GETTING DEPRECIATION (ALMOST) RIGHT[1]

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1. Introduction

Getting economic depreciation "right" is an important step in developing accurate estimates of capital incomes and stocks and, by extension, for tax policy, financial accounting, and for empirical studies of economic growth and capital formation. Much attention has therefore been given to the problem of measurement, but a lot less attention has been paid to the issue of how the resulting estimates should be used.[2] The implicit assumption seems to be that once depreciation rates have been estimated for a collection of assets, the measurement issue is settled and implementation falls into place more or less automatically.

Nothing could be farther from the truth. Depreciable assets come in many forms, from screwdrivers to skyscrapers, and the diversity is such that only a fraction of the total has been studied in the detail. This leaves large gaps that must be filled in order to develop comprehensive estimates of depreciation for tax and accounting purposes. Moreover, the

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[2] The early theoretical literature includes Hotelling (1925) and Hicks (1946). Later contributions include Hall (1968), Jorgenson (1973), and Feldstein and Rothschild (1974). Empirical estimates of depreciation for a wide range on assets were made by Hulten and Wykoff (1981), and the literature reviewed in Hulten (1990), Hulten and Wykoff (1996), and Triplett (1996).

practical problem of income and wealth measurement (and guidelines) would not be solved even if estimates were available for the full range of depreciable assets. An accounting system that tried to make use of all the detailed data would collapse under its own weight.[3] And, mostly tellingly, even if this kind of accounting system didn't collapse, it would be largely irrelevant because the *operational* frame of reference for most practical applications is not the *individual* asset, but the relevant *collection* of individual assets that used in the production of income. The very businesses that generate the data generally do not attempt to attribute and report the income generated by each of their assets individually, but focus instead on the bottom-line result for the company as a whole, and perhaps its subsidiaries and specific plants or activities.

When the focus of the income measurement problem shifts to groups of assets, an interesting fact emerges: the depreciation experience of the collection of assets as a whole is not necessarily the same as, or even similar to, the experience of any individual asset. This fallacy of composition is explored in the following sections of this paper, where it is shown (following Hulten and Wykoff (1981, 1996), and Hulten (1990)) that the average experience of a group of assets is better approximated by geometric depreciation than by other forms, even if each of the component assets in the group follows a different pattern, like the intuitively plausible one-hoss shay.

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[3] The U.S. income tax code offers a good example of an overly complex system that did sink out of existence. Prior to the 1940s, the tax code required taxpayers to base depreciation deductions on the "facts and circumstances" of the assets they owned. This allowed maximum flexibility and accuracy, but taxpayers found the system burdensome, since its logic required them to observe and track the depreciation experience of their every asset. They demanded a system of guidelines that could be used to approximate actual experience while doing rough justice to their tax liabilities. The Bulletin F system emerged as a result, but this was also cumbersome and underwent a series of simplifications over time to reduce the number of asset classes. These simplifications reduced the accuracy of the system for any one asset, but increased the administrative viability of the system for both the taxpayer and the tax collector.

Once established, this result opens the way to a simplified "open-ended accounting" system based on a single depreciation rate for each type of asset. With regard to wealth accounting, this system provides a simplified variant of the perpetual inventory method measurement in which it is unnecessary to keep track of the history of past investments. A system of depreciation guidelines can be deployed that involves a single parameter per class, in place of a system that involves the depreciation patterns and average useful lives of individual assets. The U.S. National Accounts are an example of this simpler single-rate system with a very large number of asset guideline classes (see the Appendix Table for the list). Countries with fewer budgetary resources, or a less developed national accounting capability, can implement the system with many fewer classes. For tax payers with depreciable assets, the open-ended single-rate class system simplifies record keeping because it is unnecessary to keep track of individual investments made in the past.

The sections that follow describe the theory of asset productivity and pricing that underpin these results. The distinction between the deterioration in an asset's productivity over time and the associated decline it its price is developed in the next two sections. The "age-efficiency" and "age-price" profiles are described in these sections, along with the linkage between the two concepts. The following section turns to the problem of characterizing the age-efficiency profiles for a group of assets that are essentially identical except for their expected date of retirement. This sets the stage for the main result of this paper: when practical necessity and data constraints force the analyst to combined assets that are not identical in the broader groups, the group age-efficiency profile is dominated by the heterogeneity of the retirement patterns of the various component assets, not the age-efficiency profiles of the component assets themselves. Given the retirement distributions commonly in use, the group age-efficiency profile will tend to approach the geometric form of depreciation even if each individual asset are highly non-geometric. In other words, even if all the assets in a particular grouping follow the "one-hoss shay" pattern in which there is no loss of productivity until an asset is retired, the overall results is likely to be approximately geometric.

2. The Case of the Single Asset – Efficiency Loss

Depreciable assets have the essential characteristic that they are used up in the process of producing output. The notion of being "used up" is the result of many factors, including: casualty loss and breakage, wear and tear, increased maintenance requirements, and obsolescence due to competition from new assets of a superior design or location. For whatever reason, the depreciable asset reaches a point in its life at which it is no longer profitable to operate and is retired from service.[4] At this point, the asset no longer contributes directly to the production of output, and its economic value is zero.

