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Concepts of Capital for Production Accounts and for Wealth Accounts: The Implications for Statistical Programs

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By

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I. Introduction

This paper concerns the data on capital stocks and capital flows that are necessary for income and wealth accounting, on the one hand, and for production accounting and productivity analysis on the other. It has been written because the 1993 System of National Accounts (SNA) contains a Production Account (chapter 6) whose treatment of production, and especially of the contribution of capital to production, is seriously incomplete.

The main conceptual problem with the SNA Production Account is its failure to maintain a clear distinction between the capital stock as a measure of wealth -- what I call in this paper the "wealth capital stock"-- and the capital stock measure that contributes the flow of capital services to production -- what I call in this paper the "productive capital stock." In particular, the SNA Production Account makes an inappropriate linkage between two quite different, though complementary, ideas: consumption of fixed capital and capital services. The consumption of fixed capital which is derived from the wealth capital stock, is not the same thing as the flow of capital services to production that is required in a production account. The latter is derived from the productive capital stock.

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The paper is a companion to Triplett (1996). That previous paper explores the old controversy over the interpretation of depreciation (capital consumption), a controversy associated in the United States particularly with Jorgenson and Griliches (1972), on the one hand, and Denison (1972), on the other.

Triplett (1996) confirms that economic depreciation is identical to capital consumption, and defines the difference between, e.g., gross domestic product and net domestic product, or between gross saving and net saving. It is also the case that capital consumption, and hence depreciation, is the valuation of capital "used up in production," as that term has traditionally been used in the national accounts literature. Triplett (1996) shows that these national account concepts can be derived from capital theory, and are fully consistent with the theory.

Triplett (1996) also shows, however, that capital consumption does not measure the flow of capital services to production. The inappropriate linking of two similar-sounding, but conceptually very different, terms has been the source of much confusion over the treatment of capital in national accounts.

The present paper is a companion to Triplett (1996) in the sense that the economic interpretation of 'depreciation, capital consumption and of capital used up in production that are contained in that paper are maintained in this one. Because resolving the old debate on the interpretation of depreciation in national accounts required a lengthy and somewhat technical paper', the content of Triplett (1996) cannot be repeated here, but it is essential background for the data specifications in this paper.

A complete accounting for production, containing in particular the appropriate accounting for capital in production analysis, was laid out some time ago in a series of papers by Dale Jorgenson and his associates. The earliest of these accounts is Christensen and Jorgenson (1973), and a fully developed series of production accounts for the United States is contained in Jorgenson, Gollop, and Fraumeni (1987).

In section II of this paper I develop at some length the capital stock, capital services, and price of capital services relations that are required for production accounting. This section draws heavily on the work of Jorgenson and his associates. Many users of national accounts and many of their compilers have not understood the implications of Jorgenson and associates' accounting system. The time has come to recognize in the SNA this major contribution to economic accounting.

In section III, I review how particular sections of the SNA should be corrected to give an accounting framework that is appropriate for doing production analysis and productivity. In section IV, I discuss much more briefly the capital measures required for income and wealth accounts, and compare them with the capital data needed for production accounts. A final section, V, wraps up.

II. Capital Measures in Productivity and Production Analysis

This section develops capital concepts and capita data requirements for the analysis of production and for the measurement of productivity. Much of it concerns two concepts: The productive capital stock, which does not really appear in the SNA at all, and the flow of capital services to production, which is inadequately and misleadingly portrayed in the SNA.

The definition of the productive capital stock, and the measurement of the flow of services from the capital stock, do not matter if the only reason one wants a capital stock is to produce net national product, or to make an appropriate adjustment to other income flows, such as saving, profits, and so forth. For those uses, one needs only an appropriate measure of depreciation, which is the same thing as saying that one needs only the wealth capital stock. This point is developed in Triplett (1996).

The wealth capital stock concept, and the measure of depreciation (capital consumption), are also sufficient measures of capital for industry and sector accounts, provided that the only thing one wants to do with industry or sector accounts is to account for incomes flowing out of those sectors, or to construct industry and sector accounts that can be aggregated to get net domestic product. Because some countries estimate aggregate NNP or GDP from industry or sector accounts, it is natural to construct industry or sector accounts that facilitate such aggregation.

However, industry and sector accounts will be used for production analysis, and they have often been used to estimate productivity. Indeed, the production accounts portions of the SNA are written in a way that seems to encourage such use. Sector and industry accounts built according to the production account model of the SNA are seriously deficient for the analysis of production.

A. The Production Analysis Framework

A great deal of the economic research on capital theory and measurement over the past 35 years has been conducted with productivity and production analysis uses in mind. It will be convenient to lay out the data requirements for a production account using productivity measurement as an example.

Multifactor productivity may be defined in the following way:

$$\text{Productivity} = \frac{\text{The aggregation consisting of all of the outputs produced in the economy (or in some sector, or some industry)}}{\text{The aggregation consisting of all of the inputs (capital, labor, materials) used in the sector specified in the numerator}}$$

What is usually calculated, of course, is not the level of productivity, which is what the above expression represents, but rather the change in productivity.

Two approaches exist. In one approach, productivity change is calculated by estimating some explicit production function, and adding a "shift term" to capture technical change. In general terms, one estimates:

(1) $Y_t = f(K_t, L_t, M_t)$

where Y is a measure of output, K, L, and M are measures of capital, labor, and materials, respectively, all measured at time t, where t designates each interval in the time series. Then, the shift in the production function measures technical change, which is identified as the rate of productivity improvement. Production functions commonly employed include the Cobb-Douglas and the translog.
Note that Y_t measures what is sometimes referred to in the national accounts literature as "gross output." Y_t is not a measure of value added in a sector or industry.

Productivity change is also computed by forming ratios of index numbers of outputs and inputs. If $Q(Y)_{0t}$ is a quantity index number that expresses the change in real output between some initial period (0) and some other period (t), and $Q(I)_{0t}$ is an equivalent quantity index of inputs over the same interval, then the measure of technical change is:

(2) $\lambda = Q(Y)_{0t}/Q(I)_{0t}$

(2a) $= Q(Y)_{0t}/Q(K, L, M)_{0t}$

The denominator of equation (2a) is then an index number of the capital, labor, and intermediate materials inputs to production. Index number systems for calculating multifactor productivity include the Tornqvist (the one that is most frequently encountered in empirical research) and the Fisher Ideal.[2]

Domar (1962) showed that the index number and production function approaches are equivalent when the index number chosen is one that can represent the production (or cost) function. Diewert (1989) has shown that both the Fisher Ideal and the Tornqvist index number system can be given production function interpretation, and that both are equally good for calculating multifactor productivity. Both index number and production function approaches have exactly the same requirements for data, requirements that are derived from the economic theory of production that underlies both approaches. Thus, the following discussion applies to equations (1) and (2) interchangeably; generally, whenever I use the term "production function," the substantive content can be restated in "index number system" terms without change in results or conclusions.

Productivity is also sometimes computed from the cost side, in which case index numbers of output and input prices can be used, rather than the index numbers of inputs and outputs in equation (2). This does not materially affect the data requirements, because prices are needed as weights in the quantity index numbers in equation (2), and quantities are needed as weights in output and input price indexes. In describing the data needed for a production account, we can efficiently work with equation (2).

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[2] A Tornqvist quantity index number between periods o and t, T_{ot}, is defined by:

$\ln T_{ot} = \Sigma\, (q_{it}/q_{io})^{si}$ where each s_i, is the "average" share of the ith commodity in the two periods, 0 and t (so that $s_i = (s_{io} + s_{it})/2$; $s_{io} = p_{io}q_{io}/\Sigma p_{io}q_{io}$, and analogously for s_{it}). A Fisher Ideal quantity index between periods o and t is:

$$FI_{ot} = ((\Sigma q_t p_o/\Sigma q_o p_o)(\Sigma q_t p_t/\Sigma q_o p_t))^{1/2}$$

The inputs for calculating productivity include capital labor, and materials, purchased services (including energy), and so forth (equation 2). Materials, purchased services, energy and so forth are known in the SNA as "intermediate consumption." These inputs appear appropriately in the SNA production account. The labor input is conventionally measured in labor hours, and its cost in total labor compensation. In the conventional view, measuring labor input and labor cost is relatively straightforward; I believe that measuring labor inputs is a much more interesting and complex problem than the conventional view of it permits, but these complexities can be addressed within the framework of the 1993 SNA.[3]

A. Stocks of Capital Goods and Flows of capital Services

Capital inputs, however, are not appropriately specified in the SNA production account. Because the production function (equation 1) relates flows of inputs to flows of outputs, capital service measures are wanted in the denominator, in principle, "machine hours" to match "labor hours" and similar measures. A capital service can be defined as the use of a capital good for a specified time period.

For most inputs, transactions occur and provide the basis for measuring input flows and their prices, for example, labor hours and compensation rates. In some cases, capital services measures are also available directly. For example, office space may be rented, and leasing of all kinds of capital equipment has grown in recent years; where capital equipment is leased by the user, the rental payment may be available. The rental measures the payment for the use of a piece of capital equipment for one period of time. Thus, the rental price measures the price of one unit of capital service (see the definition of the price of capital services in Appendix).

However, capital equipment is commonly owned by the user, and not leased. In this case, there is no market transaction in capital services, and no rental rate, that is to say, no capital service price. The capital service quantity, as well as its price, must be inferred from information about the capital stock held by the user. Constructing a capital stock that is appropriate for inferring the flow of capital

[3] On labor cost, see Triplett (1983). On accounting for labor input see Jorgenson, Gollop, and Fraumeni (1987) and U.S. Bureau of Labor Statistics [reference].

services to production, and inferring from the stock and from other information the capital services quantities and prices are the major problems in measuring capital for production analysis.

Jorgenson's (1989; 1990) description of the measures of capital services that are appropriate for production analysis and productivity measurement summarizes procedures followed by a large number of researchers, including, except for details, the BLS productivity office (U.S. Bureau of Labor Statistics, 1983). There is no current controversy about this among those researchers who investigate production-function based measures of productivity and technical change, whether with equation (1) or equation (2). Hulten's (1990) discussion of capital data and productivity analysis, for example, is consistent with Jorgenson's, and is endorsed by Berndt (1990).

"Sources of growth" studies (for example, Denison, 1989), which resemble productivity studies, typically employ a somewhat different approach to capital. Hulten (1987) shows that sources of growth studies address subtly different, though related, economic questions from those addressed by technical change studies based on production functions or on index number methods. In this paper, I consider only national accounts and production analysis uses, without considering sources of growth studies as a third use.[4]

1. Measuring capital services: A simplified example.

Suppose a trucking company has purchased some number of trucks (lorries) in each of 5 successive years. Except for the year in which they were purchased, the trucks (lorries) are identical -- no quality change has taken place. At the present date, therefore, the remaining trucks in the fleet differ only in age.

Let us use the term "Deterioration" to define the loss in productiveness of that fleet of trucks as it ages.[5] Deterioration arises from two sources. As the truck gets older its productiveness declines because it is less efficient than it was when it was new, spends more time in the repair shop, and so forth. In the Appendix, this loss of

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[4] In particular, I do not consider whether capital should be constructed to correspond to a consumption foregone concept, as proposed by Kuznets (1956) and recently advocated by Denison (1989). i am, however, not convinced by Denison's reasoning. Consumption foregone is most certainly not the right way to measure capital for industry and sector productivity studies.

