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THE MEASUREMENT OF DEPRECIATION IN THE U.S. NATIONAL INCOME AND PRODUCT ACCOUNTS

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The Measurement of Depreciation in the U.S. National Income and Product Accounts

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As part of the recent comprehensive revision of the NIPA's, BEA introduced an improved methodology for calculating depreciation. The improved methodology uses empirical evidence on the prices of used equipment and structures in resale markets, which has shown that depreciation for most types of assets approximates a geometric pattern. Previously, the depreciation estimates were derived using straight-line depreciation and assumed patterns of retirements.

This article describes the theoretical and empirical literature that supports the new BEA methodology. The author, a professor of economics at Northeastern University, Boston, Massachusetts, drafted the article while she was serving as a consultant to BEA for this project. The views expressed are the author's and do not necessarily represent those of BEA.

This article describes the basis for the new depreciation methodology used by the Bureau of Economic Analysis (BEA).[1] The new BEA methodology reflects the results of empirical studies on the prices of used equipment and structures in resale markets, which have shown that depreciation for most kinds of equipment and structures does not follow a straight-line pattern. For most assets, empirical studies on specific assets conclude a geometric pattern of depreciation is appropriate.[2] The new BEA methodology also uses a geometric pattern of depreciation as the default option when information on specific assets is unavailable.[3] In either case, the geometric (constant) rate of depreciation is determined from empirical studies of used assets. For some assets (autos, computers, missiles, and nuclear fuel), empirical studies, BEA data, or technological factors justify the use of a nongeometric pattern of depreciation by BEA. This article reviews the empirical research on depreciation, the basis for the improvement in BEA methodology.

Previous BEA estimates of depreciation were based on a straight-line pattern for depreciation; the switch is to a geometric pattern for depreciation for most assets. A straight-line pattern assumes equal dollar depreciation over the life of the asset. For example, with straight-line depreciation, depreciation in the first year is equal to depreciation in the second year, which is equal to depreciation in the third year, and so on. A geometric pattern is a specific type of accelerated pattern. An accelerated pattern assumes higher dollar depreciation in the early years of an asset's service life than in the later years. For example, with accelerated depreciation, depreciation in the first year is greater than that in the second year, which is in turn greater than that in the third year, and so on. In BEA calculations, in the absence of investment, geometric depreciation is calculated as a constant fraction of detailed constant-dollar net stocks.

In most cases, the rates of geometric depreciation are based on the Hulten-Wykoff estimates (Hulten and Wykoff 1981b). For some assets (computer equipment and autos), nongeometric depreciation rates estimated in empirical studies or from BEA data are used. For a few assets (missiles and nuclear fuel rods), BEA has retained its prior methodology of deriving estimates of depreciation using straight-line depreciation and Winfrey retirement patterns.[4] The original Hulten-Wykoff rates are modified to reflect service lives currently used by BEA.

The first section of this article briefly describes the relevant depreciation concepts. The second section discusses previous BEA methodology and Hulten-Wykoff methodology in the context of these depreciation concepts. The empirical research on depreciation is summarized in the third section. In the fourth section, the new BEA depreciation rates for all assets except autos, computers, missiles, and nuclear fuel are listed and their derivation documented. The fifth section consists of a brief conclusion.

1. The improved methodology was summarized in Parker and Triplett (1995). The new estimates of capital stock were described in Katz and Herman (1997).

2. These assets are listed as type A and B assets in table 3.

3. These assets are listed as type C assets in table 3.

4. Retirement patterns refer to the patterns of assets withdrawn from service.

Depreciation Concepts [5]

Definitions

The value of an asset changes as the result of depreciation and revaluation.[6] Depreciation is the change in value associated with the aging of an asset. As an asset ages, its price changes because it declines in efficiency, or yields fewer productive services, in the current period and in all future periods. Depreciation reflects the present value of all such current and future changes in productive services.

Revaluation is the change in value or price per unit that is associated with everything other than aging. Revaluation includes pure inflation, obsolescence, and any other impact on the price of an asset not associated with aging.

The decomposition of the change in the value of an asset is illustrated in table 1 for an asset with price per unit. The price of an asset, $P_{time,age}$, in time 0 and the price of an asset in time 1 is observed. There are two possible sources of the price change: The first being a change in the price of an asset because it has aged and the second being a change in the price of an asset because it is a different time period. The decomposition can be illustrated in the simplest case by reference to the well-known used-car price book. Prices for 1-year-old cars of the same make and model in the 1997 book and their prices when new provide an estimate of depreciation because everything but age is held constant. Prices for 1-year-old cars of the same make and model in the 1996 and 1997 price books provide an estimate of revaluation, because age is held constant while everything else changes.

Obsolescence is a decrease in the value of an asset because a new asset is more productive, efficient, or suitable for production. A new asset might be more suited for production because it economizes on an input that has become relatively more expensive. Obsolescence has played a big part in the debate about the impact of the oil embargo on productivity.[7] Other impacts on the price of an asset include the price effect of any changes in taxes or interest rates facing business not anticipated when the asset was new. If depreciation and retirement patterns did not change over time, revaluation could be estimated from a used-asset-price book, as described above.

5. The sources for this section include papers by Triplett (1992a, 1992b, 1996), by Jorgenson (1989, 1996), by Young and Musgrave (1980), and by BEA (1993).

6. BEA and the author of this article differ in their definition of depreciation in national accounts. This will be discussed briefly in the section "BEA definition."

Table 1.—Depreciation Versus Revaluation

Represent the price of an asset by ($P_{\text{time,age}}$).

A change in the price of an asset at time = 1, ($P_{\text{time=1,age=1}} - P_{\text{time=0,age=0}}$),
is equal to
depreciation, ($P_{\text{time=0,age=1}} - P_{\text{time=0,age=0}}$),
or age effects, holding time constant
plus
revaluation, ($P_{\text{time=1,age=1}} - P_{\text{time=0,age=1}}$),
or time effects, holding age constant.

Schematically, representing the decomposition of the observed price change ($P_{\text{time=1,age=1}} - P_{\text{time=0,age=0}}$), in bold and with arrows, and the matrix of price changes over time = $0, 1, \ldots T$ and age = $0, 1, \ldots A$, where D is depreciation and R is revaluation:

$$
\begin{array}{llllll}
 & & \text{TIME} & & & \\
 & P_{\text{time=0,age=0}} & P_{\text{time=1,age=0}} & P_{\text{time=2,age=0}} & \cdots & P_{\text{time=T,age=0}} \\
 & \downarrow D \downarrow & \searrow & & & \\
\text{AGE} & P_{\text{time=0,age=1}} \rightarrow R \rightarrow & P_{\text{time=1,age=1}} & P_{\text{time=2,age=1}} & \cdots & P_{\text{time=T,age=1}} \\
 & \vdots & \vdots & \vdots & \cdots & \vdots \\
 & P_{\text{time=0,age=A}} & P_{\text{time=1,age=A}} & P_{\text{time=2,age=A}} & \cdots & P_{\text{time=T,age=A}}
\end{array}
$$

BEA definition

BEA defines depreciation as "the decline in value due to wear and tear, obsolescence, accidental damage, and aging" (Katz and Herman 1997, 70), which includes retirements, or discards as they are frequently called.[8] BEA includes the destruction of privately owned fixed assets that is associated with natural disasters in depreciation.[9] BEA focuses on depreciation as the consumption of fixed capital or as a cost of production. Depreciation is viewed as a cost incurred in the production of gross domestic product (GDP), as a deduction in the calculation of business income,

7. Martin N. Baily (1981) argues that the rapid increase in energy prices during the oil embargo rendered certain types of assets obsolete, leading to a decline in the rate of productivity change. A rebuttal to this argument is contained in Hulten, Robertson, and Wykoff (1989).

8. Retirements or discards are assets withdrawn from service.

9. The current BEA treatment of natural disasters in part reflects the absence from the national income and product accounts of an integrated balance sheet and raises another set of issues that will not be discussed here.

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and as a partial measure of the value of services of government fixed assets. BEA's conceptualization of depreciation as such is generally consistent with the work of Fabricant (1938, 12–14) and Denison (1957) and the definition of depreciation in the System of National Accounts (SNA).[10] It is also consistent with the concept of the consumption of fixed capital in the context of estimates of sustainable product, or income, where depreciation is subtracted from GDP to derive net domestic product and net domestic income—a rough measure of that level of income or consumption that can be maintained while leaving capital intact.

The essential difference between BEA's depreciation definition and the definition in this article is the treatment of obsolescence. Obsolescence shows up in the national income and product accounts (NIPA's) in at least two ways. One, BEA depreciation estimates include obsolescence through a service-life effect and through the use of depreciation rates estimated from used-asset prices unadjusted for the effects of obsolescence. Assets may be retired early, when they are still productive, because of obsolescence; this is reflected in BEA's depreciation estimates, as service lives affect the estimate of the geometric rates of depreciation used for most assets.[11] Two, obsolescence is reflected in the constant-quality prices that are part of the NIPA's.[12] In addition to the theoretical usefulness of separating the effects of obsolescence from those associated with the physical deterioration of an asset, BEA's use of hedonic and other quality-adjusted price indexes suggests an empirical reason why greater attention may have to be paid to the effects of obsolescence. In its future work, BEA plans to conduct studies focusing on quality change and obsolescence.[13]

10. The SNA defines depreciation as "the decline, during the course of the accounting period, in the current value of the stock of fixed assets owned and used by a producer as a result of physical deterioration, normal obsolescence, or normal accidental damage" (*SNA* 1993, 147, 6.179).

