining balance rate that is assumed determines the service life of R&D capital. In the 1994 BEA study, the depreciation rate was picked as opposed to a service life. With a double declining balance rate, an 11 percent rate corresponds to an eighteen-year service life; with a 1.65 declining balance rate (the current BEA default for equipment), the service life is fifteen years; and with a .91 declining balance rate (the current BEA default for structures), the service life is eight years.[57] For a 20 percent depreciation rate, similar declining balance rates have corresponding service lives of 10 years, 8 years, and 4.5 years. Only the business R&D depreciation rate is varied because of the following reasons:

54. The BEA 1994 study R&D deflator is very similar to the GDP deflator, particularly in the later eighties and nineties.

55. The alternative R&D depreciation rate assumptions in BLS Bulletin 2331 (BLS 1989) are 10 percent and 20 percent.

56. See Hall, Jaffe, and Trajtenberg (2001, p. 13 and fig. 5).

57. The default rates are given in Fraumeni (1997). The formula for a geometric rate of depreciation is the declining balance rate divided by the service life. Accordingly, the service life can be derived as the declining balance rate divided by the geometric rate of depreciation (Fraumeni 1997, p. 11).

- First, the gross rate of return to nonprofit institutions and general government performers is assumed to be two-thirds of the business rate, or 16.7 percent. A depreciation rate of 20 percent implies a long-term negative 3.3 percent net return to R&D capital. This is not a reasonable assumption unless nonprofit institutions and general government are undertaking R&D because the social rate of return is positive, even though the net return to themselves is negative.
- Second, business R&D is heavily concentrated in development; the same is not true for nonprofit institutions or general government. Because development investment is generally believed to have a shorter service life than either basic or applied research, there is a rationale for lowering the average service life for all business R&D without doing the same for nonprofit institutions and general government.

For both types of contributions—returns to investment and returns to R&D—the private fixed nonresidential investment deflator used in this study produces contribution estimates that lie between those of the alternative deflators. The BEA 1994 study GDP deflator produces the lowest estimates, and the information-processing equipment and software deflator produces the highest estimates in all time periods. For 1961–2000, the three alternative deflators produce contributions of R&D investment to growth in adjusted GDP estimates of 2 percent, 4 percent, and 7 percent (see table 8A.1). For 1961–2000, the contribution of returns to R&D capital to growth in adjusted GDP estimates are 9 percent, 11 percent, and 15 percent (see table 8A.2).

Because changing the R&D depreciation rate has no effect on investment, only estimates of the contribution of return on R&D capital to adjusted GDP growth are presented for the alternative depreciation rate assumptions (table 8A.3). The depreciation rate assumption of 11 percent used in the main body of the paper consistently produces contribution estimates that are higher than either of the two alternatives, with the varying depreciation rate being the middle estimate and the 20 percent deprecia-

Table 8A.1 Contribution of R&D investment to growth in adjusted GDP alternative deflators (as a percent of GDP growth rate)

Period	1994 BEA GDP deflator	Gross private fixed nonresidential investment deflator	Information processing equipment and software deflator
1961–66	3	4	5
1967–73	0	1	4
1974–95	3	4	8
1996–2000	3	5	9
1961–2000	2	4	7

Table 8A.2 Contribution of return to R&D capital to growth in adjusted GDP alternative deflators (as a percent of GDP growth rate)

Period	1994 BEA GDP deflator	Gross private fixed nonresidential investment deflator	Information processing equipment and software deflator
1961–66	10	11	12
1967–73	10	12	14
1974–95	8	10	17
1996–2000	6	9	12
1961–2000	9	11	15

Table 8A.3 Contribution of return to R&D capital to growth in adjusted GDP alternative rates of depreciation (as a percent of GDP growth rate)

Period	11% depreciation rate	Varying depreciation rate from 10% to 20%	Constant 20% depreciation rate
1961–66	11	10	7
1967–73	12	10	7
1974–95	10	7	7
1996–2000	9	5	6
1961–2000	11	8	7

tion rate alternative being the lowest estimate. These results are not surprising, because raising the depreciation rate lowers the 1996 dollar value of R&D fixed capital stock. The total return on those stocks falls by the same percentage as the decrease in the stocks.

Three alternative lag structures are tested. The lag used in the main body of the paper is a one-year lag that reflects an average lag applied to all categories of R&D expenditures and follows the assumption used in the earlier BEA estimates of R&D capital. Past studies have identified two types of lags: gestation lags and application lags. Gestation lags refer to the time needed to complete an R&D project, and application lags, to the time between completion of the R&D and its initial commercialization. Past research has found that the gestation lags range between one and two years and that application lags range from less than one year to two years (Carson, Grimm, and Moylan 1994, p. 44).[58] A one-year lag assumption takes into account only the gestation period. To take into account gestation and application lags, alternative assumptions are a three-year and five-year lag, and a seven-year lag that takes into account lagged impacts on profits as well.