[5] This is not entirely standard terminology. See the Appendix.

efficiency is called "decay." Then, additionally, some of the trucks will be retired, taken out of service for whatever reason. The loss of efficiency from the combination of retirements and decay is deterioration, the decline, as it ages, in the ability of the truck fleet to generate capital services.

Taking a new truck as producing one unit of capital services, a 1-year old truck produces $(1 - D_1)$ units of capital services, where D_1 represents the proportionate deterioration between a new and a 1-year old truck. A similar calculation can be applied to 2-year old, 3-year old, and so forth, trucks. Each age of truck can then be expressed as some fraction of a new truck -- the proportion that has not been reduced by deterioration -- and all ages of truck can be expressed as "new truck equivalents." When a retirement occurs, the retired truck is, of course, reduced to zero new-truck equivalents. Expressing used trucks in terms of new-truck equivalents implies that all of the trucks are perfect substitutes, which Jorgenson (1989) explicitly assumes.[6]

When inputs are perfect substitutes, it is appropriate to add up all of these new truck equivalents to obtain a measure of the quantity of trucks. Thus, the quantity of "new-equivalent" trucks owned by the trucking company after 5 years of operation is:

$$(3) \qquad \Lambda = t_5 (1 - D_1)(1 - D_2)(1 - D_3)(1 - D_4)(1 - D_5) + t_4 (1 - D_1)(1 - D_2)(1 - D_3)(1 - D_4) + t_3 (1 - D_1)(1 - D_2)(1 - D_3) + t_2 (1 - D_1)(1 - D_2) + t_1 (1 - D_1)$$

where Λ is the aggregate measure of new-equivalent trucks, $t_5, \ldots, t_1$, represent the quantities of 5-year old, 4-year old, and so forth, trucks, and $D_1, \ldots, D_5$ indicate the

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6 The assumption that old trucks can be represented as some smaller quantity of new trucks (that is, reduced proportionately by deterioration) implies somewhat unrealistic conditions about the way trucks and other inputs combine in the production process. One can think of the deteriorated truck as equivalent to a lower quality truck (compared to a new one). In the quality change literature, the equivalent assumption that permits expressing improved trucks as "more" unimproved ones is termed "repackaging." The repackaging assumption and its limitations are discussed in Fisher and Shell (1972). In Triplett (1983), I considered an equivalent assumption in the context where heterogeneous goods such as trucks are explicitly measured in terms of their productive characteristics (reliability, load capacity, and so forth); again, the necessary assumptions required to represent new and deteriorated trucks solely as multiples of each other are not appealing. Necessity, not realism, is the motivation for the assumption in the capital measurement case (as it is in other cases) and one hopes that the error introduced by unrealistic assumptions is not large.

deterioration profile for trucks as they age, from their first year to their fifth. The second term in the expression, for example, represents the quantity of 4-year old trucks (t_4), proportionately reduced by four years' deterioration.

Under the procedures and assumptions stated, the flow of capital services provided by the truck fleet will be proportional to the constructed stock of new equivalent trucks. This is so mainly because the measures of deterioration (D_1 . . . . . D_5) are derived from the service contributions from trucks of various ages. For this reason, we may designate λ, in equation (3), as the productive capital stock of trucks.

A number of points about the productive capital stock need emphasis. First, note that the productive capital stock is formed out of a perpetual inventory that uses investment flows, or it may be constructed from a census of capital stock where the ages, or vintages, of capital are recorded.

Second, those different vintages of capital are reduced by estimates of their deterioration profiles. The productive capital stock is not obtained by applying depreciation profiles to the vintages of capital. Applying depreciation profiles to the vintages of capital in the stock results in the wealth capital stock (see section IV). In general, the wealth capital stock is different from the productive capital stock.

Third, note that additional maintenance, if required on older trucks (this is input decay, as defined in the Appendix), is incorporated into the deterioration measures: If a 2-year old truck provides $(1 - D_1) \times (1 - D_2)$ smaller quantity of services than are provided by a new truck, it may be because it hauls less per period than a new truck, or because it requires more maintenance per period to haul as much as a new truck, or both. Input decay and increased maintenance as trucks age pose some problems for the assumptions needed for capital aggregation, but this issue is best set aside for present purposes.[7]

Return now to equation (1).

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[7] If there is input decay because of increased maintenance as trucks age, equation (3) would be re-formulated to include truck and, e.g., maintenance labor, not just trucks alone. Input decay thus poses problems for capital aggregation, which is a major reason why it is often assumed away in empirical work on capital. See also note 6, above.

The measure of capital services in the production function (K, in equation (1)), is the measure of capital services that represents the use of this new-equivalent truck fleet for one period of time. That is, $K_t = \lambda \Lambda_t$ where Λ_t is defined by equation (3), and λ is a constant of proportionality that expresses the relation between the quantity of the productive capital stock and the quantity of the capital services it yields. This measure of trucking services, K, is equivalent to calculating measures of trucking services specific to each truck in the fleet, and then aggregating those services.

A more elaborate and explicit procedure for estimating trucking services involves measuring each truck's contribution in units such as ton-miles of capacity, or as measured with a vector of the productive characteristics of trucks; this procedure could be used if the trucks in the fleet were not of identical specification. For example, if the fleet were a mix of 1-ton, 2-ton, and 5-ton vehicles, the characteristics of the trucks can be used to "adjust" the various trucks for differences in quality or productiveness. These same characteristics could also provide an explicit measure of the dimensions in which input decay or output decay take place. For example, an older truck may yield fewer ton-miles of capacity per period than a newer one, so decay could in principle be measured by obtaining information on ton-miles of services performed by identical trucks of different ages, among those that have accumulated different mileages.

Heterogeneity, or quality change, or decay can also be handled in less traditional ways, using trucking characteristics. For example, one could treat the characteristics of trucks, or of trucking services, as inputs to the production function, rather than working with "quality-adjusted' quantities of trucks or of trucking services. The issues raised by heterogeneity in capital goods are set aside for the present paper, in order to avoid additionally complicating an already complex topic.[8]

In an alternative way of describing equation (3), the $(1 - D_t)$ terms represent relative marginal products of the services of trucks of different ages. For

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[8] The quality change problem in economic measurement, though pervasive, would require too extensive a discussion for the present article. See the various contributions in Griliches (1971); Triplett (1975), for a review of empirical research; Triplett (1989), for a review of a "high tech" good (computers); and Gordon (1990), for studies on a variety of investment goods.

example, $(1 - D_1)/(1 - D_1)(1 - D_2)$ indicates the relative marginal products of 1-year old and 2-year old trucks. This way of describing deterioration is more nearly consistent with the exposition of Jorgenson (1990) and also Hulten (1990). Hulten (1990), in fact, shows how one can use the marginal product interpretation to draw inferences about relative marginal products, and thus about deterioration, from rental price data.

The choice of interpretations lies at least partly in the preferences of the expositor. I emphasize the sources of deterioration, and the possibility of directly observing performance measures, rather than relying on the marginal product interpretation, because the former evokes the underlying engineering relationships that define the technology. Emphasis on decay and on deterioration makes more clear that one ultimately needs technical information about input decay, output decay, and about retirements, and that this technical information might in principle be gathered to resolve the empirical issues. Since one could seldom execute an experiment that would extract relative marginal products of 1-year old and 2-year old trucks from the same production technology, the marginal product terminology may suggest (inappropriately) that empirical information on deterioration either cannot be collected, or that its collection requires estimating marginal products, rather than gathering engineering information.

2. Data required to implement a measure of capital services

I now review the data that are required to compute capital stocks that are appropriate for generating capital service flows, that is, to estimate the productive capital stock. These methods can be applied either to a perpetual inventory method for estimating capital stocks or to a capital census.

Consider, first, measures of the capital stock and capital services for a single capital good. Aggregation across goods is considered later.

The unadjusted stock measures are typically constructed by the perpetual inventory method, by cumulating past investments flows for each type of capital good. The perpetual inventory method is described in Young and Musgrave (1980) and in SNA (1993), chapter X. Goldsmith (1962) originated much of the procedure followed in this work.

There are difficulties in the perpetual inventory method. For long-lived investment goods, it requires data over a very long period, which are not always of the quality that one might like. Moreover, revaluing past investments to current valuations requires accurate price indexes; the problems created in price indexes by quality change, particularly in goods that experience rapid rates of technological change, are well known.[9] Despite the difficulties, the perpetual inventory method remains the primary procedure for constructing capital stock estimates in the United States.

The unadjusted stock measures are usually called "gross capital stocks." To move from the gross capital stocks to the productive capital stock needed for production and productivity analysis, deterioration measures are needed (equation (3)). Measures of deterioration equate the productiveness of the stocks of a given type across vintages.

One element of deterioration is retirements. For retirements, one needs estimates of service lives for different kinds of assets. Such information is in fact abundant for trucks and motor vehicles, because of vehicle registration requirements. For other classes of assets, the retirements data actually available consist of a small quantity of (usually not very current) service lives and a large quantity of assumptions. There is also debate about the appropriate treatment of capital goods that are "retired" to stand-by status.

The decay component of deterioration (both input decay and output decay) is an even more serious lacuna: Very little information exists on the decline in capital services yielded by older assets, relative to new assets of the identical type. One might in principle gather data on how much additional maintenance an n-year old truck requires, relative to a new one, as an estimate of input decay, or measure the loss in accuracy of a scientific instrument after it has been in use for some period, as a measure of output decay. Decay information is obviously asset-specific, and because there are so many types of assets in the capital stock, gathering estimates of decay for any reasonably comprehensive portion of capital goods would be very expensive, and has never been undertaken. The U.S. Treasury Department has made an attempt to gather decay data for some products (see U.S. Department of the Treasury, 1990).

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[9] Hedonic price indexes are one method for using characteristics to adjust for characteristics of capital goods. See Triplett (1986, 1989a, 1989b)

In the absence of actual data on decay, two things are done, First, the literature is full of speculations and assumptions that express what various individuals believe are plausible decay patterns.

A particular assumption is "one-hoss shay" deterioration (see the Appendix), in which there is no deterioration in capital goods until they are actually retired at age T (that is, $D_1 = D_2 = ... = D_{T-1} = 0$, and $D_T = 1$ when the capital good is scrapped). Another assumption often made is that deterioration is a constant proportion in each period, $D_1 = D_2 = ... = D_{T-1} = D_T = \delta$, where δ is the rate of deterioration. This assumption is known as "geometric" deterioration. It has some convenient properties for empirical work. In Bureau of Labour Statistics productivity estimates, a "hyperbolic" decay function is assumed (BLS, 1983).

Hulten (1990) cites Fawcett for the opinion that one-hoss shay is a reasonable decay pattern. However, as usually stated, the "case" for one-hoss shay consists of the assertion that capital goods are maintained so that there is no loss in their productiveness. That speculation cannot support the one-hoss shay pattern because it ignores the distinction between input decay and output decay (see the definitions in the Appendix). Even if increased maintenance can produce an output decay profile that does not decline over time (as has been asserted), this is no support for one-hoss shay decay, since decay must be measured inclusive of both input and output decay.