Deterioration is a complex process, involving both decisions by the user and events outside the user's control. Each depreciable asset is, in a sense, a unique case, and this complexity creates problems for anyone who wants to measure capital (or even to characterize the processes in a succinct analytical way).[5] Simplifying assumptions are needed and early treatments tended to impose a specific pattern of efficiency decay with age, like the geometric and "one-hoss shay" forms. Hall (1968,1971) subsequently showed how to use the hedonic price

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[4] A complication arises when the asset is taken out of production and put into reserve capacity to meet surges in demand for the user's product. Its expected future output is not zero, even if its current productivity is. We will ignore this case because it really does not affect the main conclusions of the analysis.

[5] See Feldstein and Rothschild (1974) for a detailed discussion of the various factors that contribute to depreciation and the complexity that they introduce into the analysis.

model to estimate a more general form of the age-efficiency relationship, and Jorgenson (1973) worked out the conceptual link between the general age-efficiency profile $[\phi(0), \phi(1), \ldots, \phi(N)]$ and the corresponding age-price profile of the following section. The first element in the sequence $[\phi(0), \phi(1), \ldots, \phi(N)]$, $\phi(0)$, is an index of the productivity of a new asset, which is normalized to one. The rest of the sequence, $\phi(s)$, are indexes of the asset efficiency relative to a new asset. When the asset is retired after N years of service, its relative efficiency index goes to zero.

In the one-hoss shay pattern, an asset retains its full productive capacity up to the point it is retired (thus, $\phi(s) = 1$ for ages s between 0 and N, and $\phi(N+s) = 0$ thereafter). The Bureau of Labor Statistic favors the hyperbolic pattern of decay for use its multifactor productivity program.[6] The straight-line pattern is another popular form in which the asset loses 1/N of its productive capacity every year until retirement. Declining balance, or geometric, depreciation is the third widely used pattern, in which efficiency declines at a constant rate δ (yielding the sequence $\phi(s) = (1-\delta)^s$). Unlike the other two forms, there is no specific retirement date N because efficiency decay is entirely characterized by the rate δ. However, the rate δ and the life N are related by the following formula $\delta = X/N$, where X is the parameter fixing the degree of the declining balance (X = 2 implies doubled-declining balance form, etc.). There is, of course, no *a priori* reason that the age-efficiency profile should assume any of these forms. This is an empirical issue, which is deferred to a subsequent section.

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[6] The hyperbolic form has the general form $\phi(s) = (N - s)/(N - \beta s)$ for ages s between 0 and N, and $\phi(N+s) = 0$ thereafter. The BLS selected the values of β that best fitted the Hulten-Wykoff estimates of the age-price profiles described in the following section of this paper. Their analysis led them select a value for β of 0.75 for structures and 0.50 for equipment (Bureau of Labor Statistics (1983), pages 41 to 45).

While this framework rests on some fairly restrictive assumption (Feldstein-Rothschild (1974)), it has the virtue of practicality. Once the sequence [$\phi(0), \phi(1), \ldots, \phi(N)$] has been estimated, the corresponding stock of capital can be computed by summing past investments, weighted by their respective relative efficiencies:

$$K(t) = \phi(0)I(t) + \phi(1)I(t-1) + \ldots + \phi(N)I(t-N). \qquad (1)$$

$I(t-s)$ is the quantity of investment goods put in place s years before the present and $K(t)$ is the associated stock. Defined this way, capital stock is equivalent to the amount of investment in new assets needed to replace the collection of existing vintage assets.

3. The Case of the Single Asset – Depreciation

We have thus far focused on asset deterioration and retirement from service. There is a parallel loss in asset *value* as the asset ages, due to declining productivity while the asset is in service and to the approaching date of retirement (at which time the asset's net-of-scrap value is zero). The value of an asset of age s, $P^I(t,s)$, is equal, in equilibrium, to the discounted present value of the income stream generated by the asset over the remaining years of its life:

$$P^I(t,s) = \sum_{\tau=0}^{N} \frac{P^K(t+\tau, s+\tau)}{(1+r)^{\tau+1}} = \sum_{\tau=0}^{N} \frac{\phi(s+\tau)P^K(t+\tau, 0)}{(1+r)^{\tau+1}} \ . \qquad (2)$$

Annual income is represented in the expression above by the service price $P^K(t,s)$. This is the amount of money that an asset of age s in year t would generate in rent during that year, and it is also equal to the value of the marginal product of that asset over this period (hence the various names given to $P^K(t,s)$: 'user cost', 'service price', 'implicit rent', and 'rent').

Two factors influence this price as the asset becomes older: price inflation from changes in the demand for the asset, and the effects of wear and tear and approaching retirement. The former is captured by the partial derivative of $P^I(t,s)$ with respect to time, t, and the latter by the partial derivative with respect to age. For discrete time changes, the total change in price from one year to the next can be expressed as

$$P^I(t+1,s+1) - P^I(t,s) = [P^I(t+1,s) - P^I(t,s)] + [P^I(t+1,s+1) - P^I(t+1,s)] \qquad (3)$$

The first term in square brackets in this expression is the time effect (revaluation), and the second is the age effect (depreciation). In practice, measuring the depreciation term involves the comparison of the value of one asset of age s at time t+1 with a similar asset of age s+1 in the same year.