11. See the next section and "BEA default geometric-depreciation rates."

12. See Oliner (1993, 55) for a discussion of constant-quality prices and depreciation in the context of a study of mainframe computers. BEA is using Oliner's partial depreciation measure, which is consistent with BEA's hedonic price index for computers.

13. The author of this article and BEA both agree that further work needs to be done to quantify obsolescence and to identify the impact of obsolescence and quality change on national income accounting measures. Further consideration of the major issues surrounding the definitional differences described above could be one component of future work on obsolescence and quality change.

Specifics of BEA Methodology and Hulten-Wykoff Methodology

Specifics of BEA methodology[14]

As noted, BEA has used a straight-line pattern of depreciation since the 1950's. Depreciation is an equal dollar amount per period over the lifetime of the asset.

Retirements for a group of assets depended on the group's average service life and on the pattern of retirements (the distribution of retirements around the mean service life).

Once retirements have begun, the combined effects of straight-line depreciation and retirements result in a depreciation pattern that is more accelerated than a straight-line depreciation pattern. An accelerated depreciation pattern assumes higher dollar depreciation in the early years of an asset's service life than in the later years.

Mean service lives are estimated from a wide variety of sources, both government and private. In general, information is not available to provide different mean service lives by industry. Production-type manufacturing equipment is a notable exception. Similarly, in general, information is not available on changes in mean service lives over time, if they do occur; aircraft is one exception to this general rule. When a mean service life is changed, the new mean service life is applied only to new assets. There is no effect on depreciation of existing assets.

A modified S-3 Winfrey curve was used for most assets to estimate the pattern of actual retirements around the mean; a L-2 Winfrey curve was used for consumer durables (Winfrey 1967; Russo and Cowles 1980). The S-3 curve is a bell-shaped distribution centered on the mean service life of the asset. It was used for private nonresidential equipment (except autos) and structures, private residential equipment, and government residential equipment and structures. The L-2 curve is an asymmetrical distribution with heavier discards before the mean service life. Both sets of Winfrey curves were modified to reflect different assumptions about when retirements begin and end as a percentage of the mean service life of the asset.

Expected obsolescence implicitly enters into BEA estimates of depreciation through shorter asset lifetimes and through the retirement pattern previously used. The mean service life of a class of assets could be shorter because obsolescence

14. See BEA (1993).

has occurred consistently over the historical period or is reflected in the occasional revision of mean service lives. In addition, as obsolescence can result in early retirement, the modified Winfrey patterns may have been picking up some of the obsolescence effects.[15]

BEA adjusts depreciation estimates to capture the effect of natural disasters that destroy large amounts of fixed capital.

Specifics of Hulten-Wykoff methodology[16]

Initially, Hulten and Wykoff made no assumption about what form depreciation patterns take. Instead, they estimated used-asset age-price profiles for eight producers' durable equipment or nonresidential equipment assets, which they called type A assets, with a Box-Cox model (Box and Cox 1964).[17] They tested to see whether the resulting depreciation patterns most nearly resembled patterns arising from one-hoss-shay, straight-line, or geometric efficiency patterns.[18]

There is a direct correspondence between efficiency patterns and depreciation patterns. Present and future declines in efficiency result in depreciation or declines in the value of an asset as it ages. A one-hoss-shay efficiency pattern assumes that no loss in efficiency occurs until the asset is retired. The corresponding depreciation pattern is less accelerated than a straight-line pattern of depreciation with lower dollar depreciation in the early years of an asset's service life than in the later years. A straight-line efficiency pattern assumes equal declines in efficiency in each period over the life of the asset. The corresponding depreciation pattern, which has higher dollar depreciation in the early years of an asset's service life than in the later years, is accelerated relative to a straight-line pattern of depreciation. A geometric efficiency pattern also gives rise to an accelerated depreciation pattern. The geometric pattern is a special case because the efficiency pattern and the depreciation pattern have the same form, with declines in efficiency and depreciation occurring at the same rate.

Hulten and Wykoff concluded that depreciation patterns for eight assets are accelerated. In addition, although all three patterns were rejected statistically, they concluded that the depreciation pattern was approximately geometric in all cases. In 1977, the eight producers' durable equipment or nonresidential equipment assets—tractors, construction machinery, metalworking machinery, general industrial equipment, trucks, autos, industrial buildings, and commercial buildings—amounted to 55 percent of investment expenditures on producers' durable equipment and 42 percent of spending on nonresidential structures. They assumed that the depreciation pattern for the remaining 24 out of 32 producers' durable equipment and nonresidential structures NIPA classes contemporary to their study was geometric. These were categorized as type B or type C assets.

Since used-asset prices reflect only surviving assets (a censored-sample problem), Hulten and Wykoff weighted used-asset prices by the probability of survival before estimating the depreciation patterns.[19] Weighted used-asset prices reflect surviving and retired assets. The probability of survival, the weight, depends upon the mean service lives of assets and on the deviation of retirements around the mean service life. Mean service lives were assumed to be 100 percent of *Bulletin F*. An L_0 Winfrey curve was used to estimate the pattern of actual retirements about the mean for structures. The L_0 curve is an asymmetrical distribution that allows for some assets to survive to very old ages relative to the mean service lives. An S-3 curve, described above, was used for metalworking machinery and general industrial machinery.[20] Finally, an assumption was needed about the net value of an asset (scrappage value less demolition costs) to complete the transformation of a surviving-asset sample to an estimated sample of both surviving and retired assets. Hulten and Wykoff assumed that the net value of an asset retired from service was on average zero. The used-asset prices inputted to the Box-Cox model were thus weighted and net value adjusted. As a result, the depreciation estimates from the Box-Cox model reflected both efficiency declines and retirements.

15. Young and Musgrave maintain that expected obsolescence should be charged when the asset is retired (Young and Musgrave 1980, 34, figure 1.1). BEA's methodology does not do this.

16. The information on Hulten-Wykoff methodology is taken from three sources: Hulten and Wykoff (1981a and 1981b) and Wykoff and Hulten (1979).

17. Age-price profiles map ages of assets with their prices.

18. An efficiency pattern is a pattern describing the productive services from an asset as it ages. The efficiency of a new asset is typically normalized to 1.0. As an asset declines in efficiency, its efficiency has a value of less than one.

19. The censored-sample problem can be illustrated by the following example. Suppose that two cars are bought new in 1980. By 1990, one is still in service and one has been junked. The one that is still is service is sold as a used car, say for $1,000. If we take the used-car sales price to be representative of all cars bought new in 1980, we would assume that the 1990 value of all cars bought new in 1980 is $2,000. In fact, the 1990 value of the cars is $1,000 or on average $500 per car. Hulten and Wykoff, by weighting used-asset prices by the probability of survival, are calculating the used-asset price equivalent of an average 1990 value of $500 per car bought new in 1980. Their procedure assumes that the used-asset price of nonsurvivors is zero.

20. BEA at the time typically assumed mean service lives were 85 percent of *Bulletin F* and used a modified S-3 Winfrey curve for most assets except consumer durables.

The used-asset prices were adjusted for the effects of inflation on these prices by the inclusion of a time variable in the Box-Cox estimation procedure.

With a geometric pattern, the rate of depreciation, δ, depends only on the declining-balance rate and the asset's service life:

$$\delta_G = \frac{R}{T}$$

where T is the average asset service life from *Bulletin F*, and R is the estimated declining-balance rate.[21] δ_G is constant over the lifetime of the asset, and depreciation is higher in the early years of an asset's service life. With a geometric pattern, depreciation, $d_{i,G}$, for 1 dollar of investment

$$d_{i,G} = \delta_G(1-\delta_G)^{i-1},$$
$$i = 1, 2, 3, \ldots$$

where i is the age of the asset. The higher the declining-balance rate, R, the higher the geometric rate of depreciation, δ_G, and the higher depreciation is in the early years of an asset's service life. This contrasts with a straight-line depreciation pattern. With a straight-line pattern:

$$d_{i,SL} = 1/n,$$
$$i = 1, 2, 3, \ldots, n$$

where i is the age of the asset, and n is the retirement age of the asset, which can be distributed about the average service life of the asset, T. δ for a straight-line pattern:

$$\delta_{i,SL} = \frac{1}{n-(i-1)}$$
$$i = 1, 2, 3, \ldots, n$$

where i and n are, as before, increases with the age of the asset.

For some assets, called type B assets, empirical research by others and the judgement of Hulten and Wykoff were used to estimate δ. For the remaining assets, called type C assets, an average declining-balance rate R was estimated from the 8 assets and combined with information on the lifetime of the 24 assets still remaining to produce an asset-specific δ. Hulten and Wykoff determined that, on average, the declining-balance rate for producers' durable equipment was 1.65, and for private nonresidential structures, 0.91.[22] In both cases, the declining-balance rate was estimated on average to be significantly less than a double-declining-balance rate ($R = 2$).[23]

Summary of Empirical Research

Empirical research on depreciation has been conducted on most asset categories included in the U.S. national income and wealth accounts. These studies can be broadly classified into studies that looked at market-based used-asset prices to estimate depreciation and those that did not.[24]

Research based on used-asset prices

A large number of studies have employed price data from individual market transactions, dealers' price lists, insurance records, or rental prices to estimate actual depreciation. Table 2 lists these studies. Two studies cover a large number of asset classes or industries: Hulten-Wykoff covering U.S. assets and Koumanakos-Hwang covering Canadian assets. Of the 29 studies listed, half deal

21. The rate of declining-balance depreciation is the multiple of the comparable straight-line rate used to calculate the geometric rate of depreciation. For example, a 1.65 declining-balance depreciation rate refers to a geometric rate of depreciation of 1.65/L, where L is the service life of the asset in years and 1/L is the straight-line rate.

22. With truncation, 0.9 was frequently used in the actual calculations.

23. At the time of Hulten and Wykoff's research, researchers commonly assumed that the appropriate declining-balance rate was double declining.

