# R&D Depreciation Rates in the 2007 R&D Satellite Account

## Bureau of Economic Analysis/National Science Foundation 2007 R&D Satellite Account Background Paper

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# Preface

This paper discusses how the industry-specific rates of depreciation for R&D used to construct the 2007 R&D Satellite Account were determined after a review of the literature.

# Acknowledgements

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## Abstract

This paper is part of a series that provides the details behind the Bureau of Economic Analysis's (BEA) satellite account on research and development (R&D) activity. In the current work, the focus is on industry-specific depreciation rates for business R&D capital. This paper begins by discussing the literature on R&D depreciation rates. It then describes how the rates in the 2007 satellite account were chosen from the related findings.

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One of the improvements introduced in the 2007 Research and Development Satellite Account (R&DSA) are industry-specific depreciation rates that affect the measures presented for rates of return, capital stocks, and consumption of fixed capital. This change not only increases the quality of the measures presented in the main satellite account, but it also allows for the presentation of meaningful estimates on industry-specific rates of return to R&D capital. This paper discusses how the industry-specific depreciation rates used in the R&D satellite account were determined.

## I. Background

The 2006 R&DSA was based on two sets of assumptions about the rate at which R&D capital depreciates. In the "base case," all R&D capital was assumed to depreciate (obsolesce) at an annual rate of 15.0 percent. In the "alternative scenarios," all R&D capital was assumed to depreciate at the same rate as that of nonresidential equipment and software before 1987 and at the same rate as that of information processing equipment afterwards. These rates were based on a literature review on that focused on an aggregate rate of depreciation for all business R&D capital, which was the level of aggregation presented in the 2006 estimates.

In 2007, a review of literature was undertaken that resulted in the choice of the following set industry-specific depreciation rates for R&D capital in the 2007 R&DSA: Transportation equipment, 18.0 percent; computer and electronics, 16.5 percent;

chemicals, 11.0 percent, and "all other," 15.0 percent.[1] In the featured results, these individual rates are assumed to be constant over time. However, some evidence suggests that a more appropriate assumption might be R&D depreciation rates that increase over time. To see the effect that increasing rates would have on the measures in the satellite account, alternative measures based on this assumption are presented in the R&D background paper on rates of return to capital.[2]

## II. Review of the Literature

Since studies that calculate industry-specific depreciation rates are limited and have varying results, this section begins by focusing on depreciation rates for the R&D capital of business. This initial focus allows the industry-specific rates that are discussed afterwards to be effectively benchmarked to a reasonable rate for the R&D capital of business in the final section of the paper.

### A) Empirical methods

Four types of empirical specifications are used to estimate R&D depreciation rates—production functions, amortization models, patent renewal models, and market valuation models. However, the most appropriate choice among these models is still an unresolved issue: None seem completely satisfactory because they are based on strong identifying assumptions or applied to data that lack sufficient variation to separately identify R&D depreciation rates.

Hall (2007) clearly illustrates some of the issues associated with estimating R&D depreciation rates using a production function by discussing the types of identifying assumptions that are often needed to separately identify R&D depreciation rates. The first of these models assumes that firms exist in a perfectly competitive market place, which Hall mentions is inconsistent with the notion that R&D is often conducted to generate monopolistic returns. The second assumes that the output elasticities of ordinary capital and R&D capital are proportional to their input shares, which Hall

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[1] Since the literature examines businesses, the R&D of government and nonprofit institutions is assumed to depreciate at 15 percent in the 2007 R&DSA, which is the same assumption used in the 2006 R&DSA. This lower depreciation rate reflects the likelihood that the R&D activity of government and nonprofit institutions is more heavily weighted toward basic research, and thus depreciates more slowly.

[2] See Brian K. Sliker, "Rates of Return to R&D Capital," 2007 R&D Satellite Account Methodology Paper, BEA Website Publication, forthcoming.

characterizes as a “heroic” assumption that also may also introduce a notable amount of specification error into estimation results.