The *rate of depreciation* is defined as $\delta(s) = [P^I(t+1,s+1) - P^I(t+1,s)]/ P^I(t+1,s)$. In general, the rate of depreciation changes as the asset ages, as does the *rate of efficiency decay* $d(s) = \Delta\phi(s)\ \phi(s)$. The two rates are related, but in a complicated way. The link comes through the service price $P^K(t,s)$, which is equal in equilibrium to the service price of a new asset weighted by the relative efficiency of the s-year old asset: $P^K(t,s) = \phi(s)P^K(t,0)$. Jorgenson (1973) uses this relation to link the rate of depreciation $\delta(s)$ and the rate of efficiency decay d(s). He replaces $P^K(t,s)$ with $\phi(s)P^K(t,0)$ in the present value equation (2) (yielding the second equality in (2)), and then puts the result into the definition of depreciation $[P^I(t+1,s+1) - P^I(t+1,s)]$. This implies that the difference in asset prices, $P^I(t+1,s+1) - P^I(t+1,s)$, is equal to the first differences of the relative efficiencies, $[\Delta\phi(s), \Delta\phi(s+1), \ldots , \Delta\phi(N)]$, multiplied by the corresponding service price of a new asset, $P^K(t+s+1,0)$, discounted at the rate r. This formulation, in turn, leads to the interpretation of depreciation as the amount of income that is lost because of the change in age-related change in efficiency in *each* of the remaining years of its life.

The *rate* of depreciation $\delta(s)$ can then be shown to be the *weighted average* of the *rates* of decay d(s), where the weights are the share of the value of the asset $P^I(t+1,s)$ accounted for by the future service prices $P^K(t+\tau 1,s+\tau)$:

$$\delta(s) = \sum_{\tau=0}^{N} [\frac{P^K(t+\tau, s+\tau)}{(1+r)^{\tau+1} P^I(t+1,s)}] d(s+\tau) \qquad (5).$$

The link between the two rates is complex for most patterns of ϕ efficiency. In the one-hoss shay case, the ϕ's are all equal to one until retirement at age N, after which they are all zero. In view of (5), the corresponding δ(s) must follow a different path, which depends among other things, on the rate of discount *r*. When *r* is zero, the pattern of depreciation has a straight-line form, but positive values of *r* give concave patterns.

The case of geometric depreciation is felicitous because it is the one (and only) case in which the rate of depreciation is constant across asset ages and is equal to the corresponding rate of efficiency decay: δ = d.[7] This is felicitous because it saves the analyst the trouble of working

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[7] This formulation assumes that there are no technological improvements in the design of capital that lead to increases in asset efficiency. There are cases like computers where this assumption is clearly false. The presence of embodied technical change increases the complexity of the problem and introduces the possibility of obsolescence and holding gains. The conventional way of dealing with this issue is based on Hall (1968, 1971), who showed that embodied technical change raises the marginal product of the new asset relative to the corresponding unimproved asset available in the preceding year. In the notation of relative asset efficiency, this raises the efficiency index of the superior asset from ϕ(t,0) to ϕ(t+1,0), where the t index indicates the year the asset enters service (the vintage). This establishes a new level of efficiency against which the wear, tear, and retirement take place. The cross-sectional age-efficiency profile in any year is now composed of assets from different vintages as well as different ages: [ϕ(t+1,0), ϕ(t,1), ... , ϕ(t-N,N)].

The arrival of the superior new vintage does not reduce the ϕ-efficiencies of existing assets in the conventional approach, but the new vintage does reduce the *value* of the older vintages through a process described in Solow (1970): the increased efficiency of the new vintage reduces the cost of production, which leads to a lower output price; this then lowers the value of the marginal product of the older vintages (and thus their used market prices), and accelerates the date at which they are retired from service. This is the process of *obsolescence*, and it is built into the assets' age-price profile. The rate of depreciation δ(s) then reflects the combined effects of wear and tear and obsolescence (in the pure Solow model, only obsolescence is present in the age-price profile). This drives a wedge between δ(s) and d(s). Hall shows that the gap can be bridged using price hedonic techniques, since the jump from ϕ(t,0) to ϕ(t+1,0) should be reflected in the "characteristic" prices of the assets when new.

with the complexities of equation (5), in favor of a *single* common number for both deterioration and depreciation. These advantages will be discussed in the section of class guidelines.

4. Empirical Evidence on the Patterns of Depreciation and Asset Efficiency

The preceding discussion suggests that the case of geometric depreciation/deterioration permits a significant simplification of the measurement of capital stock and income. Absent any evidence to the contrary, it would be the natural assumption on which to base the measurement of capital. What does the evidence show? Direct evidence on the ϕ-efficiency patterns is virtually impossible to collect, as already noted, and data on depreciation is difficult to obtain for a similar reason: most assets are owner-utilized, so market price data on service prices and asset values for the *same* asset, the $P^I(t,s)$ and $P^K(t,s)$, are at best spotty. Much of the evidence of patterns comes from analysis of vintage prices $P^I(t,s)$ from a collection of different assets (this is the approach taken in the studies by Hulten and Wykoff). The Hulten-Wykoff results support the geometric pattern as a reasonable approximation for those assets they studied, and this result has tended to hold up in later studies, though with some exceptions.

However, the key result of this paper is that the more that assets are group together, the more the *group* experience tends to the a geometric-like pattern, regardless of the actual patterns of the individual assets in the group. If the individual patterns are themselves nearly geometric, the group effect is reinforced, but this is not a necessary condition. This result is developed in the following two sections.