24. This section draws heavily on three previous surveys of empirical research on depreciation. They are Hulten and Wykoff (1981b), Jorgenson (1996), and Brazell, Dworin, and Walsh (1989).

Table 2.—Studies of Depreciation Based on Used-Asset Prices

Assets	Studies [1]
32 classes of assets	Hulten and Wykoff 1981b
27 classes of assets or 43 industries	Koumanokos and Hwang 1988
Automobiles	Ackerman 1973; Cagan 1971 Chow 1957, 1960 Ohta and Griliches 1975 Ramm 1970 Office of Tax Analysis 1991a Wykoff 1970, 1989
Trucks	Hall 1971 Office of Tax Analysis 1991b
Farm tractors	Griliches 1960 Penson, Hughes, and Nelson 1977 Penson, Romain, and Hughes 1981 Perry and Glyer 1988
Ships:	
Oil tankers	Cockburn and Frank 1992
Fishing boats	Lee 1978
Residential housing	Chinloy 1977 Malpezzi, Ozanne, and Thibodeau 1987
Office buildings	Taubman and Rasche 1969
Computers	Jorgenson and Stiroh 1994
Computer peripheral equipment	Oliner 1992
Mainframe computers	Oliner 1993
Machine tools	Beidelman 1976; Oliner 1996
Industrial machinery and equipment	Shriver 1988
Scientific instruments	Office of Tax Analysis 1990

1. See the list of references at the end of this article.

with mechanized vehicles (automobiles, trucks, or farm tractors). Data on used prices are readily available for these assets. Three studies each investigate depreciation for computers and real estate. Two studies each cover ships (fishing boats and oil tankers) and machine tools. One study, by Shriver, deals with industrial machinery and equipment. The remaining study is a study of scientific instruments by the Office of Tax Analysis. A variety of methodological approaches were used. They include hedonics, an analysis of variance, and Box-Cox or polynomial forms for the estimated equation.[25]

General issues affecting used-asset-price studies

All used-asset-price studies are potentially biased, because the asset sample may not be representative of the population as a whole or because economic conditions affect prices.[26] First, asset samples normally represent only surviving assets. Second, surviving-asset samples or their sale prices may not represent the population of surviving assets. Third, changes in economic conditions, including taxes and interest rates, may affect used-asset prices. Finally, a used-asset price may be affected by the value of an associated input.

If asset samples represent only surviving assets, then age-price profiles of used-asset samples underestimate depreciation for the population as a whole because retirements are not included.[27] Hulten and Wykoff estimated for commercial and industrial buildings that such an error would reduce depreciation estimates by more than one-half. There are two possible solutions to this problem. One, retirements can be added to depreciation, similar to the way BEA modifies its straight-line depreciation pattern to allow for the pattern of retirements. Two, a censored-sample adjustment can be made to the used-asset prices before the depreciation pattern is estimated, in a manner similar to Hulten and Wykoff. It is important for the researcher and user to know whether the depreciation pattern includes retirements (as in Hulten-Wykoff) or excludes retirements (as in the BEA accounts). A straight-line pattern excluding retirements will no longer be a straight-line pattern once retirements are included, and a geometric pattern excluding retirements will no longer be a geometric pattern once retirements are included.

Surviving-asset samples or their prices may not represent the population of surviving assets. Business may put up for sale their superior or inferior assets. Assets may be worth more or less to the buyers than to the sellers. Finally, buyers may not be able to accurately perceive the value of the assets for sale.

It is not clear what is the extent or direction of a possible surviving-asset-sample bias. Whether or not businesses put up for sale their superior or inferior assets depends on whether they are trying to maximize the proceeds from such sales or to sell off less desirable or obsolete assets. Differences in buyer-versus-seller asset value may bias used-asset prices in either direction as well. A declining business may be selling off an asset that represents idle capacity and that another business in the same industry could fully utilize or an asset that has limited use to businesses in other industries. Assets may be configured to meet the needs of a particular business so that they are more valuable to their seller than to their buyer. Finally, buyers may underestimate or overestimate the value of used assets for sale.

The lemons hypothesis maintains that the value of assets for sale will underestimate the value of all assets in the stock (Ackerlof 1970). It argues that a disproportionate number of assets sold will be lemons, particularly if inspection by buyers does not reveal which assets are lemons. Under the lemons hypothesis, buyers will assume that assets for sale are lemons; therefore, they will offer lower prices for all used assets. Sellers have an incentive to offer lemons, since they will be paid lemons prices for both lemons and more desirable assets. Therefore, buyers' assumptions are validated. If sellers have superior assets for sale, the incentive will be to sell these privately to obtain a reasonable price for the asset. Used-asset prices will be less than the average price of the stock of assets because of the disproportionate number of lemons for sale and because buyers will assume all used assets are lemons. The existence of asymmetric information between buyer and seller is crucial in this hypothesis. Depreciation would be overestimated if inferred from used-asset prices because the average price for assets in the stock would be underestimated.

Hulten and Wykoff argue that most assets are sold in markets with professional buyers who frequently buy and sell assets. Furthermore, these buyers, who have the knowledge and expertise

25. Triplett (1989, 128) defines a hedonic function as a relation between prices of varieties or models of heterogeneous goods—or services—and the quantities of characteristics contained in them. A Box-Cox model is a model that transforms the form of the variables in the model (Box and Cox 1964).

26. The authors who have addressed the question of sample bias in used-asset-price studies include Triplett (1996), DeLeeuw (1981), Hulten and Wykoff (1981b) and Boskin, Robinson, and Roberts (1989).

27. An example illustrating this point is given in footnote 19.

to identify lemons, are not affected by asymmetric information. Hulten and Wykoff tested for the existence of a lemons bias by comparing the depreciation profiles of assets that might have a lemons bias to an asset that arguably would not (heavy construction equipment). Heavy construction equipment is commonly sold at the end of a construction project and repurchased at the beginning of the next construction project. They found that the depreciation profiles for assets possibly with and without a lemons bias were both approximately geometric; therefore, they concluded that the lemons bias is unimportant in depreciation estimates.

Changes in tax laws, interest rates, and other economic conditions might affect the value of secondhand assets independently of any sample bias problems. For example, changes in allowable tax depreciation taken for corporate income tax purposes may change the prices that businesses are willing to pay for used assets. Changes in interest rates may affect the cost of borrowing to finance asset acquisition. Finally, demand conditions determine whether businesses are expanding or contracting, affecting both the demand for and supply of used assets. Obsolescence can also affect used-asset prices, as, for example, discussed above in the context of the energy crisis.[28]

If changes in tax laws, interest rates, and other economic conditions significantly affect the value of secondhand assets, age-price profile or retirement patterns would change over time unless these changes are counterbalanced by offsetting effects. The question of whether the age-price profile or retirement patterns change over time has been discussed in the context of several empirical studies. Hulten and Wykoff (1981a, 1981b) tested the stability of the age-price profiles for office buildings, one of their largest samples. In almost all cases, estimates of the rate of depreciation were stable over time. Hulten, Robertson, Wykoff, and Shriver reached similar conclusions. Hulten, Robertson, and Wykoff (1989) looked at the effect of the energy crisis on used-asset prices for four types of used machine tools and five types of construction equipment. Shriver (1986b) looked at the rates of economic depreciation for industrial machinery and equipment in 3 different years with different demand characteristics. Cockburn and Frank (1992) found in a study of oil tankers that economic depreciation or decay was largely unaffected by economic conditions, but that retirements are quite sensitive to economic conditions. Powers (1988), using book values, found that retirements for two-digit Standard Industrial Classification manufacturing industries exhibit a cyclical pattern. Taubman and Rasche (1971) and Feldstein and Rothschild (1974) discuss in general the impact of variables that change over time on age-price profiles. Taubman and Rasche (1969) in their study of office buildings found that changes in rents and tax laws had little effect on depreciation rates. In most cases, studies have not been done on different vintages of assets to determine whether age-price profiles do significantly change over time. Therefore, there is no definitive answer to the question of whether age-price profiles shift over time.

In addition, used-asset prices can reflect the fact that it may be difficult for buyers to separate the value of an asset such as a building from the value of the land on which it sits (the shopping-mall effect). The building may be incorrectly valued because of the value of the site or the land on which it sits.

Summary of research based on used-asset prices

Most of the used-asset studies do not directly deal with possible biases arising from samples, such as those discussed in the previous section (see table 2). In any case, the extent and the net direction of the possible biases are unclear. Four studies—Hulten-Wykoff, Koumanakos-Hwang, Oliner (1996), and Perry-Glyer—did adjust used-asset prices downward to reflect zero valuation of retired assets in the original cohort. In addition, the Cockburn-Frank paper illustrates how misleading it can be to estimate patterns of depreciation without accounting for retirements.

Of the two studies covering a large number of asset classes or industries, Hulten and Wykoff's has already been discussed. The Koumanakos-Hwang study of Canadian assets, the other study, bears a number of similarities to the Hulten-Wykoff study. It used a modified Box-Cox model to estimate depreciation for up to 27 different asset classes for manufacturing and nonmanufacturing separately. Depreciation for building construction and machinery and equipment for up to 43 different industries were calculated from a weighted average of the depreciation functions of individual assets. Some depreciation estimates were done for engineering construction as well. Koumanakos and Hwang conclude that depreciation patterns for individual assets are approximately geometric for both the manufacturing

28. For example, see footnote 7.

and nonmanufacturing sectors, with the degree of convexity more pronounced in the manufacturing sectors.[29] At the industry level, they conclude that the geometric pattern is preferred because it is the simplest pattern that gives a best approximation of the actual data.