Other assumptions are also used in the production function approach framework. For instance, the empirical results presented in Nadiri and Prucha (1996) and in Bernstein and Mamuneas (2004; 2006) are based on assumptions about future price expectations. It is unclear how much specification error these assumptions may introduce into the estimates. In addition, some economists, such as Huang and Diewert (2007), have more broadly argued that many of these models may inappropriately model the role of R&D in production by treating it in the same as ordinary physical capital. In particular, since R&D capital does not lose value in the same manner as physical capital (wearing out from general use in production), some argue that R&D capital should be treated as a factor that increases the production possibilities faced by a firm rather than an input in production.

Perhaps the most intellectually appealing of these models is Huang and Diewert. Not only does it treat R&D capital as a factor that shifts out the production possibilities faced by a firm, but it also considers firms that can experience monopolistic markups associated with R&D investment. However, Huang and Diewert state that the estimation results are preliminary because their model still excludes some important features associated with R&D investment, such as the role of uncertainty, and their results have not been checked against the results from other functional forms for a production function. Their model also does not fit the data well in some industries.

Results from amortization models, such as those presented in Lev and Sougiannis (1996) and Ballester, Garcia-Ayuso, and Livnat (2003), are based on more general set of models that attempt to explain the returns on R&D investment. However, the resulting estimates are subject to similar concerns as those raised about results from production function models. For example, the results of Lev and Sougiannis are based on an assumed relationship between the amortization rate of R&D capital and earnings that these assets generate. The results are also based on the assumption that operating income serves as a good proxy for R&D benefits.

Results from patent renewal models, such as those presented in Pakes and Shankerman (1984), are subject to a different set of concerns. These models estimate the rate of obsolescence associated with R&D capital by using information on renewed patents to estimate a model in which firms maximize the present discounted value of their returns to R&D investment. Yet patent renewals are not necessarily a good measure of the value of the knowledge created by R&D because the value of this knowledge may not be well approximated by the price of the renewal. Even when attempts are made to address this consideration, another limitation is that not all R&D activity is associated with the filing of patents.

Market valuation models, such as those presented in Hall (2006), estimate R&D depreciation rates from model related to the market value of a firm. A potential problem related to such models is that capital markets may be inefficient, which is inconsistent with what these models assume.

Although none of the empirical models are completely satisfactory or totally preferable to the others, there is one data issue that affects the selection of the depreciation rates used in the R&D satellite account. Specifically, results from studies that rely on data collected at the industry level, such as those in Bernstein and Mamuneas (2006) and in Huang and Diewert, are more applicable than results from studies that rely on data collected at the firm level, such as those in Lev and Sougiannis and in Ballester, Garcia-Ayuso, and Livnat, because the 2007 R&DSA plans to present industry-level data. Yet firm-level results may be driven by a large number of firms that actually contribute little to industry-level capital stocks. R&D capital may also obsolesce quicker for individual firms than for an industry as a whole.[3]

**B) Estimates for business R&D**

Studies of business R&D find depreciation rates that range from 12 percent to 29 percent. However, the three highest rates in this range should be discounted in the consideration of the appropriate rates for the 2007 R&DSA for a variety of reasons (table 1).[4]

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[3] The notion that R&D capital may obsolesce quicker for individual firms than for an industry as a whole is discussed in Sviekauskas (2004).

[4] The study of Cabellero and Jaffe (1995) is excluded from this section because the results are difficult to relate to those of the other studies and are more closely relate to the depreciation rates that increase over time, which are discussed later in the paper.

The European-based rate found in Pakes and Shankerman should be discounted for two reasons. First, it is based on a sample of patent returns over the period of 1930-1939. The other studies use data related that are related to the more recent periods of time that are covered in the 2007 R&DSA. Second, the European-based depreciation rate for R&D capital may differ from those in the United States.