58. See also BLS (1989, pp. 6–7, 19–21) for a discussion of studies that look at the lag between research and profits and productivity growth.

The 1961–2000 average contribution of return to R&D capital to growth in adjusted GDP for the alternative lags is at most 1 to 2 percentage points lower than in the one-year lag scenario (table 8A.4). The contribution estimates vary by period, reflecting the impact of a longer lag. Not surprisingly, the 1967–73 contributions in the three- and five-year lag scenarios are higher than in the one-year lag scenario, reflecting the delayed impact of the high rates of growth of R&D expenditures in 1953–1961 and 1961–1966 (see table 8.8).

The spillover gross rate of return may be lower than the 25 percent for business and 16.7 percent for nonprofit institutions and general government assumed in the main body of the paper. Two alternative scenarios are examined (see table 8A.5) and compared to those presented in the main body of the paper. The first assumes a spillover rate of return of 12.5 percent for R&D performed by business and 8.3 percent for R&D performed by nonprofit institutions and general government, and the second, a spillover gross rate of return that varies from 25 percent to 12.5 percent for R&D performed by business and from 16.7 percent to 8.3 percent for R&D performed by nonprofit institutions and general government. The contributions of return to R&D capital to growth in adjusted GDP are highest for the assumptions used in the main body of the paper, ranging from 9

Table 8A.4 **Contribution of return to R&D capital to growth in adjusted GDP alternative lags (as a percent of GDP growth rate)**

Period	One Year Lag	Three Year Lag	Five Year Lag	Seven Year Lag
1961–66	11	9	8	6
1967–73	12	13	13	12
1974–95	10	9	9	9
1996–2000	9	7	7	7
1961–2000	11	10	9	9

Table 8A.5 **Contribution of return to R&D capital to growth in adjusted GDP alternative spillover gross rates of return (as a percent of GDP growth rate)**

Period	Constant at 25% for business, 16.7% for NP&GG	Varying from 25% to 12.5% for business, 16.7% to 8.3% for NP&GG	Constant at 12.5% for business, 8.3% for NP&GG
1961–66	11	10	8
1967–73	12	10	9
1974–95	10	7	8
1996–2000	9	6	7
1961–2000	11	8	8

Note: NP&GG is an abbreviation for nonprofit institutions and general government.

percent to 12 percent for the periods. The alternative scenario contributions are at most 3 percentage points lower. These results initially seem surprising—the contribution for the lowest assumed spillover gross rate of return is sometimes higher than that for the scenario in which the spillover gross rate of return varies. However, even though in nominal dollars the spillover return is higher in the "varying" scenario, as the spillover gross rate of return falls, the rate of growth of constant dollar return to R&D capital is lower in the scenario with varying returns than in the scenario with constant 12.5 percent, 8.3 percent spillover gross rates of return. Whether the contribution in the varying scenario is lower or higher than the constant scenario depends upon the relative effect of the higher current dollar weight in the varying scenario versus the lower rate of growth of 1996 dollar return to R&D capital in the varying scenario.

Table 8A.6 presents the full range of the possible magnitudes of the contribution of return to capital to growth in adjusted GDP looking at all possible permutations of assumptions. It shows that, regardless of the assumptions used, the contribution of R&D to economic growth is very significant. The lowest contribution for 1961–2000 is 4 percent, and the highest is 15 percent. For the base case, with the assumptions used in the main body of the paper, the contribution is in the middle range at 11 percent. Using the information-processing equipment and software deflator alone accounts for the 4 percentage point increase of the contribution from the base case to the highest contribution case. A higher depreciation rate is the main factor that lowers the contribution from the base case; however,

Table 8A.6 **Contribution of return to R&D capital to growth in adjusted GDP alternative scenarios: Lowest contribution, base case, and highest contribution (as a percent of GDP growth rate)**

Scenario	Lowest	Base case	Highest
Deflator	1994 BEA GDP deflator	Gross private fixed nonresidential investment deflator	Information processing equipment and software deflator
Depreciation	Constant 20% depreciation rate	11% depreciation rate	11% depreciation rate
Lag	Seven year	One year	One year
Spillover gross rate of return	Constant at 12.5% for business, 8.3% for NP&GG	Constant at 25% for business, 16.7% for NP&GG	Constant at 25% for business, 16.7% for NP&GG
Period			
1961–66	4	11	12
1967–73	6	12	14
1974–95	4	10	17
1996–2000	3	9	12
1961–2000	4	11	15

Note: NP&GG is an abbreviation for nonprofit institutions and general government.

lowering the spillover gross rate of return is also a factor. Other variations in assumptions are less important.