The 15 papers on motorized vehicles (automobiles, pickup trucks, or farm tractors) can be distinguished by whether a depreciation pattern was assumed, whether the validity of such assumptions were tested econometrically, and whether any general statements were made about the pattern of the used asset-price profile observed or estimated.

Ackerman (1973) and Cagan (1971) for automobiles and Griliches (1960) for farm tractors assumed a geometric rate of depreciation, and in the case of Ackerman and Cagan, the assumption allowed for the separate identification of quality. None of these models were tested to see if the assumption of a geometric rate was appropriate.

Seven studies—one for trucks (Hall 1971), three for automobiles (Ohta and Griliches 1975; Wykoff 1970, 1989), and three for farm tractors (Penson, Hughes, and Nelson 1977; Penson, Romain, and Hughes 1981; Perry and Glyer 1988)—tested the appropriateness of a geometric assumption. With the exception of the two studies by Penson and others and one by Perry-Glyer, these studies concluded that although the assumption of a geometric rate was not proven, that a geometric rate, in the words of Hall (1971, 258), "is probably a reasonable approximation for most purposes." Perry and Glyer found in their econometric model, which excluded tractor care and usage, that depreciation rates were constant over time. However, they found that depreciation rates were not constant when these variables were omitted. In their two studies, Penson and others estimated from engineering data that the pattern of productive-capacity depreciation for farm tractors lies in between straight-line and one-hoss-shay. However, if productive-capacity depreciation is one-hoss-shay, depreciation as defined in this article follows a concave, or bowed-away-from-the-origin, pattern.[30] Some researchers found that the first-year decline in asset prices was significantly greater than the decline suggested by a geometric rate (Wykoff 1970; Ackerman 1973), but question whether listed prices accurately represent transactions prices. Ohta and Griliches (1975, 362), though concluding that a geometric assumption is "not too bad an assumption 'on the average'," conclude without empirically testing that actual depreciation occurs at a faster rate with age. There is evidence among the other studies that geometric rates may change over time (Ackerman 1973; Perry and Glyer 1988; Wykoff 1970), but there is no conclusive econometric evidence or consensus about the direction of the change. None of the motorized-vehicle studies performed econometric tests for the existence of other than a geometric depreciation pattern.

Three studies—one for trucks (OTA 1991b) and two for automobiles (OTA 1991a; Ramm 1970)—calculated or econometrically estimated used-asset age-price profiles, but did not report any attempts to determine the general shape of the depreciation pattern. However in each study, in general the age-price profile initially declined more rapidly than it would under a straight-line pattern of depreciation.

Lee (1978) and Cockburn and Frank (1992) studied ships. The Lee study looked at data on the insured value of Japanese fishing boats as a proxy for new- and used-asset prices. The estimated depreciation pattern was geometric in some cases (in general for steel boats) and not in others (in general for wooden boats). Cockburn and Frank concluded that a geometric pattern is an appropriate pattern for surviving-asset age-price profiles, but with proper accounting for retirements as a component of economic depreciation, the pattern of economic depreciation is clearly not geometric. Neither study considered or tested for other commonly used depreciation patterns, such as patterns arising from straight-line or one-hoss-shay efficiency patterns.

Beidleman (1976) and Oliner (1996) estimated depreciation for machine tools or assets sold by machine-tool builders. Beidleman's study of sales by machine-tool builders, which are primarily machine tools, concluded that a negative exponential function was best able to explain asset-value variation in the majority of cases.[31] This supports the assumption of a geometric depreciation pattern. Beidleman tested linear, exponential, reciprocal, polynomial, and parabolic functions as possible alternatives. Oliner concluded that when used-machine-tool prices are adjusted

29. A convex depreciation pattern is bowed towards the origin in a graph of price versus age.

30. Productive-capacity depreciation is measured by the additions to productive capacity required to maintain productive capacity at a constant level. If an asset does not decline in efficiency or productive services yielded over its lifetime until it is retired, (the lightbulb example), depreciation as defined in this article still occurs because as the asset ages, it is getting closer to its retirement (or light-going-out) date. The present value of future declines in efficiency increases or depreciation occurs even if there is no current decline in efficiency.

31. A negative exponential function estimates a geometric rate of depreciation.

for retirements, the pattern of depreciation is not geometric. However, based on the evidence from machine tools, actual depreciation for metalworking machinery is more rapid during the early years and the pattern more accelerated than BEA formerly had assumed.

Two studies—Chinloy (1977) and Malpezzi, Ozanne, and Thibodeau (1987)—looked at residential real estate and one study—Taubman and Rasche (1969)—looked at commercial real estate. The Chinloy study of sale prices for residential real estate concluded that the hypothesis of a geometric rate of depreciation could not be rejected. The Malpezzi-Ozanne-Thibodeau study on the other hand concluded that the decline in the value of owner-occupied housing with age occurs at an increasing, not a constant, rate but that rents for residential real estate decline with age of the property at a nearly constant or geometric rate. The Taubman-Rasche study of office buildings, in contrast to most other studies of depreciation, concluded that depreciation occurs at a rate slower than straight-line and, in fact, that a depreciation pattern arising from a one-hoss-shay efficiency pattern is a more appropriate pattern. This result may be due to the existence of relatively long-term, fixed-price leases for office buildings.[32]

Three studies measure depreciation of computers or computer peripheral equipment—two by Oliner (1992, 1993) and one by Jorgenson and Stiroh (1994). All three studies assume that the efficiency of assets in this category is constant over time or best described by a one-hoss-shay pattern, but Oliner includes a measure of partial depreciation. Oliner defines partial depreciation as the effect of age on price that is not captured by a hedonic equation and that is unmeasured, because researchers are unable to identify all relevant characteristics. The pattern of partial depreciation appears to be approximately geometric for all the computer peripheral equipment studied, except for disk drives. The pattern of partial depreciation for mainframe computers was decidedly not geometric, because the values of mainframes did not always consistently decline with age. The issue of the appropriate measure of depreciation for computers will be discussed in the section "The New BEA Depreciation Estimates."

Shriver's study of machinery and equipment (1988) concluded that used-asset values decline at a rate that is faster than straight-line depreciation but slower than double-declining-balance depreciation.

The Office of Tax Analysis study of scientific instruments (1990) did not report any attempts to determine the general shape of the depreciation pattern. However, the age-value profile appears to approximate a geometric pattern, even after adjusting for retirements.

Other research

The major approaches used in nonprice-based research on depreciation include a retirement approach, an investment approach, a polynomial benchmark approach, and a factor-demand, or production-model, approach. In addition, there are a number of studies whose primary emphasis is on the estimation of retirement patterns or useful lives.

With a retirement approach, retirements are estimated. These retirements are then applied to an assumed depreciation pattern to derive an estimate of actual depreciation. Former BEA methodology is an example of such an approach, modified with adjustments to reflect natural disasters. Retirements depended upon service lives and the assumed Winfrey distribution of retirements around the mean retirement age. The pattern of depreciation was assumed to be straight-line.

With an investment approach, an investment model is used to estimate depreciation or the pattern of depreciation. Robert Coen (1975, 1980) used a neoclassical investment model to determine which of 4 possible loss-of-efficiency patterns—one-hoss-shay, straight-line, geometric, or sum-of-the-years'-digits—best explained investment flows into 21 manufacturing industries. A one-hoss-shay loss-of-efficiency pattern translates into a depreciation pattern that is less accelerated than straight-line; the other three patterns translate into depreciation patterns that are convex, or bowed towards the origin. For equipment, the best results obtained were from the following patterns: A geometric pattern in 11 industries, a straight-line pattern in 7 cases, and a sum-of-years'-digits in 3 cases. For structures, the best results obtained were from the following patterns: A geometric pattern in 11 industries, a straight-line pattern in 5 industries, a sum-of-years'-digits in 3 industries, and a one-hoss-shay pattern in 2 industries. Coen (1980, 125) concludes "that something approximating geometric decay rather than straight-line loss of efficiency is typical of capital used in manufacturing."

32. Leases are payments for office building services, most likely reflecting productive capacity (see footnote 30), not the present value of future (post-lease) declines in efficiency.

The polynomial benchmark approach begins with the perpetual inventory method of estimating capital stock:

$$K_t = I_t + (1 - \delta)K_{t-1},$$

where K_t is capital stock, I_t is gross investment, and δ is the constant rate of depreciation under a geometric assumption. By repetitively substituting this expression for prior periods' capital stock, an expression is derived that depends only on gross investment, δ, and the initial or benchmark capital stock and the final capital stock, K_t. A parametric estimate for δ can then be determined with an econometric model of investment and capital stock. These studies routinely assume that the pattern of depreciation is geometric. They do not address the question of an appropriate pattern for depreciation, only the appropriate geometric rate.

The factor-demand, or production-model, approach estimates a rate of depreciation affecting capital entering into the demand for factors or the production function directly. Nadiri and Prucha (1996) looked at the demands for labor and materials in the manufacturing sector that depend on the level of output and the capital stock of research and development (R&D) and other types of capital. These two factor-demand equations plus the perpetual inventory equations for R&D and other types of capital are used in a system of equations to estimate the geometric rate of depreciation for R&D and other types of capital. Doms (1996) substituted an investment stream into a value-added production function for a group of steel plants to estimate the efficiency pattern of assets. He estimated three different efficiency schedules—one assuming a geometric pattern, one using a Box-Cox model, and one using a polynomial model. Even though the Box-Cox and polynomial models can exhibit other than a geometric pattern of depreciation, in both cases the best model fits were obtained from geometric-like patterns.