Although the U.S. rates found in Bernstein and Mamuneas (2004) and in Hung and Diewert are based on industry-level data and the most applicable to the 2007 R&DSA, the results of these two studies are discounted for their own separate reasons. The empirical model in Bernstein and Mamuneas produces industry-level depreciation rates that are notably higher than those of studies based on firm-level data. Although this result might be the result of industry-level data, one would expect the estimated rates in Bernstein and Mamuneas to be lower than those usually found in the studies that use firm-level data because R&D capital is more likely to obsolesce at slower rate within an industry than within an individual firm. As previously mentioned, the empirical results of Huang and Diewert are preliminary, and sometimes their model has difficulty separately identifying depreciation rates for the R&D capital of some industries.

In light of these considerations, the 15 percent depreciation rate for R&D capital that is commonly assumed in studies of the net return to R&D capital is consistent with the empirical evidence, which seems to indicate that the range of 15 to 20 percent is correct for the depreciation rate of business R&D.

**C) Estimates for industry-specific R&D**

Studies of industry-specific R&D find depreciation rates that range from -11 percent to 52 percent (table 2). However, the rates found in Hall are dropped from consideration in the 2007 R&DSA because the rates that are presented in the first portion of the study, which are based on a production function seem unreasonably low, and the rates that are presented in the second portion of the paper, which are based on a market valuation model, seem unreasonably high. Once these rates are dropped, the industry-specific depreciation rates more reasonably range from 1 percent to 29 percent.

The industry-specific rates found both in Bernstein and Mamuneas (2006) and in Huang and Diewert are also discounted. In addition to the reasons mentioned above, a few of the industry-specific rates in Huang and Diewert are estimated with poorlybehaving data, which may explain the questionable magnitude of the estimates for industrial machinery and chemicals.

Two notable characteristics that are associated with the relative magnitudes of the depreciation rates are found in the remaining studies. First, with the exception of Ballester, Garcia-Ayuso, and Livnat, the chemical industry always has the lowest estimated depreciation rate when compared to other industries within a study. Second, with the exception of Bernstein and Mamuneas, the transportation equipment and scientific instrument industries always have depreciation rates that are higher than average within a study.

## III. Estimates for the Satellite Account

The industry-level estimates featured in the 2007 R&DSA are based on a two-step process. In the first, the midpoints of the range of estimates given by all the studies other than Hall are calculated for each industry. In the second step, these midpoints are scaled down so that the recommended rates are more closely centered on a value of 15 and that the overall ranking of industry-level rates suggested by the literature is preserved. Although more detailed estimates for R&D depreciation rates are provided in the literature, the rates in the 2007 R&DSA are limited to a few 3-digit North American Industry Classification System codes.

Since there is no clear empirical evidence to indicate otherwise, R&D capital is assumed to decline in a geometric pattern, which is consistent with the use of constant depreciation rates. Further, related measures for consumption of fixed capital are calculated with the standard half-year adjustment used by BEA. Both of these practices also maintain consistency with the treatment of most other types of assets in the BEA's accounts.[5]

Although the featured measures in the 2007 R&DSA are based on constant depreciation rates for R&D capital, some argue that R&D depreciation rates should

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[5] For more information on the conventions used by BEA to calculate capital stocks and consumption of fixed capital estimates, see the chapter entitled "Concepts and Methods" in Bureau of Economic Analysis, *Fixed Asset and Consumer Durable Goods in the United States, 1925-97* (Washington, DC: U.S. Government Printing Office, September 2003).

increase over time. For example, Cabellero and Jaffe (1995) find increasing obsolescence rates for all R&D capital over time. However, it is unclear whether its results are primarily driven by changes in the composition of R&D assets across industries or "true" increases in obsolescence rates because the study does not estimate industry-level depreciation rates. Regardless, many practitioners in the field also believe that R&D depreciation rates have increased in more recent years within their own industries.