The actual deterioration that takes place in a capital good, such as trucks, is wholly an empirical issue. Nothing can be known about it without finding out what happens to the productiveness of trucks and other capital goods as they are used. Obviously, speculation -- even if well-informed speculation -- is just that, and does not satisfy the need for capital decay data.

A second approach is to try to infer a decay pattern from a depreciation profile. For the case of geometric depreciation, decay is also geometric (see Hulten, 1990), so establishing one profile establishes the other. However, the correspondence between decay and depreciation profiles for specifications other than geometric is more complicated. In general, the relation between depreciation and decay profiles will depend on the interest rate. Harper (1982) carried out simulations that showed that a variety of decay profiles were consistent with convex from below, or "accelerated," depreciation profiles that resembled geometric patterns; these other, non-geometric, but accelerated, profiles could not be distinguished from geometric patterns with econometric tests. Inferring decay from depreciation does have the advantage of making use, in principle, of actual data, but extensive problems remain.

A logical circularity in the specification of data needs for production analysis seems insufficiently stressed in the capital literature. Constructing the productive capital stock requires an estimate of deterioration, and, therefore, information on decay profiles. Computing decay profiles requires information on the capital services yielded by capital goods of different ages. But if information about yields of capital services were available, that same capital services information could be employed in productivity and production analysis directly, since it is K, the capital services, that are used in equation (1). Obtaining data on capital services in order to impute decay to a capital stock measure, and then using that capital stock to derive a measure of capital services, obviously involves a redundant step.

C. Prices of Capital Goods and Prices of Capital Services

The preceding section concerned the quantities--the capital goods in the productive capital stock and the flows of capital services in the production function. Corresponding relations exist between the prices of capital goods and the prices of capital services. The latter are often referred to as rental rates of capital goods.

1. Service prices: A one-period example.

Consider the example from the previous section, a trucking firm, that owns trucks. The one-period cost of providing itself with trucking services is:

$$(4) \quad c_t = P_t\,(d + i\,) - (P_t - P_{t-1})$$

In equation (4), c_t is the per-period cost of a unit of trucking services, P_t designates the price of the truck in period t, d is depreciation (defined in the Appendix as the loss in value of a capital good as it ages), and i is some measure of the cost of financial capital -- the market (borrowing) rate of interest, for example.

Of the terms on the right-hand side of equation (4), the first term--that is, P_t (d + i) -- measures the capital cost of using a capital good for one period. That cost consists of depreciation (expressed in the equation as a proportion of the asset's value), plus the cost of having one's resources tied up in the capital good, which is the interest cost. The second term -- that is, (P_t - P_{t-1}) -- measures capital gains or losses (if any) from holding the capital good for one period: A general increase in the price of used trucks, for example, reduces the cost of holding trucks for those who already own stocks of used trucks.[10] Thus, depreciation is part of, but only part of, the cost of using capital in production, a proposition that Jorgenson correctly pointed out many years ago (Jorgenson, 1963). And because depreciation equals the national accounts concept of capital consumption, equation (4) also shows that capital consumption is only part of the cost of employing capital services. See also Hill (1997), for additional discussion of this point.

An alternative version of equation (4) is useful, in which the rental rate, or price of capital services, appears on the left-hand side:

$$(4a)\quad p_t = P_t\,(d+r) - (P_t - P_{t-1})$$

In this equation, lower-case "p" represents the price received for the capital service flow (the truck rental rate), r is the profit rate on the asset, commonly termed the "internal rate of return," and P_t and d are defined as in equation (4).

Suppose our truck-owning firm owns a fleet of trucks and rents trucks to others. Suppose also for simplicity that both the prices of (new and used) trucks that it may buy or sell and the rental price it receives are fixed to the renting firm, as they would be in competitive markets. The firm has some expectation[11] about next year's price level for trucks of all ages, which fixes, additionally, the expected capital gains and the depreciation terms in equation (4) and (4c). The market interest rate, i, is also fixed to the truck owner. One can then use equation (4) to calculate the cost to the trucking firm of renting out trucks, given all the variables on the right-hand side of the equation; equation (4a) can be used to calculate r, the rate of return, provided p_t , the capital service price, or rental rate, on the left-hand side is available. When capital equipment is actually rented, of course, p_t is available.

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[10] The one-period rule is appropriate if trucks can be resold. Selling costs are neglected.

[11] Any economic relationship that involves future prices or quantities depends on expected values, which are generally not observed, except when expectations are gathered as part of a survey (see, for example, the discussion in Wachtel (1977) and DeMenil (1977)). A great amount of speculation, mostly in macroeconomics, has occurred about how economic agents form expectations. The subject is relevant to capital measurement issues, but cannot be explored here.

In equilibrium and under competitive conditions, theory says the expected rental price of trucks will be bid up or down through expansion or contraction of the truck leasing business, until it is just equal to the costs of rental firms -- that is, in equilibrium, $p_t = c_t$. This also implies (compare equations 4 and 4a) that in equilibrium, r = i.

The rental rate for capital equipment that is owned by the user cannot normally be observed. It is often therefore proposed that equation (4a) be used to impute rental rates (i.e., p_t) for different classes and vintages of capital goods that are owned by users. if one had actual values on internal rates of return (r), there would be no great problem with such imputation; one equation would be available to solve for one unknown. However, in the absence of information on the internal rate of return, equation (4a) becomes a single equation with two unknowns, and obviously cannot be used as it stands to calculate rental rates.

A frequently proposed approach is to make use of the equilibrium condition that the expected value of r will be bid down until it is equal to the relevant borrowing rate of interest -- that is, $r_t = i_t$ (terms from equations (4) and (4a)). Because, as already noted, this also implies that $p_t = c_t$, that rental rates equal costs in each period, the equilibrium condition implies that one can "plug in" some market interest rate in place of r in equation (4a) and solve the equation for the rental rate, p_t.

Serious problems emerge when this imputation is implemented empirically. The basic difficulty arises from the fact that realized the capital gain (P_t - P_{t-1}) is observed after the fact, but realized r generally is not, because r is the rate of return to a specific asset. This does not necessarily equal the firm's overall profit rate, if the firm holds many types of capital goods.

If the rate of change in asset prices is inversely correlated with changes in interest rates, which it often is, the capital gain term is highly volatile, as it was for housing in the 1970's, and realized r may differ greatly from expected r. This realized (but unmeasured) r may fluctuate wildly with respect to any market interest rate that is "plugged into" equation (4a). In the case of housing in the U.S., the difference between realized r and its proxy, i, was so large that it created negative imputed rental rates, which is obviously nonsense and shows the limitation of the procedure (Gillingham, 1980). A more recent and general discussion of this issue appears in Harper, Berndt, and Wood (1989).

2. <u>The multiple-period model.</u>

Capital goods are typically held for multiple periods. This section extends the previous section's single-period case to summarize the intertemporal relation between the capital good's price, its service price, and the values of future service flows over the capital good's lifetime.[12]

The relation between capital good price-service flow involves a standard capital theory equation, which (ignoring for simplicity capital gains) may be written:

$$P_t = \sum_{s-t}^{T} p_s q_s [1/(1+i)]^{s-t} \quad (5)$$

In equation (5), capital letters and lower case letters are defined as before, so that P_t is the price of a capital good in period t, p_s and q_s, are capital service prices and quantities for some future period, s (where the service quantities reflect reduction for deterioration as described in the preceding section); i is the appropriate discount rate, and T is the period that marks the expected end of the asset's useful life. Thus, T-s indicates the expected number of periods of use remaining at period s. Equation (5) is generalized to include the effects of taxes and other influences in Hall and Jorgenson (1968), but those factors are ignored here.[13]

For simplicity in the following, assume no decay (so that $q_s = q_{s+1}$ for all s). Suppose equation (5) applies to a newly-produced capital good. The capital good will be purchased so long as the right-hand side of equation (5)--the present

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[12] It is customary in theoretical work to present the equations in this section in continuous time rather than in discrete time, as used here. Harper, Berndt, and Wood (1989, pp. 336-341, and 345-356) present a concise comparison of alternative theoretical formulations, show the essential equivalence of the discrete time and continuous time alternatives, and discuss the implications for empirical implementations.

[13] The periods over which equations (5) and (6) are defined should be short enough that one can neglect how the flow of services proceeds across the period (in the limit, periods are instantaneous, which is why continuous-time representations are common -- see note 12). If the intervals are actually as long as a year, either the price is taken at the midpoint of the year or a correction can be applied to the equation to incorporate some assumption about how the flows are spread across the period. This is a technical point for implementing the theory with discrete data, rather than any fundamental modification of the theory.

value of the stream of services the good yields over its lifetime--exceeds the asset price. If the supply of a newly-produced capital good is elastic, so its price does not rise as demand for that capital good increases, then investment will proceed until the quantity of investment depresses returns from that capital good (in this formulation, the service price expectation terms p_t ,.... p_s ,... p_T) sufficiently to drive the right-hand side of equation (5) into equality with the capital good price. Suppose, on the other hand, equation (5) is applied to a used capital good. Then the quantity of the capital good is presumably fixed. Investment demand for it pushes the capital good price up or down to bring about equality with the right-hand side. In either the new or the used capital good case, equation (5) is an equilibrium condition.

Now consider an identical capital good except that it is one period older, which means that it has exhausted (refer to the definition of exhaustion in the Appendix) one period of its lifetime.[14] The expression for this capital good's value (in the same period, t)is given by equation (6).

$$(6) \qquad P_t = \Sigma^{T-1}_{s=t}\; p_s q_s [1/(1+i)]^{s-t}$$

If equation (5) referred to a new truck with a 5-year lifetime (T - t = 5), equation (6) refers to an identical, but 1-year old, truck that has 4 years of life (T - 1 - t = 4) remaining. In equation (6), the summation proceeds only to period T - 1 because this older asset will be retired one period earlier than will the new one depicted in equation (5).

The economic interpretation of equation (6) is the same as for equation (5). If the price of the 1-year old truck did not equal the present value of its services over the remainder of its lifetime, the used-truck price would be bid up or down in the direction of the equilibrium condition. The only difference between equations (5) and (6) is that in the latter the truck's remaining lifetime has been shortened by 1 year, and the stream of services, which is discounted to the present, also extends over 1 fewer year.

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[14] Recall that, for simplicity, we are assuming in this section no decay over the periods that the capital good remains in use

Comparison of the two equations yields the age-price profile, or the change in price of the capital good as it ages -- call this $P_t(5) - P_t(6)$, where the numbers identify equations (5) and (6), respectively. The age-price profile is determined by the difference between the two discounted service streams: When there is no decay, this difference equals the value of the final year's service, discounted to the present. Thus, when there is no decay, depreciation for one period is equal to the discounted value of the final period's service that is exhausted by the asset's being in use in the current period.

In the general case, where decay is present, the older capital good will yield fewer quantities of services in each future period. With decay, therefore, the age-price profile, $P_t(5) - P_t(6)$, will involve the discounted value of the difference in the entire service streams, not just the final period's service. Depreciation thus values all the accumulated decay and exhaustion in the future that results from one period's aging. Note, because it is important for the following sections, that the loss in value of an asset as it ages is the discounted value of decay and exhaustions over all the remaining periods of the good's lifetime--compare equations (5) and (6).