There were a number of studies related to depreciation undertaken by the Treasury Department.[33] Forty-six studies of survival probabilities were undertaken by the Office of Industrial Economics over the 1971 to 1981 period. Of these studies, 27 provide information on useful lives. These studies provide estimates of the actual retention periods for the assets covered. It is possible that more information from these studies could be incorporated into other depreciation studies. Later, under the auspices of the Office of Tax Analysis, a used-asset-price approach was employed. These studies, listed in table 2, are discussed in the previous section.

33. See Brazell, Dworin, and Walsh (1989) for a summary of 27 of these studies.

The New BEA Depreciation Estimates

Empirical basis for the new BEA methodology: A summary

The largest and most complete studies of depreciation are those of Hulten and Wykoff and Koumanakos and Hwang, followed by that of Coen. Hulten and Wykoff (1981a, 1981b) and Koumanakos and Hwang (1988) concluded that the pattern of geometric depreciation is approximately geometric. Coen (1975) concluded that a geometric pattern provided the best fit in the majority of manufacturing industries studied. In addition, he concluded that a convex pattern (geometric being a special case) provided the best fit for all manufacturing industries for equipment and all but two manufacturing industries for structures.

The results of the other depreciation studies based on used-asset prices in table 2 in general support an accelerated pattern of depreciation. Most conclude that a geometric pattern is preferred, none determine that overall a straight-line pattern is the best choice, and with the exception of computers, only a few maintain that some other pattern is the appropriate pattern.

The Bureau of Labor Statistics (BLS) uses a hyperbolic efficiency function that is concave, or bowed away from the origin, rather than a geometric efficiency function that is convex, or bowed towards the origin (Harper 1982; Gullickson and Harper 1987; BLS 1983, n.d.).[34] BLS tested their hyperbolic efficiency function with the Hulten-Wykoff Box-Cox estimated age-price functions by constructing the age-price function corresponding to their hyperbolic efficiency function. BLS found there was no statistically significant difference between the geometric and their hyperbolic form.[35] However, the maintained hypothesis of a hyperbolic age-price function that

34. The hyperbolic function is a general function whose special cases include the one-hoss-shay and straight-line cases. A hyperbolic function can also approximate a geometric function. The particular form of the hyperbolic function used by BLS is concave, being intermediate between one-hoss-shay and straight-line.

35. Because both the geometric and the hyperbolic efficiency functions have an age-price counterpart that is convex, or bowed towards the origin, the likelihood of there being no statistical difference between the age-price functions is increased. Note that under a geometric assumption, the efficiency function and the age-price function are identical and bowed towards the origin.

corresponds to a concave hyperbolic efficiency function was rejected.[36]

One disadvantage of the hyperbolic function is that age-price functions estimated from a hyperbolic function (or alternatively, hyperbolic functions estimated from an age-price function) require an assumption to be made about a real discount rate. The geometric function does not require such an assumption.

Geometric depreciation as the default

There are several arguments for the adoption of a geometric pattern for depreciation as the default.[37] First, the empirical evidence is that a geometric depreciation pattern is a better approximation to reality than a straight-line pattern and is at least as good as any other pattern. Second, estimates of an appropriate default geometric rate of depreciation are readily available from Hulten and Wykoff (1981a, 1981b). Third, the geometric pattern is a simple default rule. Finally, the geometric pattern is one that can readily be used if and when a balance sheet or a production account is implemented by BEA, thereby minimizing future potential revisions.[38]

BEA default geometric-depreciation rates

The new BEA rates of economic depreciation are listed in table 3. All assets except for computers and computer peripherals, nuclear fuel, autos, and missiles are depreciated at a geometric rate.

These rates are derived from the Hulten-Wykoff estimates. If new estimates of service lives have become available since the original Hulten-Wykoff research (Hulten and Wykoff 1981b; Wykoff and Hulten 1979), the geometric rate, δ, is recalculated from the earlier formula by substituting in the new service life:

$$\delta_{new} = \frac{R_{old}}{T_{new}},$$

or equivalently,

$$\delta_{new} = (T_{old}/T_{new})\,\delta_{old}.$$

Similarly, whenever BEA uses different service lives for different time periods, the geometric rate of depreciation, δ, varies and is recalculated with the above formula.

The formula above presumes that the declining-balance rate R is not changing. Recall the question previously discussed of whether age-price profiles or retirement patterns have been changing over time. In addition, since T's or service lives were used to center the retirement distribution when the Hulten-Wykoff used-asset prices were adjusted to correct for censored-sample bias, it presumes that a "re-centering" on the new service life would not significantly affect the estimate of R.[39]

Table 3 documents how the geometric rates of depreciation were calculated on the basis of the declining-balance rate and the service life of the asset as well as indicating the Hulten-Wykoff asset type. Hulten and Wykoff classified assets into one of three types—A, B or C (Hulten and Wykoff 1981b; Wykoff and Hulten 1979). Hulten and Wykoff had extensive data on type A assets. These data were used to estimate geometric rates of depreciation. For type B assets, there were some existing studies on depreciation, or some data existed. Hulten and Wykoff concluded that defensible estimates of the rate of geometric depreciation could not be generated based solely on the data. They used the results of empirical research by others—the treatment of depreciation by BEA, Dale Jorgenson, BLS, and Jack Faucett Associates (1973)—and their own judgement to determine the geometric rate of depreciation for type B assets on a case by case basis. For type C assets, Hulten and Wykoff had no data whatsoever. The average best-guess-assumption rates of declining-balance and service lives were used to calculate the geometric rate of depreciation as described in "Specifics of Hulten-Wykoff methodology" (Wykoff and Hulten 1979, 30–38).

Computers and computer peripherals, nuclear fuel, autos, and missiles

An alternative approach to estimating depreciation is used when detailed data are currently available or when a geometric pattern seems inappropriate.

For computers and computer peripherals, Oliner's studies provide a solid base for

36. As noted earlier in "Specifics of Hulten-Wykoff methodology," Hulten and Wykoff tested three age-price functions—one-hoss-shay, straight-line, and geometric. In each case, the maintained hypothesis was rejected.

37. As previously noted, a geometric pattern of depreciation will be used for all assets except for computers and computer peripherals, missiles, nuclear fuel, and autos.

38. This article contains only a brief explanation of this theoretical point. The most complete explanation is presented in Triplett (1997), but the reader should also refer to Jorgenson (1974, 1996). Triplett (1997, 31) discusses "the distinctions between the capital data needed for production analysis .... and the capital data needed for income and wealth accounting," concluding that "the crucial distinctions are between the wealth capital stock and the productive capital stock and between two related yet different declines in a cohort of capital goods as the cohort is employed in production—deterioration, the decline in productiveness or efficiency of the cohort, and depreciation, the decline in the cohort's value." Replacement is the term used by Jorgenson to describe the investment necessary to offset the effects of what Triplett calls deterioration. In general, only when depreciation is geometric is the value of replacements equal to depreciation. This is because under a geometric assumption, the efficiency function and the age-price function are identical.

39. This is one of the issues discussed in Hulten and Wykoff (1996).

Table 3.—BEA Rates of Depreciation, Service Lives, Declining-Balance Rates, and Hulten-Wykoff Categories