Appendix B

1995–2000 Compared with 1961–66

Although the 1961–66 and 1995–2000 periods appear to be similar, there are some notable differences. The 1961–66 period, often viewed as a heyday of U.S. economic and productivity growth, and the 1995–2000 period are similar in terms of the annual rate of growth of R&D, 8 percent and 9 percent, respectively, and an above-average annual rate of growth of GDP, 4 percent and 6 percent, respectively. The differences relate to who funded and performed R&D, the type and composition of R&D being performed, and growth in R&D expenditures leading up to the period. In 1995–2000, acceleration in business R&D is the major catalyst for the high overall rate of growth, whereas in 1961–66, it is nonprofit institutions and general government (table 8.8).[59] Business performed the bulk of R&D in both periods, but the 2 percentage points increase in the share of R&D performed by business in 1996–2000 compared to 1961–66 is matched by an equivalent decrease in the share of R&D performed by general government. In the 1960s and early 1970s, general government on net funded the bulk of total R&D, especially for defense and the space race.[60] Its share has declined steadily, from 66 percent of the total in 1961–66 to 32 percent in 1996–2000. Moreover, while general government funding of nonprofit institutions' R&D has been relatively stable at about 7 percent of total R&D, government's support of R&D performed by business has fallen from over 40 percent of total R&D in the 1961–66 period to 10 percent in 1996–2000. This decline in general government financing of R&D performed by business reflects, in part, the de-emphasis in government programs on defense R&D.[61] Another difference between the two periods can be attributed to the rise in the importance of information technology (IT) R&D.[62]

59. However, note that there is a significant shift between 1953–61 and 1961–66. In the earlier period, the rates of growth for R&D performed by business and nonprofit institutions are significantly higher than the rate of growth for R&D performed by general government. In addition, the drop between 1953–60 and 1961–66 in the share of R&D performed by business is almost equal to the increase in the share of R&D performed by nonprofit institutions.

60. Funding of general government R&D by others is subtracted from general government R&D expenditures, including funding of others, to arrive at net funding by general government.

61. Table 3.11 in NIPA shows little growth (1 percent between 1982 and 2000) in government expenditures for defense R&D. Defense R&D peaked in 1987 (National Science Board 1998).

62. The increase in the importance of IT R&D relative to R&D in industries other than IT is reflected in patent data. These data indicate that the shares of total patent applications for

The nature of R&D performed by businesses, nonprofit institutions, and general government has also changed over the two periods. In the past, according to NSF data, nonprofit institutions and the federal government performed the bulk of basic research (that is, work undertaken to acquire new knowledge without any particular application in mind), accounting for about 75 percent of basic research in 1961–66.[63] The share of total basic R&D performed by the federal government has declined from 15 percent in 1961 to 7 percent by 2000, while that of business rose from 26 percent in 1961 to 34 percent of total basic R&D in 2000, and that of nonprofit institutions has stayed relatively constant (around 60 percent).[64]

The runup in R&D investment in 1953–60 (see table 8.8) and the slow rate of growth in R&D investment in the years just preceding 1995 are reflected in the growth of real R&D stock; real R&D fixed capital stock grew at a record rate in 1961–66, but not in 1995–2000 (see table 8.9). As the benefits from R&D investment occur over a number of years, it is highly likely that we will be enjoying the fruits of the R&D mainly undertaken by business in the second half of the nineties through the first decade of the new millennium. An important consideration in this story is whether the service life of R&D has shortened since the sixties or, equivalently, whether the obsolescence rate of R&D has increased. The sensitivity of our results to our service life assumptions is discussed in appendix A. R&D investment represents 13 percent of current fixed investment; R&D fixed capital stock is less than half that in percentage terms at 6 percent of current fixed capital stock, reflecting the shorter service life of R&D compared to the average service life of all fixed assets currently included in the national accounts (see table 8.12).

computers and communications have risen steeply, from 5 percent in the 1960s to 20 percent in the late 1990s, and applications for electrical items and electronics had a steady share at 16–18 percent. Shares of the three traditional fields (chemical, mechanical, and others) declined from 76 percent in 1965 to 54 percent in 1997. See Hall, Jaffe, and Trajtenberg (2001, p. 13 and fig. 5).

63. The other two categories of R&D are "applied research," aimed at gaining the knowledge to meet a specific recognized need, and "development," which is the systematic use of the knowledge gained from research directed toward the production of useful materials, devices, systems, or methods. See National Science Board (1998, pp. 4–9).