3. Data requirements for calculating capital service prices.

> "The history of both conceptual and empirical research on multi-factor productivity measurement since Solow (1957) is almost entirely taken up with this task [i.e., measuring or imputing, prices and quantities]. And of ll the difficult problems, perhaps the most troublesome ... has been the measurement of capital input service prices" (Harper, Berndt, and Wood, 1989, page 332).

Equation (4a) documents the data needed to compute capital service prices. The variable r (the rate of return for a specific asset) and the capital gain term ($P_t - P_{t-1}$) require data on expectations, if the equation is interpreted as "forward-looking". If calculated from data collected "after the fact", both must refer to realized values. In practice, a number of choices have to be made. Harper, Berndt, and Wood (1989) explore five alternative specifications, and conclude that the empirical results are sensitive to the alternatives, though none of the options is clearly superior on conceptual grounds. For more information, see Harper, Berndt, and Wood (1989); Wykoff (1989); and Hulten (1990).

Also appearing in equation (4a) is depreciation -- the decline in value of an asset as it ages. Depreciation is considered at greater length in Triplett (1996).

Note a paradox. Capital rental rates are needed by productivity researchers as prices for the capital services inputs to production. They are usually imputed through use of information on depreciation and the other variables included on the right-hand side equation (4a). But using the depreciation and capital gains terms on the right-hand side to impute rental rates of capital services through equation (4a) requires information on asset-specific internal rates of return --which are generally not available in the absence of rental data!

This paradox is parallel to a problem already discussed on the quantity side of the productivity researchers' capital measurement problem. As noted in section II.B, had researchers measures of capital services, they would have no need for a capital stock measure; but deriving capital services measures from the capital stock requires an estimate of decay, which implies information on capital services.

Hence, though much of the controversy in capital measurement has hinged around measuring depreciation, capital decay, and so forth, obtaining the data that would settle these controversies (e.g., actual capital service patterns, or actual measures of capital rental prices) would also make the controversies irrelevant, at least for productivity and production analysis purposes. If capital services measures and capital service prices became available, estimates of either decay or depreciation would no longer be needed for production analysis -- essentially because capital stock data would no longer be needed.

D. Remarks on Capital Services in National Accounts

Several misunderstandings about productivity needs for capital data appear in some portions of the national accounts literature. I do not imply that all are in the SNA, only that they are frequent sources of misunderstanding.

1) Contrary to frequent statements in the national accounts literature, it is owned capital, not rented or leased capital, that creates problems for productivity and production analysis. One sometimes encounters in the national accounts literature proposals to treat rented capital as if it were owned in the using industry -- ie., to ignore rental payments on capital goods as costs of purchased inputs, and instead to transfer the capital, or its depreciation, from the owning industry into the industry that leases it. This proposal has the problem backwards: Productivity and production analysis requires measures of the flow of capital services and of capital service prices, not the quantities of capital stock as such. Replacing service flow measures by capital stock measures, where the service flows measures already exist and services are exchanged in market transactions, is a retrograde step.

2) The national accounts literature often identifies its own concept of

capital consumption with the flow of capital services that are used in production analysis and productivity measurement. This identification is incorrect. The issue is discussed more fully in Triplett (1996).

E. Conclusions: Capital Measures for Productivity Analysis

Constructing capital stock data for production analysis and productivity measurement requires a number of steps.

1) Ultimately, one needs a measure of capital services, the K term in equation (1). If direct measures of capital services are not available, and they usually are not, it will be necessary to construct the productive capital stock in order to estimate the flow of capital services.

2) The productive capital stock can be constructed through the usual perpetual inventory method, or from a census of capital goods. In either case, earlier vintages of capital goods are reduced by deterioration -- the loss of productive efficiency through decay and actual retirements.

3) Obtaining estimates of the decay profile -- the loss of a capital good's productive efficiency as it ages -- is particularly difficult. Usually, the decay profile is an assumption. Obtaining empirical data to validate or evaluate assumptions deserve high priority.

4) The second major requirement is for estimates of the price of capital services, the rental rates of capital goods. Sometimes, direct information on rental rates are available, from capital equipment that is actually rented or leased. If not, the price of capital services must be estimated.

5) A key -- but not the only -- component to estimate the price of capital services is depreciation. Depreciation is the change in the price of a capital good as it ages -- the change in the age-price profile for a particular kind of capital good. Obtaining empirical information on depreciation patterns to supplement the work of Hulten and Wykoff (1982) deserves high priority.

6) Applying depreciation profiles to the various vintages of capital goods, either from a perpetual inventory model or from data from a capital goods census, results in the wealth capital stock.

7) Thus, there are two similar age-related capital stock concepts -- the productive stock and the wealth stock -- and two similar profiles: the deterioration profile and the depreciation profile. The deterioration profile determines the productive capital stock, and through it the quantity of capital services that flow to

production. The deterioration profile is derived from information on input decay, output decay and retirement. The depreciation profile measures the decline in value of capital goods as they age; it depends on input decay, output decay, and exhaustions. Depreciation is one component of capital service prices, or the rental price of capital. Both profiles are needed for productivity analysis.

An illustration of the difference between deterioration and depreciation profiles is the "one-hoss shay" capital good. As the one-hoss shay ages, it has, by assumption, no deterioration, so there is no decline in the capital services it renders until it is actually retired. The asset does, however, depreciate in each period because exhaustion affects the value of the asset. The wealth capital stock therefore declines from one period to the next.

8) The decay component of deterioration needs to be estimated empirically, as does depreciation (estimating actual retirement patterns is also difficult but somewhat more tractable). In practice, both decay and depreciation are often obtained --in the absence of actual, asset-specific information -- by assuming some probable profile, or a decay or depreciation function. A large part of the empirical debate in the capital literature revolves around whose assumptions are thought to be more (or less) reasonable. It seems obvious that the best way to resolve these speculations is through gathering appropriate data.

9) It is clear that productivity needs for capital data, both on the price and quantity side, are very far from being met. It is difficult to see how those needs could be met completely, absent a system of price and quantity measures for capital services. In the absence of such a data system, researchers must continue to infer capital service data from capital stock estimates.

10) Despite the great difficulty in assembling the data, it is important that a modern production account be added to the SNA. Incorporating such an account into the SNA avoids much confusion. The work of Jorgensen and his associates provides the appropriate conceptual framework.

III What Does the SNA Say About Capital in Production Accounts? What Should It Say?

The SNA production account is contained in (1993), chapter VI. Most of chapter VI, as well as most of chapter X, on the capital account is consistent with capital theory and much of the language is compatible with the needs of production and productivity analysis. Yet, the Production Account itself is seriously incomplete. Its incompleteness lies in its failure to distinguish, adequately, between the concepts and data on capital required for production analysis on the one hand and the complementary concepts and data required for income and wealth accounting on the other. It is this incompleteness that is misleading and the source of error rather than (with a few exceptions) mistakes, in the chapters themselves.

The first point to establish is that the purpose for which the SNA production account was designed is for the analysis of production. That is, the SNA production account is intended for the some analytic purpose as the one--production analysis and productivity measurement -- outlined in section II, above.

> "Production can be described in general terms as an activity in which an enterprise uses inputs to produce outputs" (paragraph 6.6)
>
> "Economic Production may be defined as an activity carried out under the control and responsibility of an institutional unit that uses inputs of labor, capital, and goods and services to produce outputs of goods or services." (paragraph 6.15).

Thus, the description of the SNA production account is consistent with equation (1), above.

As a second point, the SNA correctly records the relationship between the price of a capital good and the present value of its future flow of capital services. For example:

> "The value of a fixed asset to its owner at any point of time is determined by the present value of the future rentals (i.e., the sum of the discounted values of the stream of future rentals) that can be expected over its remaining service life. Consumption of fixed capital is therefore measured by the decrease, between the beginning and the end of the current accounting period, in the present value of the remaining sequence of rentals. The extent of the decrease will be influenced not only by the amount by which the efficiency of the asset may have declined during the current period but also by the shortening of its service life and the rate at which its economic efficiency declines over its remaining service life. The flow of future rentals which determine the present values used to derive consumption of fixed capital must, of course, be valued at current prices or rentals."

Thus, this paragraph presents in words the content of equation (5), above. The SNA definition of the consumption of fixed capital is identical to the usual economic definition of depreciation, as discussed in Triplett (1996).

As a third point, the SNA correctly incorporates the conclusion that capital consumption is only part of the cost of using capital equipment in production. For example:

> "The rental is the amount payable by the user of a fixed asset to its owner, under an operating lease or similar contract, for the right to use that asset in production for a specified period of time. The rental needs to be large enough to cover not only the reduction in the value of the asset over that period -- i.e., the consumption of fixed capital -- but also the interest costs on the value of the asset at the start of the period and any other costs incurred by the owner. The interest costs may consist either of actual interest paid on borrowed funds or the loss of interest incurred as a result of investing own funds in the purchase of the fixed asset instead of a financial asset. Whether owned or rented, the full cost of using the fixed asset in production is measured by the actual or imputed rental on the asset and not by consumption of fixed capital alone. When the asset is actually rented under an operating lease or similar contract, the rental is recorded under intermediate consumption as the purchase of a service produced by the lessor. When the user and the owner are one and the same unit, consumption of fixed capital represents only part of the cost of using the asset."

Thus, the SNA accepts the definition of the cost of capital, or the capital rental rate, that is contained in Jorgenson's production accounting framework, and in equation (5), above.

Note, additionally, that the 1993 SNA is free of a common error made in earlier national accounts discussions of capital. In these earlier discussions, it was often argued that depreciation was a method for allocating the contribution of capital goods over the accounting periods covering the life of that good. The SNA correctly dismisses this idea.

> "... Consumption of fixed capital is not, at least in principle, a method of allocating the costs of past expenditures on fixed assets over subsequent accounting periods." (paragraph 6.183).

On this same point see paragraph 10.118 in the SNA chapter on the capital account. For further discussion, see Triplett (1996).

As a final point, the capital account chapter of the 1993 SNA (chapter X) also contains the correct relation between capital consumption and the elements in the income and wealth accounts. For example, in paragraph 10.27, the SNA indicates that capital consumption, which "represents the reduction in the value of the fixed assets used in production during the counting period..." should be deducted from gross saving to get net saving. It also states that capital consumption should be deducted from gross capital formation to obtain net capital formation. The latter statement is correct for the calculation of the wealth capital stock; however, it is not correct for the calculation of the productive capital stock.

Unfortunately, when we turn to the SNA's production account itself, things are not so satisfactory. As described in paragraph 6.4, the SNA production account has three elements: "Output, intermediate consumption and consumption of fixed capital." The problem here is: Consumption of fixed capital does not represent the flow of capital services to production, so it is not analogous, as the readers of the 1993 SNA might incorrectly infer, to intermediate consumption.

The problem is compounded somewhat by later language in the production chapter, which can be misinterpreted: "Intermediate consumption also does not include cost incurred by the gradual using up of fixed assets owned by the enterprise: the decline in their value during the accounting period is recording as consumption of fixed capital." (Paragraph 6.148). The statement is, of course, correct but it sets up an inappropriate parallel between intermediate and capital consumption. See also, paragraph 6.147. Though capital consumption is indeed the value of capital "used up" (Triplett, 1996), capital consumption is not the value of capital services provided to production, as an unwary reader might infer. Though these paragraphs on accounting for intermediate consumption do not actually constitute a statement of the way capital services are to be recorded in the production account, they are probably so interpreted by most readers.