Type of asset	Rate of depreciation	Service life (years)	Declining-balance rate	Hulten-Wykoff category [1]
Private nonresidential equipment				
Office, computing, and accounting machinery [2]:				
Before 1978	0.2729	8	2.1832	B
1978 and later	.3119	7	2.1832	B
Communications equipment:				
Business services [3]	.1500	11	1.6500	C
Other industries [3]	.1100	15	1.6500	C
Instruments [4]	.1350	12	1.6203	C
Photocopy and related equipment [5]	.1800	9	1.6203	C
Nuclear fuel [6]	....	4	....	....
Other fabricated metal products [7]	.0917	18	1.6500	C
Steam engines and turbines [8]	.0516	32	1.6500	C
Internal combustion engines [8]	.2063	8	1.6500	C
Metalworking machines [9]	.1225	16	1.9600	A
Special industrial machinery, n.e.c.	.1031	16	1.6500	C
General industrial, including materials handling equipment	.1072	16	1.7150	A
Electrical transmission, distribution, and industrial apparatus	.0500	33	1.6500	C
Trucks, buses, and truck trailers:				
Local and interurban passenger transit [10]	.1232	14	1.7252	A
Trucking and warehousing; and auto repair, services, and parking [10]	.1725	10	1.7252	A
Other industries	.1917	9	1.7252	A
Autos [11]	....	....	....	....
Aircraft:				
Transportation by air, depository institutions, and business services:				
Before 1960	.1031	16	1.6500	C
1960 and later	.0825	20	1.6500	C
Other industries:				
Before 1960	.1375	12	1.6500	C
1960 and later	.1100	15	1.6500	C
Ships and boats	.0611	27	1.6500	B
Railroad equipment	.0589	28	1.6500	C
Household furniture and fixtures [12]	.1375	12	1.6500	C
Other furniture [12]	.1179	14	1.6500	C
Farm tractors [13]	.1452	9	1.3064	A
Construction tractors [13]	.1633	8	1.3064	A
Agricultural machinery, except tractors	.1179	14	1.6500	C
Construction machinery, except tractors	.1550	10	1.5498	A
Mining and oil field machinery	.1500	11	1.6500	C
Service industry machinery:				
Wholesale and retail trade [14]	.1650	10	1.6500	C
Other industries [14]	.1500	11	1.6500	C
Household appliances [15]	.1650	10	1.6500	C
Other electrical equipment [16]	.1834	9	1.6500	C
Other [4]	.1473	11	1.6230	C
Private nonresidential structures				
Industrial buildings	.0314	31	.9747	A
Mobile offices [17]	.0556	16	.8892	A
Office buildings [17]	.0247	36	.8892	A
Commercial warehouses [17]	.0222	40	.8892	A
Other commercial buildings [17]	.0262	34	.8892	A
Religious buildings	.0188	48	.9024	C
Educational buildings	.0188	48	.9024	C
Hospital and institutional buildings	.0188	48	.9024	B
Hotels and motels [18]	.0281	32	.8990	B
Amusement and recreational buildings [18]	.0300	30	.8990	B
All other nonfarm buildings [18]	.0249	38	.8990	B
Railroad replacement track [19]	.0275	38	.9480	C
Other railroad structures [19]	.0166	54	.9480	C
Telecommunications [19]	.0237	40	.9480	C
Electric light and power [19]:				
Before 1946	.0237	40	.9480	C
1946 and later	.0211	45	.9480	C
Gas [19]	.0237	40	.9480	C
Petroleum pipelines [19]	.0237	40	.9480	C
Farm [20]	.0239	38	.9100	C
Mining exploration, shafts, and wells:				
Petroleum and natural gas [21]:				
Before 1973	.0563	16	.9008	C
1973 and later	.0751	12	.9008	C
Other [21]	.0450	20	.9008	C
Local transit [22]	.0237	38	.8990	C
Other [22]	.0225	40	.8990	C
Residential capital (private and government)				
1-to-4-unit structures-new [20]	.0114	80	.9100	A
1-to-4-unit structures-additions and alterations [20]	.0227	40	.9100	A
1-to-4-unit structures-major replacements [20]	.0364	25	.9100	A
5-or-more-unit structures-new [20]	.0140	65	.9100	A
5-or-more-unit structures-additions and alterations [20]	.0284	32	.9100	A
5-or-more-unit structures-major replacements [20]	.0455	20	.9100	A
Mobile homes [20]	.0455	20	.9100	A
Other structures [20]	.0227	40	.9100	A
Equipment [23]	.1500	11	1.6500	C
Durable goods owned by consumers [24]				
Furniture, including mattresses and bedsprings	.1179	14	1.6500	B
Kitchen and other household appliances	.1500	11	1.6500	C
China, glassware, tableware, and utensils [25]	.1650	10	1.6500	C
Other durable house furnishings [25]	.1650	10	1.6500	C
Video and audio products, computers and peripheral equipment, and musical instruments [26]	.1833	9	1.6500	B
Jewelry and watches [25]	.1500	11	1.6500	C
Ophthalmic products and orthopedic appliances [25]	.2750	6	1.6500	C
Books and maps [25]	.1650	10	1.6500	C
Wheel goods, sports and photographic equipment, boats, and pleasure aircraft [27]	.1650	10	1.6500	C
Autos [11]	....	....	....	....
Other motor vehicles [28]	.2316	8	1.8530	A
Tires, tubes, accessories, and other parts [28]	.6177	3	1.8530	A
Government nonresidential equipment [29]				
Federal:				
National defense:				
Aircraft:				
Airframes:				
Bombers	.0660	25	1.6500	C
F-14 type	.0868	19	1.6500	C
Attack, F-15 and F-16 types	.0825	20	1.6500	C
F-18 type	.1100	15	1.6500	C
Electronic warfare	.0717	23	1.6500	C
Cargo and trainers	.0660	25	1.6500	C
Helicopters	.0825	20	1.6500	C
Engines	.2750	6	1.6500	C
Other:				
Before 1982	.1179	14	1.6500	C
1982 and later	.1650	10	1.6500	C
Missiles: [30]				
Strategic	....	20	....	....
Tactical	....	15	....	....
Torpedoes	....	15	....	....
Fire control equipment	....	10	....	....
Space programs	....	20	....	....
Ships:				
Surface ships	.0550	30	1.6500	C
Submarines	.0660	25	1.6500	C
Government furnished equipment:				
Electrical	.1834	9	1.6500	C
Propulsion	.0825	20	1.6500	C
Hull, mechanical	.0660	25	1.6500	C
Ordnance	.1650	10	1.6500	C
Other	.1650	10	1.6500	C
Vehicles:				
Tanks, armored personnel carriers, and other combat vehicles	.0825	20	1.6500	C
Noncombat vehicles:				
Trucks	.2875	6	1.7252	C
Autos [31]	....	....	....	....
Other	.2465	7	1.7252	C
Electronic equipment:				
Computers and peripheral equipment [32]	....	....	....	....
Electronic countermeasures	.2357	7	1.6500	C
Other	.1650	10	1.6500	C
Other equipment:				
Medical	.1834	9	1.6500	C
Construction	.1550	10	1.5498	C
Industrial	.0917	18	1.6500	C
Ammunition plant	.0868	19	1.6500	C
Atomic energy	.1375	12	1.6500	C
Weapons and fire control	.1375	12	1.6500	C
General	.1650	10	1.6500	C
Other	.1375	12	1.6500	C
Nondefense:				
General government:				
Computers and peripheral equipment [32]	....	....	....	....
Aerospace equipment	.1100	15	1.6500	C
Vehicles	.4533	5	2.2664	C
Other	.1650	10	1.6500	C
Enterprises:				
U.S. Postal Service:				
Computers and peripheral equipment [32]	....	....	....	....
Vehicles	.3238	7	2.2664	C
Other	.1100	15	1.6500	C
Tennessee Valley Power Authority	.0500	33	1.6500	C
Bonneville Power Authority	.0500	33	1.6500	C
Other	.0660	25	1.6500	C
State and local:				
Power tools, lawn and garden equipment	.1650	10	1.6500	C

estimating depreciation. His depreciation estimates are therefore used. For personal computers, a category of computers for which there are no studies of depreciation, the depreciation-rate estimate is proxied from a computer category he did study (Oliner 1992, 1993).

BEA has information on automobiles from which it has determined depreciation figures for both private nonresidential equipment and consumer durable autos.

For nuclear fuel, a geometric pattern does not seem appropriate. Nuclear fuel is assumed to depreciate at a straight-line rate, not a geometric rate, to reflect the pattern of rotation and replacement of nuclear fuel in the core. A Winfrey S-3 pattern is used to determine retirements.[40]

BEA has decided to continue to use a straight-line pattern of depreciation and Winfrey retirement patterns for missiles, because of the special characteristics of this category of assets.

40. The information on nuclear fuel was obtained from Professor Madeline Feltus of Pennsylvania State University. A reference on nuclear fuel management is Robert Cochran and Nicholas Tsoulfanidis, *The Nuclear Fuel Cycle: Analysis and Management* (LaGrange Park, Illinois: American Nuclear Society, 1990).

Conclusion

The improvement in the methodology used in figuring depreciation is justified on empirical and theoretical grounds. The recent article "Improved Estimates of Fixed Reproducible Tangible Wealth, 1929–95" in the SURVEY OF CURRENT BUSINESS (Katz and Herman 1997) presents and discusses the new capital stock estimates. Results of current and future research can be used to refine and modify the rates listed in table 3, to further question the specific form of the depreciation profile, to adjust for quality differences across vintages, and to update service lives.

References

Ackerlof, George. 1970. "The Market for Lemons." *Quarterly Journal of Economics* (August): 488–500.

Table 3.—BEA Rates of Depreciation, Service Lives, Declining-Balance Rates, and Hulten-Wykoff Categories—Continued

Type of asset	Rate of depreciation	Service life (years)	Declining-balance rate	Hulten-Wykoff category [1]
Miscellaneous metal products	.0917	18	1.6500	C
Agricultural machinery and equipment	.1833	9	1.6500	C
Construction machinery and equipment	.1650	10	1.6500	C
Metalworking machinery and equipment	.1031	16	1.6500	C
General purpose machinery and equipment	.1500	11	1.6500	C
Special industry machinery and equipment	.1500	11	1.6500	C
Integrating and measuring instruments	.1375	12	1.6500	C
Motors, generators, motor generator sets	.0516	32	1.6500	C
Switchgear and switchboard equipment	.0500	33	1.6500	C
Electronic components and accessories	.1833	9	1.6500	C
Miscellaneous electrical machinery	.1375	12	1.6500	C
Calculating and accounting machines	.2357	7	1.6500	C
Typewriters	.2357	7	1.6500	C
Computers and peripheral equipment	....	....	....	....
Machine shop products	.2063	8	1.6500	C
Wood commercial furniture	.1179	14	1.6500	C
Metal commercial furniture	.1179	14	1.6500	C
Household appliances	.1500	11	1.6500	C
Home electronic equipment	.1500	11	1.6500	C
Motor vehicles	.1650	10	1.6500	C
Motorcycles	.1650	10	1.6500	C
Aircraft	.1100	15	1.6500	C
Railroad equipment	.0590	28	1.6500	C
Sporting and athletic goods	.1650	10	1.6500	C
Photographic and photocopying equipment	.1650	10	1.6500	C
Mobile classrooms, mobile offices, etc	.1650	10	1.6500	C
Musical instruments	.1834	9	1.6500	C
Other equipment	.1375	12	1.6500	C
Government nonresidential structures [33]				
Federal, State and local:				
National defense:				
Buildings:				
Industrial	.0285	32	.9100	C
Educational	.0182	50	.9100	C
Hospital	.0182	50	.9100	C
Other	.0182	50	.9100	C
Nonbuildings:				
Highways and streets	.0152	60	.9100	C
Conservation and development	.0152	60	.9100	C
Sewer systems	.0152	60	.9100	C
Water systems	.0152	60	.9100	C
Other	.0152	60	.9100	C