64. See National Science Board (1998, chap. 4) and National Science Foundation (2001a). The government and nonprofit institutions' sectoring used by the NSF differ from those in the rest of this paper. The relevant NSF categories are federal government, universities and colleges, and other nonprofit institutions. In this paper, following Carson, Grimm, and Moylan (1994), R&D expenditures by public universities and colleges are allocated to general government. In this paragraph when the term "federal government" is used, 1994 BEA definitions are being employed, including those for nonprofit institutions.

Appendix C

Technical Appendix

This technical appendix provides additional information about the construction of the estimates of R&D investment, R&D capital stock, and returns to R&D capital, as well as the deflation and aggregation methodologies employed. Table 8.2 lists the base case scenario assumptions. The alternative scenarios are described in appendix A. This technical appendix provides additional details of the base case scenario and describes how alternative scenarios are constructed.

R&D Investment and Capital Stock

The original BEA investment and capital stock estimates were updated through 2000 for this paper based on NSF expenditure data.[65] The NSF nominal dollar expenditure data from 1992 are adjusted for differences in the levels and composition of BEA and NSF R&D expenditures using a regression approach. For the three performer categories, simple linear regressions of the BEA categories against a constant time trend and nearest comparable NSF category are fitted for 1953–1992. A time trend times NSF data interaction term is included in the general government performer equation as the associated coefficient is significant. In all cases, the adjusted R-squared is above .9, and all coefficients are highly significant. The results from the fitted equation are used to forecast what BEA values would have been for 1993–2000. This is a simplified approach; in the earlier project a number of specific adjustments were made to the NSF data.[66] One basic difference between the BEA and NSF R&D data is the allocation of R&D expenditures by public colleges and universities. The BEA allocates these expenditures to government, while the NSF allocates these expenditures to nonprofit institutions. The NSF data only identify R&D expenditures by the federal government, not by state and local governments.

The NSF's R&D expenditures prior to 1992 are not directly comparable to those from 1992–2000 because of a change in sample design and survey methodology.[67] Surveys after 1992 provide more accurate and better-quality data because they reflect the current year distribution of companies by size and industry, changes in industry classification systems, and changes

65. See National Science Foundation (2001a).

66. In the earlier project, statistical adjustments made included those for timing and geographic coverage and to fill in missing data for some industries for some years (see Carson, Grimm, and Moylan 1994, p. 42). These adjustments raised the nominal dollar level of R&D expenditures in most years above those reported by the National Science Foundation (NSF), by at most 3 percent. In a few years, 1961–64, the nominal dollar expenditures are very slightly lower than those reported by NSF, at most by .4 percent. The level of the estimated 1993–2000 R&D data is always above the level of the NSF data, again by at most 3 percent.

67. See NSF (2001b, p. 10).

in the way industry classifications are assigned. There is no way of knowing how large the differences might be and no expectation that this can be accurately determined by judging from the attempt by, but failure of, NSF staff to create a consistent time series. However, the potential problem is reduced by using aggregate data instead of industry data or data separated out by type of R&D: basic, applied, and development.

Very little information is available to estimate imports or exports of R&D services. The NSF's data on business performance of R&D includes R&D funded by foreign entities. What little data exist to break out foreign funding of R&D performed in the United States or U.S. funding of R&D performed abroad are for unaffiliated services and come from the BEA. Estimates based on these data indicate that these imports and exports each represent well under 0.5 percent of total R&D expenditures in the United States during the 1986–2000 period.[68] Accordingly, no attempt is made to estimate the magnitude of these R&D services and the spillover from R&D performed abroad, or to gauge whether the spillover rates of return reflect only spillovers to U.S. businesses, excluding spillovers to foreign entities.

R&D expenditures are assumed to enter the capital stock with a one-year lag. With this convention, expenditure in one year becomes investment of the following year, and there is an entry for change in R&D-in-progress.