5. Patterns of Depreciation and Efficiency with Asset Retirement

The problem with the price-based evidence supporting geometric depreciation lies in the intuition that most assets do not lose much of their productivity during the early years of their life, contrary to the prediction of the geometric form. However, there is a larger problem with this critique: intuition that is based on the experience of a single asset and thus is not necessarily representative of the average experience of a collection (or cohort) of the same assets. Consider, for example, the case in which 100 identical machines are purchased in a given year t. These assets may be identical in design, but differences in utilization, maintenance, as well as accidents, will generally cause some assets to be retired from service before others. The average age-efficiency profile of the group, $\phi^*(s)$, will be influenced by the retirement process as well the age-efficiency profiles of the individual assets in the group, $\phi_i(s)$.

The implications of retirement for the age-efficiency profiles can be examined by introducing a retirement parameter into the framework laid out above for the case of the single asset. A dummy variable can be defined for each individual asset *i* in the group, $\theta_i(s)$, which takes the value one if the asset is still in service at age *s*, and is zero if the asset has been retired from service. The age-efficiency profile for each asset defined above can then be re-expressed as $[\theta_i(0)\phi_i(0), \theta_i(1)\phi_i(1), \ldots, \theta_i(N)\phi_i(N), \ldots]$, which is equivalent to the previous formulation. The retirement parameters do, however, affect the average experience of the group, which is

$$\phi^*(s) = \sum_{i=1}^{M} \frac{\theta_i(s)\phi_i(s)}{M}. \qquad (6)$$

The implications of this formulation can be seen by supposing that each individual asset follows the one-hoss shay efficiency pattern suggested by intuition (where all of the $\phi_i(s)$ are either zeroes or ones). In this case, the conditional age-efficiency profile of the cohort, $\phi^*(s)$, is entirely determined by the retirement parameter of the individual assets. In the first years of asset life, most (or all) of the individual ϕ_i's will be one, and so will the average. But, as age increases, more and more of the $\phi_i(s)$ will turn from one to zero, and the average will decline until it reaches zero. As a result, the cohort $\phi^*(s)$ in this case is just the retirement distribution expressed as the percent of assets surviving in any group.

Actual results obviously depend on which retirement pattern is selected. Many empirical capital studies use the Winfrey "Iowa" family of retirement distributions (Winfrey (1942), Marston, Winfrey, and Hempstead (1963)). The results for one such distribution, the L1, are shown in Figure 1, for three groups of assets with different mean average lives (5, 10, and 20 years). The striking result is that the group pattern shows a strongly convex pattern after a brief flat segment in the first few years of asset life. The S3 pattern shows a somewhat longer initial flat segment, because this distribution assumes that only two percent of the group's assets are retired during the first half of the group's average life. Even so, the S3 pattern still yields a strongly convex pattern that dominates the overall group age-price profile, $\phi^*(s)$.

A look at Figure 1 suggests that the intuition that favors the one-hoss shay pattern is misleading. What is true of each element of a group in Figure 1 is evidently *not* true for the group as a whole. This fallacy of composition is does not imply geometric depreciation by itself, the group but $\phi^*(s)$ become more convex as we move away from the case in which the component $\phi_i(s)$ follow the one-hoss shay form to patterns that exhibit some efficiency degree as the assets ages (e.g., the hyperbolic and straight-line forms). Geometric depreciation becomes a better and better approximation as this happens, given the retirement patterns in common use.

6. Patterns of Depreciation and Asset Efficiency When Assets Are Grouped Into Administrative Classes

The great diversity in the types of plant and equipment virtually forces the grouping of dissimilar assets for measurement for reporting purposes. For example, imagine a carpenter's tool box, with its different varieties of saws, hammers, screwdrivers, pliers, chisels, and so on. Could the carpenter keep track of the value and relative productivity of each tool as it ages (or even remember when the tool was purchased)? And, even if a greater effort were made to observe and preserve this information, could the accountant or statistician keep track of all the data generated by all the tool boxes of all the carpenters (and plumbers, electricians, metal workers, and so on)? And hand tools are just a tiny fraction of all producers' equipment. The BEA breaks Private Nonresidential Equipment into 34 different classes (Appendix Table 1), but even this level of detail involves broad classes like metalworking machinery, office, computing and accounting machinery, ships and boats, to name just a few. Many of these groups are composed of a range of assets that are not that similar. Metalworking equipment, for example, includes short-lived grinders and long-lived metal-forming machines. Buildings are a composite of long-lived components like the structural shell and shorter-lived components like the heating and electrical systems.

The fallacy of composition described in the preceding section is reinforced when dissimilar assets are grouped together into administrative classes. In the context of the theory of depreciation set out above, the grouping of dissimilar assets into a single class is analytically equivalent to assuming that the assets are identical except for the dates at which they are retired. In other words, grouping grinders and metal-forming equipment together into the same class is to postulate the existence of an asset called a "metal-working machine," and to ignore the fact that most of the early retirements of "metal-working machines" are mostly due to the grinders and the later retirements are mostly the metal-forming machines. The result of this pretense is a combined group age-efficiency profile, $\phi^*(s)$, which is even more dominated by the retirement parameters and therefore even more like the geometric pattern. This is illustrated in Figure 2, in which the 5, 10 and 20 assets of Figure 1 are combined into a single administrative class, and the average $\phi^*(s)$ plotted against age. The average age-price profile is even more convex than the components, because the flat segment apparent in the individual cases is greatly attenuated by the presence of short-lived assets in the average. A look at Figure 3 indicates that this is even true of the Winfrey S3 distribution, which was designed to perpetuate the flat segments up to one-half the average life of each individual type of asset.