1. This column refers to Hulten-Wykoff categories (Hulten and Wykoff 1981b; Wykoff and Hulten 1979). Type A assets are types of assets for which Hulten and Wykoff specifically estimated age-price profiles. Type B assets are those for which they used empirical research by others and their judgement to estimate the depreciation rate. Type C assets are assets for which they estimated an average declining-balance rate from data for all type A and B assets.
2. The depreciation rate for this type of asset is not used for computers and peripheral equipment. Depreciation rates for these assets are taken from Oliner as described in the text.
3. The declining-balance rate is from the Hulten-Wykoff communications equipment aggregate.
4. Instruments and other private nonresidential equipment, called producer durable equipment by Hulten-Wykoff, are classified by them as type C but appear to be type B as they were given a declining-balance rate of 1.6203.
5. The declining-balance rate is from the Hulten-Wykoff other producer durable equipment aggregate.
6. The depreciation rates for nuclear fuel are based on a straight-line rate pattern and a Winfrey retirement pattern.
7. The declining-balance rate is from the Hulten-Wykoff fabricated metal products aggregate.
8. The declining-balance rate is from the Hulten-Wykoff engines and turbines aggregate.
9. The depreciation rate and service life listed apply to nonmanufacturing industries; the service lives and depreciation rates used for manufacturing industries differ by industry. The Hulten-Wykoff type of asset listed applies to all industries.
10. The declining-balance rate is from the Hulten-Wykoff trucks, buses, and truck trailer aggregate.
11. Depreciation rates for autos are derived from data on new- and used-auto prices.
12. The declining-balance rate is from the Hulten-Wykoff furniture and fixtures aggregate.
13. The declining-balance rate is from the Hulten-Wykoff tractors aggregate.
14. The declining-balance rate is from the Hulten-Wykoff service industry machinery aggregate.
15. The declining-balance rate is set to the Hulten-Wykoff producer durable equipment default.
16. The declining-balance rate is from the Hulten-Wykoff electrical equipment (not elsewhere classified) aggregate.
17. The declining-balance rate is from the Hulten-Wykoff commercial aggregate.
18. The declining-balance rate is from the Hulten-Wykoff other private nonresidential structures aggregate, which consists of buildings used primarily for social and recreational activities and buildings not elsewhere classified.
19. The declining-balance rate is from the Hulten-Wykoff public utilities aggregate.
20. The declining-balance rate is set to the Hulten-Wykoff private nonresidential structures default.
21. The declining-balance rate is from the Hulten-Wykoff mining exploration, shafts, and wells aggregate.
22. The declining-balance rate is from the Hulten-Wykoff other private nonresidential structures aggregate, which consists of streets, dams and reservoirs, and sewer and water facilities.
23. The declining-balance rate is set to the Hulten-Wykoff producer durable equipment default.
24. For all consumer durables except for motor vehicles and parts and computing equipment, the declining-balance rate is set to the Hulten-Wykoff producer durable equipment default.
25. The corresponding Hulten-Wykoff consumer durables category is other.
26. Depreciation rates for computers and peripheral equipment are taken from Oliner as described in the text of the article. The information listed applies to video and audio products and musical instruments. The corresponding Hulten-Wykoff aggregate is radio and television receivers, recorders, and musical instruments. Radio and television receivers, recorders, and musical instruments are classified by Hulten-Wykoff as type B but are indistinguishable from type C as their declining-balance rate is 1.65.
27. The corresponding Hulten-Wykoff consumer durables category is wheel goods, durable toys, sports equipment.
28. The declining-balance rate is from the Hulten-Wykoff motor vehicles and parts aggregate. The declining-balance rate for this category is calculated under the assumption that the service life for consumer durables motor vehicles and parts is equal to the service life for producer durable equipment autos previously used by BEA.
29. For most government nonresidential equipment, the declining-balance rate is set to the Hulten-Wykoff producer durable equipment default. Where possible, the rate is set equal to the rate used for comparable equipment in the private sector.
30. Missiles are depreciated using straight-line patterns of depreciation and a Winfrey retirement pattern.
31. Depreciation rates for government-owned autos are derived from data on autos that are privately owned.
32. Depreciation rates for these assets are taken from Oliner as described in the text of the article.
33. For all government nonresidential structures, the declining-balance rate is set to the Hulten-Wykoff private nonresidential structures default.

Ackerman, Susan Rose. 1973. "Used Cars as a Depreciating Asset." *Western Economic Journal* (December): 463–474.

Baily, Martin N. 1981. "Productivity and the Services of Capital and Labor." In *Brookings Papers on Economic Activity*, vol. 1: 1–50.

Bar-Yosef, Sasson, and Steven Lustgarten. 1994."Economic Depreciation, Accounting Depreciation, and Their Relation to Current Cost Accounting." *Journal of Accounting, Auditing and Finance* 9, no. 1 (Winter): 41–60.

Beidleman, Carl R. 1976. "Economic Depreciation in a Capital Goods Industry." *National Tax Journal* 29, no. 4 (December): 379–390.

Boskin, Michael J., Marc S. Robinson, and John M. Roberts. 1989. "New Estimates of Federal Government Tangible Capital and Net Investment." In *Technology and Capital Formation*, edited by Dale W. Jorgenson and Ralph Landau, 451–483. Cambridge: MIT Press.

Box, George E.P., and David R. Cox. 1964. "An Analysis of Transformations."*Journal of the Royal Statistical Society*, Series B 26, no. 2:211–243.

Brazell, David W., Lowell Dworin, and Michael Walsh. 1989. *A History of Federal Tax Depreciation Policy*. U.S. Department of the Treasury, Office of Tax Analysis Paper No. 64. Washington, DC: Office of Tax Analysis, May.

Bureau of Economic Analysis (BEA), U.S. Department of Commerce. 1993. *Fixed Reproducible Tangible Wealth in the United States, 1925–89*. Washington, DC: U.S. Government Printing Office, January.

Bureau of Labor Statistics (BLS), U.S. Department of Labor. 1983. *Trends in Multifactor Productivity, 1948–81*. Bulletin 2178. Washington, DC: U.S. Government Printing Office, September.

_________. n.d. "Choice of Efficiency Function." Washington, DC: Office of Productivity and Technology.

Cagan, Phillip. 1971. "Measuring Quality Changes and the Purchasing Power of Money: An Exploratory Study of Automobiles." In *Price Indexes and Quality Change*, edited by Zvi Griliches, 215–239. Cambridge: Harvard University Press.

Cartwright, David W. 1986. "Improved Deflation of Purchases of Computers," SURVEY OF CURRENT BUSINESS 66 (March): 7–9.

Chinloy, Peter. 1977. "Hedonic Price and Depreciation Indexes for Residential Housing: A Longitudinal Approach." *Journal of Urban Economics* 4:469–482.

Chow, Gregory C. 1957. *The Demand for Automobiles in the United States*. Amsterdam, The Netherlands: North Holland.

_________. 1960."Statistical Demand Functions for Automobiles and Their Use for Forecasting." In *The Demand for Durable Goods*, edited by Arnold Harberger, 149–178. Chicago: University of Chicago Press.

Cockburn, Iain, and Murray Frank. 1992. "Market Conditions and Retirement of Physical Capital: Evidence From Oil Tankers." Paper presented at the Workshop on the Measurement of Depreciation and Capital Stock at the Conference on Research in Income and Wealth, National Bureau of Economic Research, Washington, DC, June 5, 1992.

Coen, Robert. 1975. "Investment Behavior: The Measurement of Depreciation and Tax Policy."*American Economic Review* 65 (March): 59–74.

_________. 1980. "Depreciation, Profits, and Rates of Return in Manufacturing Industries." In *The Measurement of Capital*. Studies in Income and Wealth, vol. 45, edited by Dan Usher, 121–152. Chicago: University of Chicago Press, for the National Bureau of Economic Research.

DeLeeuw, Frank. 1981. "Discussion." In *Depreciation, Inflation, and the Taxation of Income From Capital*, edited by Charles R. Hulten, 126–129. Washington, DC: The Urban Institute Press.

Denison, Edward F. 1957. "Theoretical Aspects of Quality Change, Capital Consumption, and Net Capital Formation." In *Problems of Capital Formation: Concepts, Measurement, and Controlling Factors*. Studies in Income and Wealth, vol. 19, edited by Franco Modigliani, 215–261. Princeton: Princeton University Press.

Doms, Mark E. 1996. "Estimating Capital Efficiency Schedules Within Production Functions." *Economic Inquiry* 24 (January): 78–92.

Downs, Thomas W., and Keith A. Shriver. 1992. "The Analytical Derivation and Empirical Test of a Tax-Adjusted Fundamental Value Model." *Journal of Accounting Research* 30, Supplement: 77–102.

Fabricant, Solomon. 1938. *Capital Consumption and Adjustment*. New York: National Bureau of Economic Research.

Faucett, Jack G. 1973. "Development of Capital Stock Series by Industry Sector." Washington, DC: U.S. Office of Emergency Preparedness.

Feldstein, Martin S., and Michael Rothschild. 1974. "Towards an Economic Theory of Replacement Investment." *Econometrica* 42, no. 3 (May): 393–423.

Griliches, Zvi. 1960. "The Demand for a Durable Input: U.S. Farm Tractors, 1921–57." In *The Demand for Durable Goods*, edited by Arnold Harberger, 181–207. Chicago: University of Chicago Press.

Gullickson, William, and Michael Harper. 1987. "Multifactor Productivity in U.S. Manufacturing, 1949–83." *Monthly Labor Review* (October): 18–28.

Hall, Robert E. 1971. "The Measurement of Quality Changes from Vintage Price Data." In *Price Indexes and Quality Change*, edited by Zvi Griliches, 240–271. Cambridge: Harvard University Press.

Harper, Michael J. 1982. "The Measurement of Productive Capital Stock, Capital Wealth, and Capital Services." Bureau of Labor Statistics Working Paper 128. Washington, DC: Bureau of Labor Statistics, June.