The investment equation is as follows:

$$\text{(C1)}\quad \text{GDP total investment}_t = \text{expenditures}_{t-1} + \text{change in R\&D-in-progress}_t = \text{expenditures}_t,$$

where by definition:

$$\text{(C2)}\quad \text{Change in R\&D-in-progress}_t = \text{expenditures}_t - \text{expenditures}_{t-1},$$

and

$$\text{(C3)}\quad \text{Completed R\&D}_t = \text{expenditures}_{t-1}$$

As previously noted, the base case scenario uses a geometric depreciation rate of 11 percent to update the capital stock. In the earlier BEA project, straight-line depreciation was combined with a Winfrey (bell-shaped) retirement distribution to construct the BEA R&D capital stocks because this methodology was used at the time to construct BEA estimates of fixed tangible capital stocks. The R&D service life was adjusted to mimic a target 11 percent geometric rate of depreciation since this rate was approxi-

68. Data are available for research, development, and testing services for unaffiliated services. See BEA (2001, table 1, pp. 64–65). R&D-affiliated services data are available from 2002 (BEA 2003).

mately the midpoint of then-available estimates of R&D depreciation rates. The previous project compared estimates using the straight-line/ Winfrey methodology and an 11 percent geometric rate and found that the differences were "modest."[69]

Two alternative depreciation rate scenarios are developed because R&D service lives may have shortened over time given the general overall increase in the rate of technical advance as well as a compositional shift in R&D expenditures over the decade of the 1990s.[70] The latter effect is reflected by the increasing share of GDP expenditures devoted to products, such as personal computers, with relatively short life spans, and away from products such as pharmaceuticals with a seventeen-year patent life. In addition, obsolescence-related depreciation rates may increase as the level of R&D expenditures rise and the pace of technical change quickens.[71] However, the magnitude and timing of a possible shortening of service lives are difficult to measure.

The capital stock equation is

$$\text{(C4)} \quad \text{Capital stock}_t = \text{expenditures}_{t-1} + (1 - \text{depreciation rate}) \times \text{capital stock}_{t-1}.$$

Returns to R&D Capital

A simplified capital service flow equation is used in this paper to estimate returns to R&D capital; all tax terms are ignored.

$$\text{(C5)} \quad \text{Return} = \text{net return} + \text{depreciation},$$

or

$$\text{(C6)} \quad \text{Return}_t = \text{net rate of return} \times \text{capital stock}_{t+1} + \text{depreciation rate} \times \text{capital stock}_{t-1},$$

where the rate of return is held constant for each scenario over all years but varies depending upon whether a private, spillover, or social rate of return is employed. Ignoring the tax terms (such as those that would reflect the

69. See Carson, Grimm, and Moylan (1994, p. 45 and box, p. 48) for a comparison for selected years.

70. The NSF's R&D expenditure data by industry are extremely limited. Data for office, computing, and accounting machines (OCAM—the computer category) are only available for 1972–80, 1993–94, and 1997–98. Data for drugs and medicine and for machinery (the latter being the category that includes OCAM) are available for most years from 1953 forward. Analysis of these data shows that the share of R&D devoted to drugs and medicine rose from 1961 to 1998, while that for machinery may have fallen since the mid-eighties. No data are available for nonmanufacturing industries, including service industries, until 1995. See NSF (2001a), "Total (company, federal, and other) funds for industrial R&D performance, by industry and by size of company: 1953–98."

71. This was suggested by Adam Jaffe in his comments at the presentation of Fraumeni and Okubo (2001).

expensing of many R&D costs and the taxation of profits from R&D) on average tends to underestimate business returns to R&D. Tax terms are not an issue for nonprofit institutions and general government. Thus, since only nonprofit institutions and general government private returns to R&D capital are a return net addition to GDP (see table 8.11), appendix equation (C6) provides a good approximation of additions to GDP due to R&D capitalization. Ideally, the equation should be revised to include taxes to adjust the estimates of the return to business R&D capital and the contribution of that capital to GDP growth.

The prior BEA project concluded that gestation lags range from one year to two years, that application lags range from something less than one year to somewhat more than two years, and that lags between the investment and its peak effect on profits may be long, particularly for basic research (Carson, Grimm, and Moylan 1994, p. 44). The application lags may have shortened over the 1959–2000 time period because of the quickening pace of technical change in the past decade and shifts in composition of industry R&D expenditures. However, we lack empirical evidence to support a specific lag form. No attempt is made to adjust for variation in the return to R&D or the time pattern of industry returns to R&D capital. The issue of the peak impact on profits would be moot if the age distribution and composition of R&D capital stock were constant over time—an unlikely case. In this paper, the alternative scenario lengthens the overall lag expenditure to capital stock lag from one to seven years.

Deflation and Aggregation

The base case deflator and one alternative deflator, the information processing equipment and software deflator, are NIPA deflators. The other alternative deflator is the BEA 1994 study deflator until 1992, then a slightly modified GDP (NIPA table 7.1, chain-type price index) deflator for all subsequent years.[72] From 1987 to 1992 the BEA 1994 study deflator and the GDP deflator are almost identical; from 1974 to 1992, the deflators are very similar except for a couple of years around 1980. The BEA 1994 deflator is extended through 2000 using the GDP deflator growth rate. From 1959 to 1988, except for a few years around 1980, the Griliches-Hall-Jaffe deflator[73] and the BEA 1994 study deflator are almost identical. The information processing equipment and software deflator is chosen as an alter-

72. No attempt is made to update the BEA R&D deflator beyond 1992 for two reasons. First, the GDP deflator and the BEA 1994 study deflator are almost identical from 1987 to 1992. Second, updating the BEA 1994 study deflator would require a substantial effort. The BEA 1994 study deflator was estimated by deriving the cost of inputs at the lowest level of detail available, then matching these costs as closely as possible with proxy prices.