Two implications of this analysis are worthy of emphasis. First, in moving from the case of a single asset to the situation in which assets are grouped into administrative classes, it makes no sense to try preserve the intuition of one-hoss shay (or similar patterns). Second, the grouping of assets into administrative classes introduces an unavoidable degree of imprecision into the problem of measuring depreciation. The need to pretend that grinders and metal-forming machines are the same asset carries with it the need to stop pretending that precise measurement is possible. What is needed is a set of guidelines for the various administrative classes of assets that does rough justice to the average experience of each class (for example, assigning guidelines to classes like computing equipment and autos that recognize that these tend to be short-lived assets, whereas guidelines for the ships and railroad equipment classes should reflect the long-lived nature of these assets).

7. Open-Ended Accounting and the Perpetual Inventory Method

The fallacy of composition, along with the weight of empirical evidence for types of capital, opens the way to a simplified approach the capital measurement based on open-end class accounting. Since the geometric pattern is characterized by a single depreciation rate, the procedure for measuring the stock of capital defined by equation (1) can be simplified to the following form:

$$K_j(t) = I_j(t)+(1-\delta_j)K_j(t-1), \qquad (1')$$

where $K_j(t)$ is the constant-price value of the capital stock in administrative class *j* in year *t*, $I_j(t)$ is the corresponding constant-price investment outlay, and δ_j is corresponding class depreciation rate.[8] This form of the accumulation equation is often called the "perpetual inventory method" because it treats the stock of capital as an inventory to which the amount of new investment is added and from which the amount of depreciation/deterioration, $\delta_j K_j(t-1)$, is subtracted. This is a significant simplification over the accumulation equation in (1), because it is not necessary to keep track of the vintage history of investments $[I_j(t), I_j(t-1), \ldots , I_j(t-N)]$.

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[8] The depreciation of the existing stock assumes that the class δ_j has been adjusted for normal retirement (e.g., using a Winfrey distribution), so extraordinary retirements should therefore be recognized as a separate contributor to total depreciation.

The corresponding *current price* accounts are constructed in a similar way. The current value of capital stock in any one year is equal to the value of the stock in the preceding year, plus the value of new investment put in place, plus the net change in value due to changes in the price of new assets (revaluation), less depreciation. The depreciation term is simply the value of the existing stock multiplied by a single class guideline depreciation rate. Thus,

$$P^{Ij}(t,0)K_j\,(t) \;=\; P^{Ij}(t\text{-}1,0)K_j(t\text{-}1) + P^{Ij}(t,0)I_j(t) - \delta_j P^{Ij}(t,0)K_j(t\text{-}1) + [P^{Ij}(t,0) - P^{Ij}(t\text{-}1,0)]K_j(t\text{-}1). \qquad (7)$$

Total class depreciation, $\delta_j P^{Ij}(t,0)K_j(t\text{-}1)$, is of interest in its own right, because it is a component of the overall depreciation that must be subtracted from gross income to arrive at net income in the national accounts.[9]

Another way to look at this formulation is to observe that it is a form of open-ended accounting. All that matters is the inventory of capital on hand at each point in time, not the composition of this inventory. It is the inventory of assets that are written down at the common rate δ_j, and the fate of any individual asset in the class is not relevant. Individual assets may drop out of the inventory according to the relevant retirement pattern, but the inventory itself simply shrinks at the retirement-adjusted rate δ_j and grows according to the rate of investment. This is enormously convenient from a practical standpoint, since equation (1') for each class can be administered each year with only three pieces of information, and (7) with two more pieces (the prices).

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[9] Considerable simplification also occurs when measuring the annual income from a capital asset, $P^K(t,s)I(t\text{-}s)$. The absence of rental market data with which to estimate the service price $P^K(t,s)$ requires the indirect imputation method pioneered by Jorgenson (1963) and Hall-Jorgenson (1967) in which the asset pricing equation (2) is solved to yield an expression for the implicit rental price. This price has the general form, without taxes, $P^K = [r - \rho + \delta]\, P^I$, where *r* is the rate of return, ρ the rate of asset price revaluation, δ the rate of depreciation, and the acquisition price of the asset, $P^I(t)$. This imputation, necessary for measuring the income associated with individual assets, is considerably easier when δ is constant.

The number of classes, *J*¸ is another parameter of the overall open-ended accounting system, and it is limited mainly by the number of categories of investment goods for which estimates are made, and the information available to formulate depreciation rates. The U.S. National Accounts, which uses a variant of this system, includes a very large number of asset guideline classes: 34 types of producer equipment, 24 types of nonresidential capital, 21 types of residential capital and consumer durables, and 48 types of government capital (see the Appendix Table). Countries with fewer budgetary resources or with a less developed national accounting capability can implement the system with many fewer classes.

One further remark on classes is in order. In its purest and simplest form, the open-ended accounting system is parameterized with the *rate* of depreciation, δ, whereas many past accounting systems are parameterized with the average asset life, N. Hulten and Wykoff develop a bridge between the two systems, by observing that when the pattern of depreciation is geometric, the rate δ and the life N are related by the formula $\delta = X/N$, where X is the parameter that establishes the degree of declining balance. Given estimates of N, Hulten and Wykoff estimate the parameter X for the various class of assets for which the δ can be estimated (the "best geometric approximation") from data on used asset prices. For those classes of assets for which used asset prices are not available, the rate δ is imputed from the estimates X's and N's. However, this works only where geometric depreciation prevails.[10]

In sum, the perpetual inventory methodology described above offers an attractive system for measuring depreciation, capital income, and capital stock in the SNA. Since it does not require that countries keep track of past vintages of investment, the information needed to operate the system is less than for the closed-end system based strictly on finite asset lives. It

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[10] The various values of X used by the BEA are shown in Appendix Table 1.

can thus be implemented by countries at all levels of economic development. Since it finds support in empirical studies, and in analyses like those underlying Figure 3 of this paper, the perpetual inventory system also offers a reasonable approximation to the depreciation experience of broad groups of assets.