To estimate the effect that increasing rates have on industry-level rates of return, the industry-level depreciation rates from the 2007 R&DSA are assumed to all increase over time at the same rate as the depreciation rate of nonresidential equipment and software before 1987 and at the same rate as that of information processing equipment afterwards. These alternative conventions, which are less than perfect due to the lack of more appropriate data, are based on the notion that the value of R&D investment is heavily embedded in these types of assets, and the resulting measures are presented in a supplemental table in the R&D background paper on rates of return to R&D capital, which is available at <www.bea.gov>.

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## Table 1. Depreciation rates for all R&D capital

| Author (Year) | Annual rate of depreciation (R&D) | Estimation technique | Comments |
|---|---|---|---|
| Pakes and Shankerman (1984) | 0.25 | Patent renewal model | Patent renewal rates over the period of 1930-1939 for France, UK, Netherlands, and Switzerland |
| Nadiri and Prucha (1996) | 0.12 | Production function (simultaneous estimation of labor and material demand functions) | U.S. manufacturing industries over the period of 1960-1988 |
| Lev and Sougiannis (1996) | 0.15<br>(average annual rate) | Amortization model | 825 U.S. firms over the period of 1975-1991 |
| Ballester, Garcia-Ayuso, and Livnat (2003) | 0.12 | Amortization model | 652 U.S. firms over the period of 1985-2001 for preferred specification |
| Bernstein and Mamuneas (2004) | 0.25 for U.S.<br>0.21 for Canada | Production function | Manufacturing industries over the period of 1953-1998 for U.S. and over the period of 1963-1995 for Canada |
| Huang and Diewert (2007) | 0.29 | Production function (R&D shifts production function, and model includes a monopolistic markup) | Manufacturing industries over the period of 1953-2001 for U.S. |

**Table 2. Depreciation rates for industry-level R&D capital**

| Author (Year) | Annual rate of depreciation (R&D) | Estimation technique | Comments |
|---|---|---|---|
| Lev and Sougiannis (1996) | • Scientific instruments, 0.20<br>• Transportation equipment, 0.14<br>• Industrial machinery, 0.14<br>• Electrical equipment, 0.13<br>• Chemicals, 0.11 | Amortization model | 825 U.S. firms over the period of 1975-1991 |
| Ballester, Garcia-Ayuso, and Livnat (2003) | • Transportation equipment, 0.17<br>• Chemicals, 0.14<br>• Industrial machinery, 0.14<br>• Scientific instruments, 0.14<br>• Electrical equipment, 0.13 | Amortization model | 1092 U.S. firms over the period of 1985-2001 for preferred specification |
| Bernstein and Mamuneas (2006) | • Electrical equipment, 0.29<br>• Industrial machinery, 0.26<br>• Transportation equipment, 0.21<br>• Chemicals, 0.18 | Production function | U.S. industries over the period of 1954-2000 |
| Hall (2006) | *Production function:*<br>• Metals and machinery, - 0.02<br>• Miscellaneous, - 0.02<br>• Chemicals, - 0.02<br>• Electrical equipment, - 0.03<br>• Computers and scientific instruments, - 0.05<br>• Drugs and medical instruments, - 0.11<br>*Market valuation model:*<br>• Electrical equipment, 0.52<br>• Metals and machinery, 0.43<br>• Computers and scientific instruments, 0.42<br>• Miscellaneous, 0.24<br>• Chemicals, 0.22<br>• Drugs and medical instruments, 0.16 | Production function (first set of results); Market valuation model (second set of results) | 16750 U.S. firms over the period of 1974-2003 |
| Huang and Diewert (2007) | • Transportation equipment, 0.27<br>• Electrical equipment, 0.14<br>• Industrial machinery, 0.03<br>• Chemicals, 0.01 | Production function (R&D shifts production function, and model includes a monopolistic markup) | U.S. industries over the period of 1953-2001 |