Moreover, capital consumption is recorded in the SNA's table 6.1 in a way that could make it appear that the 1993 SNA regards capital consumption as the measure of the flow of capital services to production. This, again, leads to a natural mistake: A reader would infer that the SNA records capital consumption in the production account because capital consumption is regarded as the input of capital services to production.

It is not, then, that the 1993 SNA contains inappropriate descriptions of capital and the relations between productive capital stocks, capital services, and production accounts. It is, rather, that the appropriate relationships for production accounting and for productivity measurement are largely missing. Because they are missing, this has led to much confusion on the part of users of national accounts, who, not unsurprisingly, have taken the elements of the SNA's production account to be the appropriate ones for the analysis of production and for measuring productivity. Unfortunately, they are not the appropriate concepts. And the incompleteness of the 1993 SNA production account becomes more of a problem at the industry and sector level.

The SNA needs to be supplemented with a chapter that describes the data needed for production analysis and for productivity measurement. This chapter should contain an explicit statement of the derivation of the productive capital stock and its relation to the wealth capital stock. It needs also to contain a description of the measurement of capital services and their relation to the productive capital stock. Additionally, it needs to explain the derivation of the rental price of capital, or the price of capital services, and to explain its relation to the concept of capital consumption. Finally, it needs to explain the purposes for which capital consumption, or depreciation, are appropriate and -- most importantly -- to explain that capital consumption does not provide a measure of capital services in the production account. This latter point is developed at considerable length in the companion article to the present one (Triplett, 1996). Most of the remaining points for an SNA production account chapter can be taken from the work of Jorgenson and associates (for example, Jorgenson, Gollop and Fraumeni, 1987).

IV. Capital Measures for Income and Wealth Analysis

The wealth capital stock is the current market valuation of a nation's productive capital. The wealth stock is usually estimated by applying depreciation patterns to the growth capital stock. The methods for constructing the wealth capital stock are described in SNA (1993) and U.S. Bureau of Economic Analysis (1987). Though there are many difficulties in constructing the gross capital stock, through perpetual inventory or other methods, these problems are well understood and do not need to be addressed separately here.

A major issue in constructing the wealth capital stock is the estimation of depreciation patterns. Information on depreciation is needed to construct the wealth capital stock, it is needed directly for national accounts, and it is also needed for production accounting. For national accounts, it is well known, depreciation provides an adjustment to income; capital consumption makes up the difference between GDP and NDP. For production accounting, depreciation is a component of the price of capital services (section II, above, equation (4)). Thus, a great amount of the literature on measuring capital is concerned with the task of measuring depreciation.

A. Alternative Methods for Measuring Depreciation

Economic depreciation is the change in value of a capital good as it ages, or the change in value of a cohort of capital goods as the cohort ages. Though it seems obvious that one would turn to market information about selling prices of used equipment in order to determine the values of capital goods that are no longer new, in fact, calculating depreciation from market price data for used equipment has been controversial. Hulten and Wykoff (1981a) discuss four alternatives that have been proposed or used to obtain estimates of economic depreciation.

1. Rental price data.

One can infer decay patterns from information on the rental prices for capital goods of different ages (see also Hulten, 1990). Information on decay, plus information on service lives and retirements, can then be combined with the rental price differentials to infer depreciation in capital goods prices. The approach, in other words, makes use of information on the price of capital services to impute prices for capital goods of different ages.

The rental price approach is an attractive alternative for cases where capital equipment is rented or leased. Where both rental price information and prices of used capital goods are available, the rental price method is a useful supplement to direct estimation of depreciation.

In a world in which price information on either capital goods or capital services is exceedingly sparse, it would be a luxury to choose between the two approaches, so there is little need to assess which is better. In practice, there are probably few cases (vehicles come to mind) where the two approaches are viable alternatives. In some of these, the rental payment may include services or costs that an owner might not necessarily need to provide or incur, which might require some sort of correction.

2. Retirements approach.

What Hulten and Wykoff (1981a) call the "retirements approach" is a commonly-employed method for estimating depreciation. In this approach, mean service-life estimates, and distributions of retirements around the mean service life, are combined with some assumed depreciation pattern to yield the estimate of economic depreciation for a cohort of capital goods. In many cases, the service lives and the retirement distributions also contain a large component of assumption.

One advantage of the retirements approach is that it can be applied with minimal information; that advantage does not extend to any other method that replaces assumptions with actual data. The retirement approach also has the advantage of making use of judgments of informed individuals.

The major problem with the retirement approach is its excessive reliance on assumption. Without empirical information to assess the various assumptions introduced into the method, it is difficult to form any impression of its accuracy. Testing or validating the assumptions underlying the retirements method involves, for the most part, applying one or more of the other alternatives for estimating depreciation that are discussed in this section.

3. <u>The investment method.</u>

This method, illustrated in the work of Coen (1980), requires assuming some model of investment behaviour. Then, conditional on the investment model chosen, one can examine alternative depreciation patterns to determine which depreciation pattern is most nearly consistent with the actual pattern of replacement investment.

The investment approach depends crucially on the validity of the investment model that is assumed. The approach would offer the most promise if replacement investment predictions were relatively insensitive to one's economic model of investment, but quite sensitive to the form of depreciation. From the meager available evidence, one suspects that the opposite may be the case.

4. <u>Capital census method.</u>

A final alternative is to compare censuses of capital stocks at two different times. Of course, the capital census must record actual values of capital goods, not just "book values" or historical cost estimates. If one has in addition the .pattern of investment in different types of assets between the two complete censuses, one can then compute the depreciation pattern implied by the observed change in stock. There is currently revived interest in capital census methods.

5. <u>An assessment of the alternatives.</u>

None of the alternatives to market-price estimation of depreciation is without problems. Perhaps the strongest case for the market-price method for estimating economic depreciation lies in the inadequacies of the alternatives.

B. Market Price Studies of Depreciation

The major study so far, Hulten and Wykoff (1981a, 1981b), presents empirical estimates of depreciation, using the market price method, for 8 of the 22 Bureau of Economic Analysis classes of capital goods. These categories amount to 55 percent of producers' durable equipment in 1977, and 42 percent of nonresidential structures in the same year (Hulten and Wykoff, 1981a, page 94). They also review a number of other studies (Hulten and Wykoff, 1981a, pages 106-107) that have used similar methods. Studies have been carried out by other researchers subsequently (Perry and Glyer, 1988, on farm tractors; Oliner, 1990, on computers; and Wykoff, 1989, on business automobiles), using similar methods. In addition, the Department of Treasury has studied some other asset classes. A recent survey of empirical estimates of depreciation is Fraumeni (1997).

1. Methods.

Hulten and Wykoff (1981a, 1981b) estimate depreciation functions with a Box-Cox procedure, to permit the form of the age-price profile, or depreciation function, to take on any shape suggested by the data.

(7) $f(P_{it}) - \alpha + g(\beta\, s_{it}) + h(Y_t) + \varepsilon_{it}.$

In this equation, P is the price of a particular capital good, i, observed on a used equipment market at time t; s is the age of that capital good at time t; and ε_{it} is the standard regression error term.

The estimated parameters are α (interpreted as the scrap value of the asset at its retirement), β, which is the depreciation rate, and Y, which Hulten and Wykoff term the rate of change of replacement cost. The Box-Cox regression contains straight-line depreciation or geometric depreciation as special cases, which permits hypothesis tests on these two widely-used depreciation functions.

2. Summary of findings

Hulten and Wykoff summarize the results of this research in a few generalizations.

1) In almost all cases, the pattern of economic depreciation for an asset class appears accelerated, relative to straight-line depreciation.

2) Hulten and Wykoff rejected, through statistical tests, both the major alternative depreciation patterns (straight-line and geometric, or declining balance). One could read this result as evidence in favor of some other form of depreciation, one having a more complex form than the simple mathematical forms implied by either straight-line or geometric depreciation.

3) Hulten and Wykoff point out, however, that if one must choose between the two major alternatives, the evidence is overwhelmingly in the direction of geometric depreciation. The actual depreciation profiles they estimated were <u>more</u> accelerated than implied by geometric forms; straight-line depreciation is, therefore, even more strongly rejected in their statistical tests.

4) Different depreciation rates apply to different classes of assets. This is a potential problem, since only a relatively small number of assets were studied. Where empirical information is lacking on the actual structure of depreciation patterns, Hulten and Wykoff conclude that the geometric assumption is better than the straight-line assumption. The reasoning is essentially that already presented in (3), above: Most depreciation patterns that have in fact been estimated are more nearly geometric than straight line, so, where depreciation patterns must be assumed for lack of empirical information, the geometric is a better assumption than the straight-line assumption.

The available studies are surely not the last word in estimates of economic depreciation. In fact, this research is almost in its infancy. More up-to-date studies on more products, with perhaps improved methodology and better data, may be forthcoming. Given the importance of depreciation for measures of capital, such research should have high priority. As more studies become available, they should make it possible to improve the estimates of depreciation used in the construction of capital stocks.

C. <u>Future Research On Market Price Depreciation Estimates</u>

I regard the work of Hulten and Wykoff (1981a, 1981b), and other similar studies, as providing empirical information that is directly relevant for the needs of national accounts, as well as for the needs of productivity analysis. Objections to the validity of market-price estimates have been raised. This section reviews two of these objections. I believe the objections that have been raised to the market price method ought really to be viewed as a research agenda that might lead to improvements in the method, rather than as valid objections to immediate adoption.

1. Lemons.

The underlying idea behind what is known as the "lemons model" is that the equipment that finds its way into used capital goods markets consists disproportionately of those pieces of equipment that provide less satisfactory service. For this reason, prices in used equipment markets, the argument goes, are biased or contaminated; they are lower than the average value for machines that are retained by their original purchasers, or that are sold in private transactions.

Anecdotal evidence suggests that the best machines (Hulten and Wykoff call them "pearls") are more likely to exchange in informal channels. This suggests that sellers expect the best assets will be undervalued if placed in regular public marketing channels, so that market prices for used equipment may not represent the value of the best machines.

One knows that the lemons bias to used asset prices exists, and the theory shows the direction of bias. What is missing from the entire discussion of lemons is perspective: How large is the bias? That requires empirical evidence, which is missing from the literature on lemons. Many economists seem to be reasoning from their own experiences in used automobile markets. My own experiences leave me with a different impression: It is not that difficult for informed buyers to distinguish lemons from pearls, and even if individual purchasers lack the required expertise, it can be obtained through pre-purchase appraisals and so forth. My intuition thus agrees with Hulten and Wykoffis assertion that the lemons problem, though clearly of considerable concern, has received altogether disproportionate attention in discussions of the usefulness of used-equipment prices for estimating depreciation. Others' intuitions differ, so this remains, of course, a topic of contention, and for empirical research.

2. An alternative, but similar, bias.

Even if a piece of equipment is not a lemon, there are reasons for believing that used equipment that is retained by its owners may be more valuable, to those owners, than equipment that finds its way into resale markets.

Even relatively standardized pieces of capital equipment may receive some custom modifications for a particular use. Once customized, this equipment will be less valuable to other users than to the user who purchased it originally. A truck configured for selling ice cream bars in the park and at public gatherings may not be useful for other employments, if the ice cream business contracts. Steel-making machinery may be difficult to adapt to any other use. Prices of used ice cream trucks may reflect the costs of altering them for alternative uses, and will thus understate the value of an ice cream truck that remains in its original use.