Hulten, Charles R., and Frank C. Wykoff. 1981a. "The Estimation of Economic Depreciation Using Vintage Asset Prices." *Journal of Econometrics* 15 (April): 367–396.

_________. 1981b. "The Measurement of Economic Depreciation." In *Depreciation, Inflation, and the Taxation of Income from Capital*, edited by Charles R. Hulten, 81–125. Washington, DC: The Urban Institute Press.

_________. 1996. "Issues in the Measurement of Economic Depreciation: Introductory Remarks." *Economic Inquiry* 24 (January): 10–23.

Hulten, Charles R., James W. Robertson, and Frank C. Wykoff. 1989. "Energy, Obsolescence, and the Productivity Slowdown." In *Technology and Capital Formation*, edited by Dale W. Jorgenson and Ralph Landau, 225–258. Cambridge: MIT Press.

Jorgenson, Dale W. 1974."The Economic Theory of Replacement and Depreciation." In *Econometrics and Economic Theory*, edited by Willy Sellekaerts, 189–221. London: Macmillan.

_________. 1989. "Capital as a Factor of Production." In *Technology and Capital Formation*, edited by Dale W. Jorgenson and Ralph Landau, 1–35. Cambridge, MA: MIT Press.

_________. 1996. "Empirical Studies of Depreciation." *Economic Inquiry* 24 (January): 24–42.

Jorgenson, Dale W., and Kevin Stiroh. 1994. "Investment in Computers and U.S. Economic Growth." Cambridge, MA: Harvard University Department of Economics.

Katz, Arnold J., and Shelby W. Herman. 1997. "Improved Estimates of Fixed Reproducible Tangible Wealth, 1929–95." SURVEY OF CURRENT BUSINESS 77 (May): 69–92.

Koumanakos, Peter, and J.C. Hwang. 1988. "The Forms and Rates of Economic Depreciation: The Canadian Experience." Paper presented at the 50th anniversary meeting of the Conference on Research in Income and Wealth, Washington, DC, May 12–14, 1988.

Lee, Bun Song. 1978. "Measurement of Capital Depreciation Within the Japanese Fishing Fleet." *Review of Economics and Statistics* (May): 225–237.

Malpezzi, Stephen, Larry Ozanne, and Thomas Thibodeau. 1987. "Microeconomic Estimates of Housing Depreciation." *Land Economics* 63, no. 4 (November): 372–385.

Marston, Anson, Robley Winfrey, and John C. Hempstead. 1953. *Engineering Valuation and Depreciation*. Ames, Iowa: McGraw-Hill.

Nadiri, M. Ishaq, and Ingmar R. Prucha. 1996. "Estimation of the Depreciation Rate of Physical and R&D Capital in the U.S. Total Manufacturing Sector." *Economic Inquiry* 24 (January): 43–56.

Office of Tax Analysis (OTA). 1990. "Report to Congress on the Depreciation of Scientific Instruments." Washington, DC: Office of Tax Analysis, U.S. Department of the Treasury, March.

_________. 1991a. "Report to Congress on the Depreciation of Business-Use Passenger Cars," Washington, DC: Office of Tax Analysis, U.S. Department of the Treasury, April.

_________. 1991b. "Report to Congress on the Depreciation of Business-Use Light Trucks." Washington, DC: Office of Tax Analysis, U.S. Department of the Treasury, September.

Ohta, Makoto, and Zvi Griliches. 1975. "Automobile Prices Revisited: Extensions of the Hedonic Price Hypothesis." In *Household Production and Consumption*. Studies in Income and Wealth, vol. 40, edited by Nestor E. Terleckyj, 325–398. Chicago: University of Chicago Press, for the National Bureau of Economic Research.

Oliner, Stephen D. 1992. "Estimates of Depreciation and Retirement for Computer Peripheral Equipment." Paper presented at the Workshop on the Measurement of Depreciation and Capital Stock at the Conference on Research in Income and Wealth, National Bureau of Economic Research. Washington, DC, June 5, 1992.

_________. 1993. "Constant-Quality Price Change, Depreciation, and Retirement of Mainframe Computers." In *Price Measurements and Their Uses*, edited by Murray F. Foss, Marilyn E.

Manser, and Allan H. Young, 19–61. Chicago: University of Chicago Press.

_________. 1994. "Measuring Stocks of Computer Peripheral Equipment: Theory and Application." Washington DC: Board of Governors of the Federal Reserve System, May.

_________. 1996. "New Evidence on the Depreciation and Retirement of Machine Tools." *Economic Inquiry* 24 (January): 57–77.

Parker, Robert P., and Jack E. Triplett. 1995. "Preview of the Comprehensive Revision of the National Income and Product Accounts: Recognition of Government Investment and Incorporation of a New Methodology for Calculating Depreciation." SURVEY OF CURRENT BUSINESS 75 (September): 33–41.

Penson, John B., Jr., Dean W. Hughes, and Glenn L. Nelson. 1977. "Measurement of Capacity Depreciation Based on Engineering Data." *American Journal of Agricultural Economics* 59, part 2 (May): 321–329.

Penson, John B., Jr., Robert F.J. Romain, and Dean W. Hughes. 1981. "Net Investment in Farm Tractors: An Econometric Analysis." *American Journal of Agricultural Economics* 63, part 4 (November): 629–635.

Perry, Gregory M., and J. David Glyer. 1988. "An Empirical Investigation of Depreciation Rates for Farm Tractors." Corvallis: Oregon State University.

Powers, Susan G. 1988. "The Role of Capital Discards in Multifactor Productivity Measurement." *Monthly Labor Review* (June) 27–35.

Prucha, Igmar R., and M. Ishaq Nadiri. 1996. "Endogenous Capital Utilization and Productivity Measurement in Dynamic Factor Demand Models: Theory and Application to the U.S. Electrical Machinery Industry." *Journal of Econometrics* 71:343–379.

Ramm, Wolfhard. 1970. "Measuring the Services of Household Durables: The Case of Automobiles." In *Proceedings of the Business and Economic Statistics Section of the American Statistical Association*, 149–158. Washington, DC: American Statistical Association.

Russo, J.G., and H.A. Cowles. 1980. "Revalidation of the Iowa Type Survivor Curves." *The Engineering Economist* 26 (Fall): 1–16.

Shriver, Keith A. 1986a. "A Statistical Test of the Stability Assumption Inherent in Empirical Estimates of Economic Depreciation." *Journal of Economic and Social Measurement* 14:145–153.

_________. 1986b. "The Valuation of Capital Assets During Time Periods Exhibiting Alternative Degrees of Demand for Industrial Machinery and Equipment." *Journal of Economic and Social Measurement* 14:289–310.

_________. 1988. "The Estimation of Current Cost Depreciation," *Advances in Accounting* 6:129–141.

_________. 1994. "The Measurement of Current Cost Data: Implications for Economic Analysis." *Journal of Economic and Social Measurement* 20:1–15.

System of National Accounts, 1993. 1993. Commission of the European Communities, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations, World Bank. Brussels, Luxemborg, Paris, New York, Washington, DC.

Taubman, Paul, and Robert Rasche. 1969. "Economic and Tax Depreciation of Office Buildings." *National Tax Journal* 22, no. 3 (September): 334–46.

_________. 1971. "Subsidies, Economic Lives, and Complete Resource Misallocation." *American Economic Review* 61 (December): 938–945.

Triplett, Jack E. 1989. "Price and Technological Change in a Capital Good." in *Technology and Capital Formation*, edited by D.W. Jorgenson and R. Landau, 128–213. Cambridge: MIT Press.

_________. 1992a. "A Fowler's for Capital: A 'Mini-Directory' of Usage on Capital Measurement." Appendix to "Measuring the Capital Stock: A Review of Concepts and Data Needs." Paper presented at the Workshop on the Measurement of Depreciation and Capital Stock at the Conference on Research in Income and Wealth, National Bureau of Economic Research, Washington, DC, June 5, 1992.

_________. 1992b. "Measuring the Capital Stock: A Review of Concepts and Data Needs." Paper presented at the Workshop on the Measurement of Depreciation and Capital Stock at the Conference on Research in Income and Wealth, National Bureau of Economic Research, Washington, DC, June 5, 1992.

_________. 1996. "Depreciation in Production Analysis and in Income and Wealth Accounts: Resolution of an Old Debate." *Economic Inquiry* 24 (January): 93–115.

_________. 1997. "Concepts of Capital for Production Accounts and for Wealth Accounts: The Implications for Statistical Programs." Paper presented at the International Conference on Capital Stock Statistics, Canberra, Australia, March 10–14, 1997.

Winfrey, Robert. 1967. *Statistical Analysis of Industrial Property Retirements*. Bulletin 125, Revised. Ames, Iowa: Engineering Research Institute, Iowa State University.

Wykoff, Frank C. 1970. "Capital Depreciation in the Postwar Period: Automobiles." *Review of Economics and Statistics* 52 (May): 168–176.

_________. 1989. "Economic Depreciation and the User Cost of Business-Leased Automobiles." In *Technology and Capital Formation*, edited by D.W. Jorgenson and R. Landau, 259–292. Cambridge: MIT Press.

Wykoff, Frank C., and Charles R. Hulten. 1979. "Tax and Economic Depreciation of Machinery and Equipment: A Theoretical and Empirical Appraisal, Phase II Report." *Economic Depreciation of the U.S. Capital Stock: A First Step*. Washington, DC: U.S. Department of the Treasury, Office of Tax Analysis, July 26, 1979.

Young, Allan H., and John C. Musgrave. 1980. "Estimation of Capital Stock in the United States." In *The Measurement of Capital*. Studies in Income and Wealth, vol. 45, edited by Dan Usher, 23–68. Chicago: University of Chicago Press.