73. The deflator is from table 3.1 of Hall (1990) and is described on page 20 of that source. It is constructed using methodology similar to Jaffe (1972). In BLS (1989, p. 45) the deflator based on the 1972 methodology is called the Jaffe-Griliches deflator.

native deflator to check the sensitivity of our results to use of a deflator that behaves very differently from either of the other two scenario deflators.

The same scenario-specific deflator is used to deflate R&D investment, stock, and returns to R&D. Additive aggregation is used when creating R&D totals because there are no differences in the underlying deflator.

A chain index number formula is used to aggregate across estimates—say, consumption and investment—with different underlying deflators, unless a component is negative. For example, if GDP is equal to the sum of investment (I) and consumption (C), the rate of growth of aggregate 1996 dollar adjusted GDP is calculated as

$$(\text{C7}) \qquad .5 \times \left(\frac{\text{nominal dollar } I_{t-1}}{\text{nominal dollar-adjusted GDP}_{t-1}} + \frac{\text{nominal dollar } I_t}{\text{nominal dollar-adjusted } GDP_t} \right) \times \frac{\text{real } I_t}{\text{real } I_{t-1}} - 1 + .5 \times \left(\frac{\text{nominal dollar } C_{t-1}}{\text{nominal dollar-adjusted } GDP_{t-1}} + \frac{\text{nominal dollar } C_t}{\text{nominal dollar-adjusted } GDP_t} \right) \times \frac{\text{real } C_t}{\text{real } C_{t-1}} - 1,$$

a methodology parallel to that used to estimate contributions of R&D to growth (see note 49). The growth rates are then used to extend the real adjusted GDP series before and after 1996, the base year.

Additive aggregation is used when a component is negative.

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Comment Bronwyn H. Hall

The paper describes an effort to create satellite national income accounts for the United States that treat R&D expenditure as an investment rather than simply current spending. Given the well-documented fact that the returns to R&D spending can occur with long and somewhat diffuse lags, making an effort to produce national accounts that incorporate a measure of the national stock of "knowledge" on a somewhat regular basis is long overdue. Although an earlier attempt was made by Carson, Grimm, and Moylan (1994), inclusion of the R&D satellite account in the NIPA is even now not done on a regular basis. Given the discussions and studies that have taken place and are taking place at international organizations such as the Organization for Economic Cooperation and Development (OECD) and the European Union concerning the measurement of intangible assets, as well as the consideration of capitalizing R&D in firm accounts on the part of the Financial Accounting Standards Board (FASB) and International Accounting Standards Board (IASB), this seems a timely exercise.[1]

After presenting the changes to the System of National Accounts (SNA) from treating both R&D and some government expenditures as investments, the paper goes on to produce some estimates of the contribution of R&D to overall economic growth, based on a set of assumptions about the private and social rate of return to R&D, and the rate of growth of R&D, using a growth-accounting framework. In my discussion I present an overview of the way in which R&D should be incorporated into the national income accounts (NIA) and then discuss some issues related to the measurement of R&D for this purpose. I will not discuss the growth-accounting exercise, because the final version of the paper omits most of

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1. See http://pages.stern.nyu.edu/~blev/ for information on accounting for R&D as a capital asset in firm accounts.

the description of how this was done and the associated numbers on which it was based, with the exception of the R&D numbers. I conclude by discussing whether the time has come for an R&D satellite account.

The Measurement of R&D in the NIA

In order to understand exactly the changes made to the NIA in order to construct a satellite R&D account, it is helpful to summarize the changes itemized in equations (1)–(16) of the Fraumeni-Okubo paper in a simplified form. The starting point is the accounting identity between the product and income side of the accounts:

$$\text{GDP} = \text{GDI} + \text{SD},$$

where SD is the "statistical" discrepancy, which is due to measurement problems, to incomplete data, and to the fact that actual profits net of taxes may not always match the notional income from private capital stock. In turn, this equation can be broken down into its components:

$$C + I + \text{NE} + G = \text{LI} + \text{PI} + \text{IBT} + \text{SD},$$

where C is consumption, I is investment, NE is net exports, G is government spending, LI is labor income, PI is property income, and IBT is indirect business and nontax liability. LI, IBT, and NE are unaffected by the R&D changes. The adjusted accounting identity between GDP and GDI is therefore the following:

$$C_A + I_A + \text{NE} + G_A = \text{LI} + \text{PI}_A + \text{IBT} + \text{SD}.$$