Again, though it has validity, one can make too much of this objection. Whenever heterogeneous goods are observed in markets, economic theory suggests that there must be differences in production functions, or in tastes, or the objective functions of users--otherwise, all would buy the same variety (Rosen, 1974). The individual who buys, say, a large sedan puts a higher value on that large car than some other buyer who, though he could have afforded it, did not buy it (this is just a variation on familiar "consumers surplus" analysis). This valuation problem will be more serious, empirically, the greater the amount of customization in capital equipment, and the greater are the dislocations and structural shifts in the economy.

V. Summary and Conclusions

This paper has drawn the distinctions between the capital data needed for production analysis, and therefore for the SNA production account, and the capital data needed for income and wealth accounting. 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.

The estimation of both capital stock measures begins from the gross capital stock. The productive capital stock is computed in order to estimate the flow of capital services to production. Accordingly, a capital good must be entered in the productive capital stock according to its ability to contribute to production. A cohort of existing capital goods in the gross stock must therefore be reduced by its deterioration--decay plus retirements--relative to a cohort of new capital goods of the same type. The most important data needed to convert the gross stock to the productive capital stock are measures of retirements and of decay.

The wealth capital is computed as a component of national balance sheets, and in order to compute capital consumption, or depreciation, as an adjustment to income to account for the loss of wealth that occurs when capital goods are employed in production. The wealth capital stock is in fact computed from the gross capital stock by applying depreciation profiles to cohorts of capital goods in the gross stock. The most important data needed to convert the gross stock to the wealth stock are good empirical measures of depreciation.

The paper also emphasizes that, contrary to much of the national accounts literature, capital consumption does not measure the services of capital goods to production. The inappropriate linking, in the past, of capital consumption and capital services has obscured the need for the productive capital stock measure. This inappropriate linking of capital consumption and capital services has also led to a production account in SNA (1993) that is not in fact appropriate for production analysis. Revising the SNA production account to incorporate an appropriate accounting for capital services and for the price of capital services deserves high priority in national accounting.

APPENDIX

A Dictionary of Usage on Capital Measurement

In the literature on capital measurement, the same term has sometimes been attached to different concepts. And where this is true, each of the concepts may also have been assigned multiple names by different writers. Not surprisingly, controversies and confusions have arisen that are at least partly terminological.

One would like one-to-one correspondence between concepts and terms, rather than -- as we have now -- many-to-many correspondences. This dictionary on capital measurement has been compiled primarily to avoid ambiguity in the accompanying review of capital measurement needs (Triplett, 1997). The definitions are also proposed as consistent terminology that can be used in writing about capital, both within statistical agencies and among economists who are interested in the subject.

The capital measurement dictionary differs in several respects from a conventional dictionary. First, it is not alphabetical: Entries are arranged in an order that emphasizes how the concepts fit together. An alphabetical index appears at the end.

Second, the dictionary is not intended, as is a conventional dictionary, solely to record actual usage and existing definitions of words. That would prolong the confusions that already exist. Though the definitions are based on the most nearly consistent usage in the capital measurement literature, so far as consistency can be found there, they have been chosen to enhance consistency in usage, to reduce prevailing inconsistencies, and to avoid potential confusions and undesired connotations.

For these, and other reasons, the dictionary corresponds more nearly to a "dictionary of usage" than to a normal dictionary of definitions. As does any other dictionary of usage (for example, Fowler, 1983), it contains suggestions on the usage of language, and in some cases, proposals for modifying usage in ways that I believe will be clearer and avoid misunderstandings. Because the dictionary expresses my own preferences for usage of terms, it obviously will not necessarily express those of others, and for this reason is best regarded as a work in progress.

The term "capital" is itself employed in different ways in economics. This dictionary is concerned with capital goods -- machines, buildings, and so forth that are used in the production of goods and services. In the System of National Accounts (SNA, 1993) this is tangible capital. The term "asset" will be used as a synonym for a capital good. "Measuring capital," in this context, refers to constructing or estimating quantitative measurements of properties of these capital goods, or frequently, of groups and aggregations of capital goods.

Productive capital assets can also include land, inventories, livestock, and intangible capital such as human capital, research and development, and so forth. Many of the concepts and definitions in the dictionary apply or can be adapted to these other productive assets.

"Capital" may also be used in a financial sense, such as, for example, to refer to a stock of working capital. /1/ Working capital, or finance, may be a productive input. The concepts in this dictionary do not, however, normally apply.

For simplicity, I assume no inflation, no obsolescence, and no distribution around capital service lives, unless explicitly stated to the contrary. These factors can be included in the analysis as refinements (even if difficult refinements) to most of the basic concepts that are relevant for capital measurement.

I. Physical concepts

The first group of capital concepts all concern physical properties of capital goods. I distinguish the elements (part A) from aggregations of the elements (part B). Value concepts of capital appear in part II.

A. Physical concepts of capital: The elements

1 Capital service -- the productive input, per period, that flows to production from a capital asset. If two or more types (or ages) of capital asset are aggregated, the capital service measure takes the form of a quantity index, combining services

1. Hicks (1974) remarks that the origin of the idea of capital lies in accounting practices that were developed to meet the needs of merchants, and "it is the merchant who thinks of his capital as a Fund that is invested in a stock of saleable goods" (page 310). The opposing view of capital (a "stock of real goods, with power of producing further goods...") Hicks referred to as the "Materialist" view (page 308). On this distinction, the materialist view of capital is the domain of this dictionary.

provided by the separate kinds of assets. Such an index number requires weights, as do all quantity indexes. The price of capital services is defined and discussed in the values section (Part II).

Notes on capital services. The measure of capital services is usually defined circularly, by assuming that the services are proportional to the productive capital stock (defined in I. B.). For example, Jorgenson (1989, page 3) writes: "...Capital services are measured in terms of the use of durable goods for a stipulated period of time." If an establishment owns 20 trucks (lorries) of a given type they yield 20 units of "trucking services" per period.

It is fully in the spirit of modern production analysis, however, to measure capital services explicitly. As noted above, the services of a light bulb might be measured in "lumens per period." Trucks could be measured in, say, ton-miles of capacity per period. If the Bureau of Economic Analysis (BEA) has measured computers appropriately (see Cole, et.al, 1986, and Cartwright, 1986), the services of computer processors are measured as a vector, with elements "instructions per period" and "memory capacity (per period)" . This extension of the capital services measurement concept provides a bridge between the traditional analysis of capital (which rests on the implicit assumption of homogeneous capital goods, at least within classes of goods) and the analysis of quality change, which is usually treated as a discrete subject. An example of such an extension into "characteristics space" is Triplett (1983).

The "capital service" is the variable that appears as an input in the production functions of production theory. Suppose the production function can be written: $Y = Y(K, L, M)$, where Y is the flow of output. Of the input variables, M is the quantity of materials used per period, L represents the quantity of labour services used in production per period, and K must also be understood to refer to the flow of capital services. The volume of the trucking company's output is not determined by the number of trucks owned, but the number of truck-miles it has utilized -- the number of trucking ton-miles is therefore a better measure of capital inputs to transportation (and even better would be a more detailed specification of the truck's characteristic and the characteristics of the output -- see, for the classic treatment, Spady and Friedlaender, 1977).

Whether capital services are measured explicitly or not (that is, whether an attempt is made to define the services of capital goods in engineering terms, or just to define them in terms of a period's use of the equipment), extracting capital services measures from data on past investment flows is a major thrust of the capital measurement literature. Past investment must be adjusted for decay and for retirements (see definitions below) in order to obtain measures of the stocks of each type of asset, that is, to show how the assets contribute to production. For details, and reference to the literature, see Jorgenson, Gollop and Fraumeni (1987), Hulten (1990), and Triplett (1996, 1997).

As already noted, the definition of capital services makes it a synonym for "capital input" to production. "...Capital services represent the quantity of capital input, just as labour services represent the quantity of labour input," (Jorgenson, 1990). Regrettably, the term "capital input" is sometimes also used to refer to the capital stock variable (usually, the productive capital stock) from which capital services flow. I regard this usage as both confusing and redundant. There are but two concepts -- capital stock and capital services. It is absolutely essential to distinguish the capital stock from the flow (capital services). Using the term "capital input" as a synonym for one stock concept is inappropriate and confusing.

2. <u>Decay</u> -- the decline in productive services yielded by an individual capital good as it ages. A light bulb that lasts for 10 periods with no loss in brightness or increases in energy consumption is an example of zero decay. Most capital goods, however, lose productiveness as they age, and so exhibit some form of physical decay. The concept is also termed "efficiency decline," (I.A.6) "efficiency decay," or "loss of efficiency" (I.A.4) in the literature, and sometimes also "deterioration" (I.B.1). The first three terms may be useful as synonyms, but I propose (below) an alternative employment of the term "deterioration."

Feldstein and Rothschild (1974) distinguish "input decay" from "output decay," as does Fawcett-BLS (1979).

3. <u>Input decay</u> -- input decay occurs when an asset requires increased usage of other inputs as it ages. A car, for example, might use more oil as it gets older, though everything else about its performance remains "good as new." Older machine tool may need more maintenance and repair, which implies that more labour must be used with it to obtain the same output.

4. <u>Output decay</u> -- the decline in services rendered by the capital good as it ages. Suppose, for example, one measures the services of a light bulb in terms of its brightness, perhaps in "lumens per period" or a truck (lorry) in terms of "ton miles

of hauling capacity per period." Output decay is the decline in lumens per period as the light bulb ages or in ton-miles as the truck ages.

5. "One hoss shay" -- a colourful term, taken from the once famous poem, "The Deacon's Masterpiece," by Oliver Wendell Holmes (both the second and third words are rendered in American dialect), to designate a capital good that exhibits neither input decay nor output decay during its lifetime. In economic literature, the one hoss shay asset is usually taken as a polar case in empirical analysis, or sometimes is introduced as a simplifying assumption in theoretical work.

6. Efficiency decline -- synonym for decay (I.A.2).

Notes on the concept of decay. The concept of decay is a crucial one in capital measurement. Some additional remarks about input and output decay may clarify the concepts.

For many classes of capital goods, owners can offset output decay by increased maintenance. The division between output decay and input decay is therefore economically, not technologically, determined. The possibility that increased maintenance could compensate for output decay cannot, however, create a one hoss shay asset, because a one hoss shay asset is by definition one with zero decay. There seems to be some confusion in this point in the literature: A good deal of the anecdotal evidence that has been cited in favour of the plausibility of the one hoss shay model has ignored input decay.

Input decay causes complications in measuring capital stocks and capital services. Researchers often wish to aggregate different kinds of capital goods, or the services from different capital goods, into an aggregate measure of "capital," or an aggregate measure of "capital services." Carrying out such aggregations requires (for technical reasons that need not be discussed here -- see Blackorby, Primont, and Russell, 1978, or Bliss, 1982) that the values placed on new and old machines do not depend on other inputs employed in production. For example, the way new and old machines combine in production should not depend on the quantity of maintenance labour employed, which seems contrary to the notion of input decay. If this "separability" condition (as it is known in the literature) is not met, the capital aggregate cannot be computed without acknowledging the labour input, or may not be legitimate at all. It is sometimes therefore assumed that all decay is output decay. But if input decay in fact exists, it must be incorporated into the capital measures, no matter how inconvenient its implications.