8. Summary and Conclusion

Much of the available information about depreciation and asset retirement is based on studies that are decades old, and does not cover the full range of depreciable assets. There is certainly a great deal of room for improvement here. However, any attempt to improve on this situation should bear in mind Voltaire's comment to the effect that the 'best is often the enemy of the good'. Complete information about the depreciation experience all assets is virtually unattainable given that many assets are owner-utilized and thus without systematic data on how price and productivity changes over time. Moreover, the way assets are used also affects the pattern of depreciation and decay, so that in principle each asset is its own special case. Still, the aspirational 'best' solution would seem to be a state of the world in which the maximum amount of information were made available to users, to select and aggregate according to their needs. In other words, more is better, since unneeded data can be ignored.

This paper has argued that this 'best' solution in this sense may not be a 'good' solution. The great heterogeneity of assets types, usage, and retirement patterns, along with incomplete data, can only be accommodated by combining assets into broad groups and treating the components as though they were the same asset. But, once this is done, a fallacy of composition comes into play. What is true about the depreciation and decay experience of every single component of the group is not generally true of the average experience of the group as a whole (or, put differently, of the representative asset in the group). However, the path forward is not blocked by this fallacy. This path involves a paradigm shift away from a focus on the experience of individual asset to a recognition that it is the average experience of broad groups of assets that matters for most applications, and that there should be a parallel shift to open-end accounting procedures. While more needs to be known about individual experience, much more needs to be learned about retirement distributions. Moreover, there needs to be more awareness that the away assets are grouped can matter as much for the "bottom-line" accuracy of capital measurement as the experience of the component assets themselves. In this regard, accuracy may involve the grouping of assets is such a way as the variance of the group retirement distribution are minimized. The selection of a depreciation class system also needs to consider criteria like administrative capability and budget. Fortunately, the BEA model provides a working prototype on which to build such a system.

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Figure 1
Cohort Age-Efficiency Profile
5, 10, and 20 Year Assets
Winfrey L1 Distribution

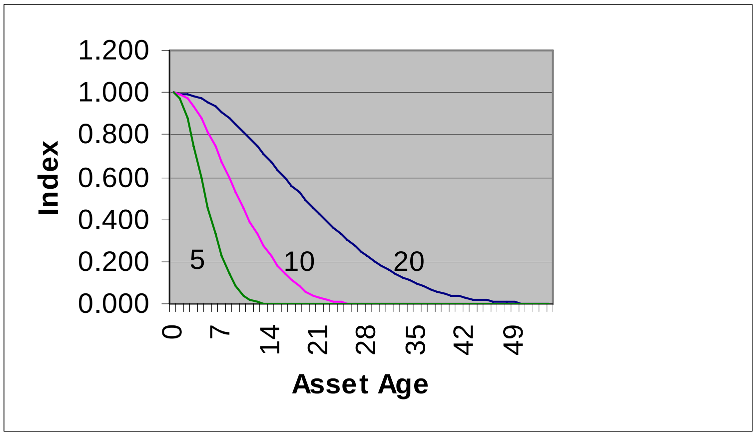


Figure 2
Class Guideline Average Age-Efficiency Profile
Average of 5, 10, and 20 Year Assets
Winfrey L1 Distribution

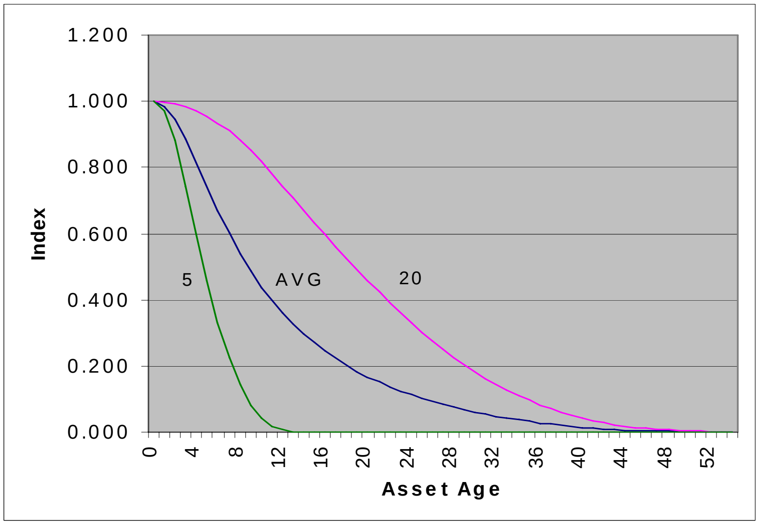
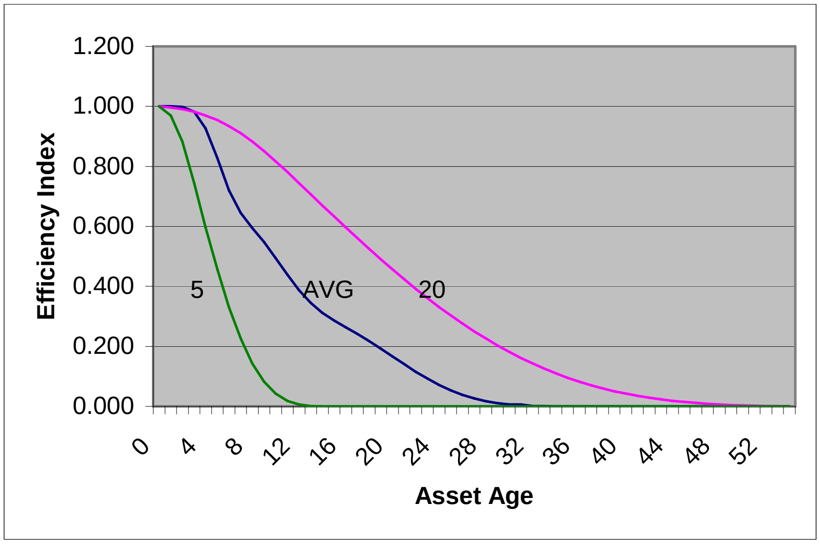