In order to compute this adjusted or satellite account, the necessary changes to C, I, and G are given by

$$C_A = C + \text{(returns to nonprofit R\&D)}$$
$$- \text{(R\&D funded by nonprofits and government/performed by others)}$$
$$- \text{(R\&D funded by business/performed by nonprofits and government)}$$
$$I_A = I + \text{(R\&D performed by business and nonprofits)}$$
$$G_A = G + \text{(returns to government-performed R\&D)}$$
$$+ \text{(R\&D performed by government)}$$
$$- \text{(R\&D funded by government/performed by business)}$$

Because PI is the only quantity on the right-hand side of the accounting identity affected by the changes, the changes to PI are simply the sum of the changes to C, I, and G:

PI_A = PI + (returns to nonprofit R&D and government-performed R&D)

+ (R&D performed by government, business, and nonprofits)

− (R&D funded by government/performed by government, business, and others)

− (R&D funded by nonprofits/performed by government, business, and others)

− (R&D funded by business/performed by nonprofits)

or

PI_A = PI + (returns to nonprofit R&D and government-performed R&D)

+ (R&D funded by business/performed by business)

Table 8.3 of the Fraumeni-Okubo paper summarizes the changes outlined here. In order to implement them, the authors need to have R&D performance broken down into three categories: government, nonprofit institutions, and private business. Unfortunately, this is not the way the data are collected by the National Science Foundation (NSF). Table 8C.1 shows the data as they come from the NSF, using the year 2000 as an example; for comparison, the BEA numbers used by Fraumeni and Okubo in table 8.4 are shown in the last row. According to the NSF, total R&D spending in current dollars during this year was 265 billion (200 in business, 10 in nonprofit, and 55 in government), whereas the BEA numbers yield a total of 270 billion (202 in business, 21 in nonprofit, and 47 in government). The sectoral differences shown in the table are probably due to the amount of extrapolation and estimation the authors were forced to do in order to conform to BEA sector definitions. In particular, the category labeled universities and colleges by NSF is composed of private institutions, which BEA apparently classifies as business, and public institutions, which BEA classifies as government. As described in appendix C, the BEA numbers post-

Table 8C.1 R&D performing and funding sectors in 2000 (in $millions)

	Performing sector			
Funding sector	Government (incl. U&C)	Industry	Nonprofit institutions	Total
Government (incl. U&C)	50,585	22,210	4,997	77,792
Industry	2,310	177,645	1,085	181,040
Nonprofit institutions	2,203		3,586	5,789
Total	55,098	199,855	9,668	264,621
BEA numbers	47,445	202,116	20,876	270,437

Source: http://www.nsf.gov/sbe/srs/nsf01309/start.htm

1992 were created by regressing their data for 1953 to 1992 on the NSF data in the closest sector and a time trend, and then extrapolating to 2000. This procedure may not be able to reproduce the actual NSF numbers very well, because of the substantial structural break in those numbers between 1992 and 1993 due to revisions.

The conclusion is that before the sectoral numbers on R&D spending are actually incorporated into the SNA some additional work needs to be done to understand exactly where the discrepancy arises and to create recommendations to the NSF as to which data are needed in order to create an accurate picture of the contribution of R&D to the economy. Fraumeni's (2003) presentations to Science, Technology, and Economic Policy (STEP) and Committee on National Statistics (CNSTAT) Workshops on Research and Development Data Needs outlined some of the work needed on R&D data for improved accuracy here and elsewhere before information on R&D could be fully incorporated into the SNA:

1. More timely data: currently, annual revisions are released in July, seven months after the end of the reference year.
2. Quarterly estimates, at least for some indicators.
3. More information to avoid double-counting of capital used by R&D.
4. Historical time series consistency at the level of business, nonprofit, and government spending, to avoid the need for the estimation and extrapolation performed in this paper.
5. Historical estimates for imports and exports of R&D.
6. Developing a complete satellite account requires industry detail, including service industries, as well as basic, applied, and development R&D by industry; domestic and international R&D by industry; and some information on the relationships between R&D performers and funders.