Terminology is by no means standard for the concept i have designated "decay." For example, Fawcett - BLS (1979) uses the term "physical depreciation" or "efficiency depreciation" to cover the combined effects of input and output decay. Harper (1982) defines "efficiency" as "the marginal technical substitution of an old asset for the new one," which includes both input and output decay. Feldstein and Rotschild (1974), as well as Griliches (1963), and Hall (1968) define "deterioration" as consisting of input and output decay. Ysher (1980, page 6) follows these writers by defining "deterioration" as the case where the capital good's "marginal product in physical sense is less than when it was new, or requires more maintenance and repair" (which amounts to input decay combined with output decay).

For reasons given below, I propose to use "decay" (without qualifier) to indicate the combination of input decay and output decay. That is (as noted in I.A.2):

Decay -- input decay combined with output decay.

The term "decay" is simpler than the other definitions that appear in the literature for the same aggregation -- it reduces both the number of terms and the number of definitional relationships to be memorized. Moreover, many times one will not need to distinguish between input decay and output decay, so dropping the adjective suffices, rather than changing to another term. Note, however, that input decay and output decay may not be measured in the same units.

Efficiency decline (I.A.6) may remain the preferred synonym among some writers on capital. Terms such as input and output efficiency decline seem more cumbersome that input and output decay; having a parallel between decay (efficiency decline) and depreciation (value decline -- II.A.x) also seem valuable, heuristically. For these reasons, I prefer the term decay.

The term "decline in efficiency" suggests discussing capital in "efficiency units," which unfortunately is a term that is also employed in discussions of quality change in capital measurement (and is, moreover, not very precisely used). I avoid terminology that is used for different, though related, concepts within the same literature.

Any alternative is preferable to "physical depreciation." If that term is employed, then whenever one uses the term "depreciation" two words are required rather than one (i.e., one must distinguish "physical depreciation" from "financial or value depreciation"). Confusion over the related, but different, concepts of decay and depreciation has been so evident in the capital literature that banning "physical depreciation" from the lexicon of capital deserves support from everyone who prefers less confusion to more.

7. <u>Retirements</u> -- also known in the literature as "discards" or "scrapping." All of these terms designate assets withdrawn from service, and all are easily interpretable, so the dictionary could well retain them as synonyms. Hulten (1990), among others, employs the "retirements" terminology. I've avoided "discards," which is perhaps a more descriptive term, because there are too many capital terms beginning with the letter "D," which frustrates the use of mnemonics in algebraic expressions.

<u>Notes on retirements</u>. For retirements, the normal metric is capital goods: A retirement is a good removed from the gross capital stock , or from the productive capital stock. For some purposes, a capital services metric may be more relevant: When a capital good is retired from the productive capital stock, deterioration (I.B.1) records the loss of capital services the retirement entails (in addition, of course to decay). The context usually makes clear which metric is meant. If capital goods are retired only when they yield no more capital services, then retirements have no effect on the productive capital stock, even though they are withdrawn from both gross and productive stock.

Most writing on capital acknowledges that actual retirements involve a distribution around the expected, or mean, service life. Empirical work on capital measurement often involves determining (or assuming) the parameters of the retirement distribution. Winfrey (1935) presents retirement distributions that are still employed. SNA (1993) treats unexpected retirements (loss from a hurricane, for example) differently from the expected distribution.

Intensity of use -- that is, speed of operation, or number of hours of employment per period -- ought to affect decay and retirements independently of the age of the asset. This does not seem to have been featured prominently in recent writing on capital (see, however, the comment by Berndt, 1990).

Hulten (1990) assumes additionally that, where there is a distribution of retirements for a given class of assets, this distribution is matched by an identical distribution of decay -- "lemons (II.A.8)," in other words, are not only retired sooner, they also give less satisfactory service while in use (which may be the reason they are retired early). This assumption is reasonable in itself; but it implies additionally that less satisfactory service predisposes the asset to accidental loss (another reason for premature retirement), which seems less plausible.

8. Exhaustion -- the capital service loss because of decline in the life expectancy of an asset. This physical capital concept appears somewhat less frequent in the capital literature. Consider a group of light bulbs, all purchased in one period. Suppose the light bulbs exhibit no decay, last for 10 periods, and all expire at the same moment. After one period, no decline in productive services is experienced, but the asset owner now has a stock of bulbs with 9 periods of use remaining, instead of a stock of 10 - periods' use. In the words of Griliches (1963, page 127), the assets have "fewer work years left," which motivates his definition of exhaustion, which I have followed here.

Exhaustion is defined as the loss of services in the last period of the capital good's lifetime. This is the same as the last period's decay, after which the capital good provides no capital services -- see the mathematical appendix to Triplett (1996). The justification for applying a special term to the last period of a capital good's decay profile is mainly heuristic: It emphasizes that the number of remaining years in a capital good's lifetime also matters for some purposes.

B. Physical concepts of capital: The aggregates

The ultimate physical aggregate of capital is the concept of the capital stock, which exists in several forms. It will be convenient, however, to discuss first several essential aggregates formed from the elements defined in section I.A.

Four major elements -- input decay, output decay, retirements, exhaustions -- are associated with the physical decline of capital goods (see the previous section). They refer to something inherently physical that happens to an asset as it ages (by the calendar) or is utilized in production. Put another way, all four concepts refer to the volume of capital services that the owner gets today from an investment that was made some years in the past.

The proportionate contributions of the four elements to the total decline are not solely technologically determined. They are at least in part subject to economic decisions of owners of capital goods. It is accordingly useful to have some summary measure or measures of this decline in physical capability of productiveness.

Unfortunately, there is again little agreement on terminology. For brevity in the following, I use "I, O, R, and E" to designate input decay (I), output decay (0), retirements (R), and exhaustions (E).

One aggregation has already appeared (I.A.2): the combination of input decay and output decay into "decay." More inclusive aggregations include the following.

1. Deterioration -- the loss in capital service from the combination of O, I, and R. Deterioration measures the decline in productiveness of a group of assets, from one period to the next. When deterioration is just offset by new investment, the current-period productiveness of the capital stock remains intact in the following period, in the sense that it yields an unchanged volume of capital services. Note that deterioration is usually defined with respect to a single period (that is, one period to the next), or as a rate of decline per unit of time.

Notes on deterioration. A variety of terms have been applied to the concept I have designated deterioration, and existing usage is neither consistent nor clear. Jorgenson (1989, but also in his earlier writings) defines "mortality" as what I have defined as "deterioration." This terminology is also employed by Hulten and Wykoff (1981) and others. From the ordinary meaning of words, it is natural to link the term "mortality" with retirements (or scrapping), and "mortality distribution" with the distribution of service lives. Because the term "mortality" and "mortality distribution" do not refer to the retirement concept or to the distribution of service lives of capital goods, clarity suggests finding alternatives.

Jorgenson (1989, but also in many of his earlier writings on capital) defines "Replacement" as the amount of investment that would have to be undertaken in order to offset the combination of decay and retirements , in order to generate in the current period the same amount of capital service that were available in a previous period. Feldstein and Rothschild (1974), on the other hand, state: "Replacement investment is the actual purchase of equipment to maintain the output capacity that is lost through output decay and (retirements)" (emphasis supplied -- and I have substituted the term "retirements" instead of "scrapping"). This differs from jorgenson's definition in the "actual purchase" language (so if the capital stock were declining, the two definitions would diverge).

The term "replacement seems less than ideal. It is often used in the investment literature to refer to the amount of replacement investment that has actually occurred (as Feldstein and Rothschild use the term), rather that the amount necessary to maintain the previous period's stock of capital services. Judging from some of the exchanges in the literature, these two definitions of "replacement" seem to have provoked some unnecessary confusion.

I have therefore searched for another usable term and have chosen deterioration, a term that was "left over" from the pattern of definitions in I.A.2, above.

Hulten (1990) assumes (as noted above) that all retirements occur when assets have completely decayed. In that circumstance, the schedule of deterioration for a group of assets is conterminous with its decay schedule. It seems, however, desirable to retain both decay and deterioration concepts, in order to encompass accidental loss or destruction of assets that still have productive potential in them.

2. Capital used up in production -- the loss of capital services, over the remaining periods of the capital good's lifetime, from the combined influences of O, I, and E (the two decay concepts, with exhaustions). This concept arises out of the historical concern in the national accounts literature with defining situations where capital is kept "intact" in the Hicksian sense, or in the wealth and income context. If capital used up in production is just replaced by new investment, then the capital stock is maintained intact, in the sense that it will be consistent with long-run sustainability of the current consumption or income flow.

Note that capital used up in production is defined with respect to the cumulative loss of services over the capital good's lifetime (or the integral of the decay function), rather than its one-period rate of change, which defines decay. See the mathematical definition of capital used up in production in the Appendix to Triplett (1996). This means that capital used up in production is a dated vector of services declines, which cannot therefore be aggregated directly--see capital consumption (entry II.A.7).

In the national accounts literature (see, for example, SNA 1968) capital used up is frequently identified with the quantity of capital services used in production. This identification is erroneous (refer to the definitions of the two concepts, in I.A.2 and I.B.2, and the discussion in Triplett, 1996).

3. Productive capital stock -- This concept is best defined by an example. Consider a cohort of new capital goods (K_o). After one period's use, their productiveness will have declined by one period's deterioration (see entry I.B.1), which we may designate "D." This cohort of one-period old capital goods is then recorded in the productive Capital stock for period 1 (K_{p1}) in "new machine equivalents," or K_{p1} = (1-D) K_o. Thus, the productive capital stock consists of all the capital goods that exist, each one reduced by the proportionate deterioration that has occurred since it was new.

Goods in the productive capital stock are normally aggregated with capital services prices weights, rather than capital goods prices weights. The main reason is that one wants the productive capital stock to obtain measures of capital services, in which service prices provide the correct weights (see entry I .A. 1).

4. Gross capital stock--The current value of all existing capital goods, valued as if all of them were new. Suppose a ten-year old machine that cost $10,000 new, where the price index for new machines of this type had risen by 20 percent over this ten-year period; in the gross capital stock, this machine would be valued at $12,000.

Sometimes the gross capital stock is used in productivity studies. If machines exhibited no decay, then the gross capital stock would equal the productive capital stock. Though computers allegedly provide a zero-decay example, decay is a fact of life for most capital goods, so the gross capital stock does not represent adequately the productiveness of capital goods. The gross stock does not provide the capital stock measure that is appropriate for productive analysis and productivity measurement.

Indeed, the gross capital stock has very little usefulness on its own. The gross stock is best thought of as an intermediate calculation that is necessary to calculate the productive capital stock (entry I.B.3), or the wealth capital stock (entry II.B.1).

I I. Value concepts

The definitions in part I pertain to physical concepts of capital. They can be thought of as yielding, in principle, numbers of machines (of a given type), numbers of "machine-equivalents," or numbers of physical performance-units of machines. Though one may need to value physical measures in order to combine them into some capital aggregation (for example, using price weights to form a quantity index number), the concepts themselves are inherently physical. In production theory, the physical concepts provide measurements that are used as inputs for a production function.

Another group of capital measurement concepts concerns the values of capital goods, the prices of capital goods in the stock, or the prices of capital services derived from the stock.