Figure 3
Class Guideline Average Age-Efficiency Profile
Average of 5, 10, and 20 Year Assets
Winfrey
S3 Distribution



APPENDIX

Table A.—BEA Depreciation Rates, Service Lives, and Declining-Balances Rates

Type of asset	Depreciation rates	Service life (years)	Declining-balance rates
Private nonresidential equipment			
Office, computing, and accounting machinery/1/:			
Years before 1978	0.2729	8	2.1832
1978 and later years	.3119	7	2.1832
Communications equipment:			
Business services	.1500	11	1.6500
Other industries	.1100	15	1.6500
Instruments	.1350	12	1.6203
Photocopy and related equipment	.1800	9	1.6203
Nuclear fuel/2/		4	
Other fabricated metal products	.0917	18	1.6500
Steam engines and turbines	.0516	32	1.6500
Internal combustion engines	.2063	8	1.6500
Metalworking machinery/3/	.1225	16	1.9600
Special industrial machinery, n.e.c.	.1031	16	1.6500
General industrial, including materials handling equipment	.1072	16	1.7150
Electrical transmission, distribution, and industrial apparatus	.0500	33	1.6500
Trucks, buses, and truck trailers:			
Local and interurban passenger transit	.1232	14	1.7252
Trucking and warehousing; and auto repair, services, and parking	.1725	10	1.7252
Other industries	.1917	9	1.7252
Autos/4/			
Aircraft:			
Transportation by air,depository institutions,and business services:			
Years before 1960	.1031	16	1.6500
1960 and later years	.0825	20	1.6500
Other industries:			
Years before 1960	.1375	12	1.6500
1960 and later years	.1100	15	1.6500
Ships and boats	.0611	27	1.6500
Railroad equipment	.0589	28	1.6500
Household furniture and fixtures	.1375	12	1.6500
Other furniture	.1179	14	1.6500
Farm tractors	.1452	9	1.3064
Construction tractors	.1633	8	1.3064
Agricultural machinery, except tractors	.1179	14	1.6500

Construction machinery, except tractors	.1550	10	1.5498
Mining and oil field machinery	.1500	11	1.6500
Service industry machinery:			
Wholesale and retail trade	.1650	10	1.6500
Other industries	.1500	11	1.6500
Household appliances	.1640	10	1.6500
Other electrical equipment	.1834	9	1.6500
Other	.1473	11	1.6230
Private nonresidential structures			
Industrial buildings	.0314	31	.9747
Mobile offices	.0556	16	.8892
Office buildings	.0247	36	.8892
Commercial warehouses	.0222	40	.8892
Other commercial buildings	.0262	34	.8892
Religious buildings	.0188	48	.9024
Educational buildings	.0188	48	.9024
Hospital and institutional buildings	.0188	48	.9024
Hotels and motels	.0281	32	.8990
Amusement and recreational buildings	.0300	30	.8990
All other nonfarm buildings	.0249	38	.9480
Railroad replacement track	.0275	38	.9480
Other railroad structures	.0166	54	.9480
Telecommunications	.0237	40	.9480
Electric light and power:			
Years before 1946	.0237	40	.9480
1946 and later years	.0211	45	.9480
Gas	.0237	40	.9480
Petroleum pipelines	.0237	40	.9480
Farm	.0239	38	.9100
Mining exploration, shafts, and wells:			
Petroleum and natural gas:			
Years before 1973	.0563	16	.9008
1973 and later years	.0751	12	.9008
Other	.0450	20	.9008
Local transit	.0237	38	.8990
Other	.0225	40	.8990
Residential capital (private and government)			
1-to-4-unit structures-new	.0114	80	.9100
1-to-4-unit structures-additions and alterations	.0227	40	.9100
1-to-4-unit structures-major replacements	.0364	25	.9100
5-or-more-unit structures-new	.0140	65	.9100
5-or-more-unit structures-additions and alterations	.0284	32	.9100
5-or-more-unit structures-major replacements	.0455	20	.9100
Mobile homes	.0455	20	.9100
Other structures	.0227	40	.9100
Equipment	.1500	11	1.6500