As Fraumeni noted in her presentation, access to NSF microdata on the part of BEA might help in some of these areas, and it is hoped that the new data-sharing legislation may facilitate this.[2]

Measuring R&D Investment

Clearly the key component of the R&D satellite account is the measurement of real R&D capital stock. R&D expenditure is composed primarily of the wages and salaries of technical personnel, expenditures on supplies and materials, and investment in equipment. Based on interviews with a

2. The Confidential Information Protection and Statistical Efficiency Act passed by Congress in 2003, which permits the Census Bureau, BEA, and Bureau of Labor Statistics to share business data for statistical purposes only, is often referred to as data-sharing legislation. Shortly after the legislation was passed, the R&D Link Project, a project to link the data from the 1997 and 1999 R&D surveys to BEA's 1997 Survey of Foreign Direct Investment in the United States and the 1999 U.S. Direct Investment Abroad survey, was developed under the sponsorship of the NSF, in order to obtain a better picture of the import and export of R&D.

number of technology-intensive global companies, Dougherty and others (2004) present an average breakdown of these expenditures into 46 percent labor, 49 percent supplies and other current expenses, and 5 percent capital expenditure.[3] At the present time the investment expenditures are counted in the fixed investment measures, and the remainder is intermediate consumption and the wages paid to labor. By treating the entire quantity as an investment in R&D, the R&D equipment investment is double-counted. Although this will create some measurement error in the SNA, the error will be quite small as a share of GDP. Given data on R&D capital equipment expenditure, it might be possible to improve the estimates.

The fact that roughly half of R&D spending is labor compensation raises a more serious question about the choice of deflator used in constructing the real stocks of R&D capital. Although the appendix to the paper constructs scenarios using a deflator based on the Jaffe-Griliches methodology as well as one based on a computing and software price index from NIPA, the body of the paper uses the NIPA fixed nonresidential investment deflator. This deflator is heavily influenced by the falling real price of computing, which in my view makes it unsuitable as an R&D deflator, given the composition of R&D expenses.[4] Not surprisingly, as the appendix tables show, the choice among these deflators makes a considerable difference to the estimates of the contribution of R&D investment or R&D capital to growth. If, as Dougherty and others (2004) suggest, the Jaffe-Griliches deflator is preferred, the contribution of R&D to GDP growth will be on the low side of the estimates presented, about 2 percent for investment and 9 percent for the returns to R&D. Over the 1961–2003 period, the real rate of growth of R&D investment would be about 3.3 percent rather than 5 percent.

If the BEA decides to go forward with an R&D satellite account, other issues will arise. The first is that gestation lags may vary a great deal across industries. For example, in the biotechnology industry, R&D projects may last ten years before generating any positive return, whereas in some IT industries, the product life cycle is a year or less. The current assumption of one year for all R&D is therefore a very rough approximation, although the likely impact of changing the lags is small as long as R&D spending is relatively smooth over time.

Obsolescence can be a bigger problem for the measurement of private returns than for total returns, because the knowledge created by R&D con-

3. These estimates are roughly consistent with the much older estimates of R&D composition used by Jaffe (1973) and then by Griliches (1984) to construct an R&D deflator (0.49 labor cost and 0.51 nonfinancial corporation output).

4. During the entire 1961–2003 period, the fixed investment deflator grew by an average annual rate of 2.4 percent, compared to about 4 percent for the Jaffe-Griliches deflator. During the 1992–2003 period, when the difference becomes larger, the corresponding numbers are 2.8 percent and –0.7 percent. The information processing and software deflator itself fell 2.4 percent per year between 1961 and 2003, and almost 5 percent per year during the past ten years.

tinues to be useful even after it no longer generates private returns. The implication is that one needs to be careful in thinking about depreciation when there are spillovers. As a productive input for individual firms, R&D capital may lose its value more quickly than as an input to the economy as a whole. In general, I would prefer to do what the authors do here: use a constant and somewhat conservative depreciation rate for R&D capital that reflects its "expected" contribution, and infer the (possibly fluctuating) private returns from firm profits. That is, private obsolescence will show up as lower net returns to R&D, due to higher actual depreciation.

Should we introduce an R&D satellite account?

With this paper and the earlier Carson, Grimm, and Moylan (1994) paper in hand, what can we say about the wisdom of introducing such an account into the SNA? Both papers have demonstrated the feasibility of such an undertaking and outlined how it should be done; Fraumeni and Okubo have also given us a sense of what the impact would be in terms of growth accounting. A beneficial side effect of such an undertaking would be to focus attention on the collection by government statistical agencies of improved data on R&D expenditures and their composition.[5]

But as the authors argue, and as is clear from the range of numbers generated under the different scenarios in appendix A, it would be premature to actually incorporate R&D in the SNA itself, so a satellite account seems to be the way to proceed, at least at first.

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5. On this issue, see National Research Council (2004).