A. The elements

1. Service price -- defined by Jorgenson (1989) as the unit cost for the use of a durable good for one period, that is, as the price for employing or obtaining one unit of capital services. Also referred to as the "rental price" of a capital good, the "capital rental rate," the "price of capital services," or the "user cost of capital" (see entry II.A.2). All these terms will

probably remain in use as synonyms.

When aggregating over more than one type (or age) of asset, the service price concept takes the form of a price index (just as the service flow measure, entry II.A.1, takes the form of a quantity index). Additional information on computing or estimating service prices is presented in Jorgenson (1989, 1990), Hulten (1990), Harper, Berndt and Wood (1989), and Triplett (1997).

Remarks on heterogeneity and quality change in the capital services definition (entry I.A.1) also apply to the service price definition. In particular, defining the service price of a characteristic (e.g., the price of an incremental unit of computer memory) is one way to extend the service price notion to encompass heterogeneous capital goods. See Triplett (1983 or 1989).

2. User cost of capital -- formally, a synonym for the service price (entry II.B.1), in that it is the measure of the cost of using a durable good for one period. The user cost of capital terminology sometimes conveys the understanding that the user cost measure will be estimated from an equation containing the determinants of the service price. The service price, on the other hand, might be observed directly, from rentals, leasing contracts and so forth. This empirical distinction, however, is not a part of the formal definitions, is not always maintained, and does not seem to be a source of confusion in the literature.

3. Age-price profile -- a schedule showing the decline (normally) in the value of an existing capital good as it ages. In principle, the age-price profile might look like a used-car price book, if no quality · change occurred in automobiles. A 1997 price book, for example, might contain prices for 1996, 1995, 1994, and so forth model cars. From such a schedule, an owner of a fleet of vehicles of a variety of ages could calculate the current value of the fleet by looking up each vehicle and valuing it according to the age-price profile. Alternatively, the owner of a fleet of vehicles could use the age-price profile to determine the value of the fleet after n periods, provided there were no inflation and all the vehicles survived for n periods.

From the same price book, one could determine the decline in value as the autos age. For many purposes, one is interested in period-to-period changes in the age-price profile--the rate at which an asset's value declines as it ages by one period, or its instantaneous rate of value decline, for economic models expressed in terms of continuous functions.

4. Depreciation -- the decline in the value of a group of existing assets as they age. If each asset survives to the following period, depreciation is determined from the change in the age-price profile (which shows the change in price for a single asset), and the number of assets of each type and age. But if all assets do not survive, depreciation equals the change in the age-price profile augmented by the value of retirements.

Thus, the total value of the surviving stock of assets reflects price changes for individual assets in the stock--changes in age-price profiles, defined above--and changes in the quantities of assets remaining in the stock. Similarly, the loss in value of a particular cohort of capital through time includes both price changes in surviving members (from the age-price profile) and quantity changes (the assets that do not survive the period).

If all retirements are expected-retirements, then the asset is retired at the point at which its net value is zero (neglecting scrap and salvage value). The age-price profile correctly values this retirement, and no additional deduction for retirements is necessary. Unexpected retirements, such as accidental losses, however, disappear from the stock when they have positive values; depreciation changes for those disappearances will not be established correctly from the age-price profile. For this reason, Hulten and Wykoff (1981a, 1981b) estimate depreciation using censored regression techniques.

Several specific patterns of depreciation appear so frequently in the literature that it will be useful to define them here, though no ambiguity about their definitions exists.

5. Straight-line depreciation -- depreciation is a constant amount per period over the lifetime of the asset. In each period, depreciation is accordingly equal to C/T, where C is the original cost and T the number of periods the asset remains in service (the service life of the good).

6. Geometric depreciation -- depreciation in each period is a constant fraction of the value of the asset:

$$d_t = \delta V_t$$

where V_t is the current (or beginning of the period) value of the asset, d_t the actual amount of depreciation, and δ is the depreciation rate. A particular geometric rate is the "double declining balance" formula, $\delta = 2/T$ (an asset with a 10-period average lifetime, for example, declines in value at the rate of 20 percent per period). Note that an asset exhibiting geometric depreciation has value yet remaining after T years; geometric depreciation has an "infinite tail" of value.

7. Capital consumption -- the value of capital used up in production. As noted in entry I.B.2, capital used up in production is a dated vector of service declines over the remaining periods of a capital good's life time that occur because of its use in production in the current period. In computing-capital consumption, it is therefore necessary to discount future services declines, so that the present value of a decline in capital services, or decay, n periods in the future is:

$$PV = (s_n p_n - s_{n-1} p_{n-1}) / (1+r)^n$$

where s and p are the capital service and capital service price, respectively. The full discounted stream of service losses as the capital good ages by one period is equal as well to the standard definition of economic depreciation; accordingly, the national accounts concept of capital consumption and the standard definition of economic depreciation are the same. Triplett (1996) elaborates this point.

Additional comment on the definition of depreciation

The "value" definition of depreciation given here differs from past usage in some of the national accounts literature -- though it does not differ from SNA (1993). Some additional remarks may be appropriate.

First of all, it is clear that "depreciation" has been used in economics to cover more than one concept. Katz (1989) noted that many prominent economists, especially in earlier years, have used the term "depreciation" to mean something closer to what I have defined above as "decay" (entry I.A.2), or possibly "deterioration" (entry I.B.1).

A capital good experiences two kinds of declines as it ages, or as it is used in production -- it declines in productiveness and it declines in value. Sometimes the distinction between physical and value declines was in the past overlooked; sometimes--because there is a connection between the two (they are "duals," in the language of production theory)--the distinction was ignored, for simplicity; or sometimes terms such as "value depreciation" and "physical depreciation" were used to distinguish between the two types of declines, and the distinction was lost or not sufficiently understood because of too-similar terminology. The Fawcett-BLS (1979) report remarks (page 20): "Unfortunately, much of the literature...uses...these terms [i.e., physical and value definitions of depreciation] interchangeably, with much confusion on the part of both writers and readers....." See also Hall (1968) and Feldstein and Rothschild (1974).

Precedent in the economics literature for a particular usage of the term "depreciation" is, of course, of interest in understanding economic writings of the past. But present terminological conventions ought not be determined solely by historical precedent. Because "depreciation" has been understood in different ways, unnecessary and undesirable confusion has been the result. To avoid perpetuating confusion, economics needs different terms to describe the decline in physical capabilities of a capital good and the decline in its asset value.

Whatever the historical usage of the term "depreciation," usage among economists writing on capital has evolved, especially since the early to mid-1970's: The preponderance of professional economists now employ the term "depreciation" to mean loss in value. It is the definition used in SNA (1993). Moreover, this is the meaning of "depreciation" in an ordinary dictionary./2/

It is useful to enumerate reasons why an existing asset declines in value as it is used, or as it ages. Value decline occurs because of those physical declines in the productiveness of aging capital goods described in section I: An older capital good, compared to a newer one of the same specification, experiences input and output decay, and thus is less valuable to its owner than one that is identical in specification, but new. In addition, the used capital has suffered some exhaustion -- it contains fewer productive years of its service life than does a new machine. We can combine these elements by saying that the age-price profile reflects the cumulative value of "capital used up in production" (defined in section I as the combined effect of input decay, output decay, and exhaustions).

The age-price schedule, however, may also reflect another element: obsolescence.

8. Obsolescence -- loss in value on an old asset because a newly-introduced asset of the same class contains improvements in productiveness or efficiency or suitability in production. Obsolescence in an old capital good is closely linked to quality change in newer capital goods of the same class, though there are some types of obsolescence that are not properly associated with technical improvements in new goods./3/ Suppose one found a new, unsold 1980 vintage computer, overlooked for 20 years in some corner of a warehouse. The 1980 computer experienced neither decay nor (by definition) exhaustion. Because of the rapid pace of technological change in computers, the 1980-era computer (state-of-the-art in its day) is substantially inferior to a computer of the present vintage, and so the 1980 computer would likely sell at a substantial discount relative to a 1997-vintage computer (we ignore the possibility of curiosity or antique value that affects some obsolete goods). As the example suggests, the actual age-price profile incorporates the combined effects of capital used up in production and of obsolescence.

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[2] My desk dictionary gives what it calls an "accounting" definition of depreciation: "Decline in value of an asset due to such causes as wear and tear or obsolescence."

[3] Hulten and Wykoff (1989, page 255) define:

"Obsolescence. ..refers to the loss in the value of existing capital because it is no longer technologically suited to economic conditions or because technically superior alternatives become available." An example of a good that is no longer suited to economic conditions would be a machine designed to economize on some scarce raw material, at the expense of using more labor input; this might not be an appropriate technology when labor costs rise relative to those of the raw material, but it would again be the preferred method if relative factor costs changed, or in an economy with abundant labor relative to materials.

Obsolescence affects only the value of a capital good: It does not affect the physical services provided by the capital good. There seems to be some controversy on this point in the capital literature. Griliches (1989) noted that when technical improvements in new capital goods cause obsolescence in old ones, technical change ought to be depicted in the data as an augmentation of the quantity of the new good (or of its services)./4/ Obsolescence should not be recorded as a reduction in the quantity of the old or of its services. Normally, obsolescence affects the price, and not the quantity, of capital goods and capital services. Any exceptions concern complex cases where obsolescence is induced by relative price changes in other inputs, complexity that need not be explored here (see footnote 4).

9. Lemons--the idea that, owing to asymmetric information among buyers and sellers, used capital goods prices estimated from resale markets understate the value of similar capital goods that do not change hands. This might occur because the defective capital goods are more likely to appear on resale markets, or because buyers think or fear this is so and lack the information to determine whether the used capital good is a "lemon." See Akerlof (1970).

B. Value Concepts of Capital: The Aggregates

1. Wealth capital stock --This concept may be defined by using an example that is parallel to the one used in the definition of the productive capital stock (entry I.B.3). Consider a cohort of new capital goods (K_o), whose value when new is V_o (= P_o K_o, where P_o is the price of new capital goods). After one period, the value of the cohort will have declined by one period's depreciation (see entry II.A.4), which we may designate "d." In the wealth capital stock, this cohort of capital goods is recorded in period i at its depreciated value. That is (assuming no retirements):

$$V_1 = V (1 - d).$$

Goods in the wealth capital stock are normally aggregated with capital goods price weights (rather than with the capital service price weights used in aggregating the productive capital stock).

2. Net capital stock -- generally, a synonym for the Wealth Capital Stock (entry II.B.1). The "net" language thus distinguishes the depreciated capital stock (the wealth capital stock) from the undepreciated, or gross capital stock (entry I.B.4). However, the traditional "gross-net" capital stock dichotomy does not encompass the productive capital stock (entry I.B.3), which could cause confusion (because the productive stock is "net" of deterioration, compared to the undeteriorated gross stock). Once the distinction between productive and wealth capital stocks fully enter the lexicon, it will probably be preferable to avoid the net capital stock terminology.

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[4] Or, in the general case, of the function in which the goods are services--see Fisher and Shell, 1972, for conditions under which quality change in one good should be described as augmenting the good on which the quality change took place.

ALPHABETICAL INDEX TO DEFINITIONS AND TERMS USED IN THE MINI-DICTIONARY

NOTE: Major Definitions are Marked with • Sign

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