Durable goods owned by consumers			
Furniture, including mattresses and bedsprings	.1179	14	1.6500
Kitchen and other household appliances	.1500	11	1.6500
China, glassware, tableware, and utensils	.1650	10	1.6500
Other durable house furnishings	.1650	10	1.6500
Video and audio products, computers and peripheral equipment, and musical instruments/1/	.1833	9	1.6500
Jewelry and watches	.1500	11	1.6500
Ophthalmic products and orthopedic appliances	.2750	6	1.6500
Books and maps	.1650	10	1.6500
Wheel goods, sports and photographic equipment, boats, and pleasure aircraft	.1650	10	1.6500
Autos/4/			
Other motor vehicles	.2316	8	1.8530
Tires, tubes, accessories, and other parts	.6177	3	1.8530
Government nonresidential equipment			
Federal:			
National defense:			
Aircraft:			
Airframes:			
Bombers	.0660	25	1.6500
F-14 type	.0868	19	1.6500
Attack, F-15 and F-16 types	.0825	20	1.6500
F-18 type	.1100	15	1.6500
Electronic warfare	.0717	23	1.6500
Cargo and trainers	.0660	25	1.6500
Helicopters	.0825	20	1.6500
Engines	.2750	6	1.6500
Other:			
Years before 1982	.1179	14	1.6500
1982 and later years	.1650	10	1.6500
Missiles:/5/			
Strategic		20	
Tactical		15	
Torpedoes		15	
Fire control equipment		10	
Space programs		20	
Ships:			
Surface ships	.0550	30	1.6500
Submarines	.0660	25	1.6500
Government furnished equipment:			
Electrical	.1834	9	1.6500
Propulsion	.0825	20	1.6500
Hull, mechanical	.0660	25	1.6500
Ordnance	.1650	10	1.6500
Other	.1650	10	1.6500
Vehicles:			
Tanks, armored personnel carriers, and other combat vehicles	.0825	20	1.6500

Noncombat vehicles:			
Trucks	.2875	6	1.7252
Autos/6/			
Other	.2465	7	1.7252
Electronic equipment:			
Computers and peripheral equipment/7/			
Electronic countermeasures	.2357	7	1.6500
Other	.1650	10	1.6500
Other equipment:			
Medical	.1834	9	1.6500
Construction	.1550	10	1.5498
Industrial	.0917	18	1.6500
Ammunition plant	.0868	19	1.6500
Atomic energy	.1375	12	1.6500
Weapons and fire control	.1375	12	1.6500
General	.1650	10	1.6500
Other	.1375	12	1.6500
Nondefense:			
General government:			
Computers and peripheral equipment/7/			
Aerospace equipment	.1100	15	1.6500
Vehicles	.4533	5	2.2664
Other	.1650	10	1.6500
Enterprises:			
U.S. Postal Service:			
Computers and peripheral equipment/7/			
Vehicles	.3238	7	2.2664
Other	.1100	15	1.6500
Tennessee Valley Power Authority	.0500	33	1.6500
Bonneville Power Authority	.0500	33	1.6500
Other	.0660	25	1.6500
State and local:			
Power tools, lawn and garden equipment	.1650	10	1.6500
Miscellaneous metal products	.0917	18	1.6500
Agricultural machinery and equipment	.1833	9	1.6500
Construction machinery and equipment	.1650	10	1.6500
Metalworking machinery and equipment	.1031	16	1.6500
General purpose machinery and equipment	.1500	11	1.6500
Special industry machinery and equipment	.1500	11	1.6500
Integrating and measuring instruments	.1375	12	1.6500
Motors, generators, motor generator sets	.0516	32	1.6500
Switchgear and switchboard equipment	.0500	33	1.6500
Electronic components and accessories	.1833	9	1.6500
Miscellaneous electrical machinery	.1375	12	1.6500
Calculating and accounting machines	.2357	7	1.6500
Typewriters	.2357	7	1.6500

Computers and peripheral equipment/7/			
Machine shop products	.2063	8	1.6500
Wood commercial furniture	.1179	14	1.6500
Metal commercial furniture	.1179	14	1.6500
Household appliances	.1500	11	1.6500
Home electronic equipment	.1500	11	1.6500
Motor vehicles	.1650	10	1.6500
Motorcycles	.1650	10	1.6500
Aircraft	.1100	15	1.6500
Railroad equipment	.0590	28	1.6500
Sporting and athletic goods	.1650	10	1.6500
Photographic and photocopying equipment	.1650	10	1.6500
Mobile classrooms, mobile offices, etc.	.1650	10	1.6500
Musical instruments	.1834	9	1.6500
Other equipment	.1375	12	1.6500
Government nonresidential structures			
Federal, State and local:			
National defense:			
Buildings:			
Industrial	.0285	32	.9100
Educational	.0182	50	.9100
Hospital	.0182	50	.9100
Other	.0182	50	.9100
Nonbuildings:			
Highways and streets	.0152	60	.9100
Conservation and development	.0152	60	.9100
Sewer systems	.0152	60	.9100
Water systems	.0152	60	.9100
Other	.0152	60	.9100

1. 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 of the article.

2. The depreciation rates for nuclear fuel are based on a straight-line rate pattern and a Winfrey retirement pattern.

3. The service life listed is the average for nonmanufacturing industries; the service lives used for manufacturing industries differ by industry.

4. The depreciation rates for autos are derived from data on new and used auto prices.

5. Depreciation rates for missiles are based on straight-line patterns of depreciation and Winfrey retirement patterns.

6. Depreciation rates for government-owned autos are derived from data on autos that are privately owned.

7. Depreciation rates for these assets are taken from Oliner as described in the text of the article.