The role of capital discards in multifactor productivity measurement

Discarding of plant and equipment varies over the business cycle, but new measures of capital input in 20 industries suggest the effect on multifactor productivity is minor

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Since the early 1970's, the United States has experienced a marked slowdown in productivity growth, in comparison with the experience of the early postwar years.[1] The slowdown focused increased attention on long-term productivity trends. This article examines a second pattern in productivity growth, prevalent since World War II. Productivity growth increased during business cycle expansions, and decreased during downturns. The cyclical pattern is illustrated in chart 1, using the Bureau of Labor Statistics multifactor productivity measure for the private business sector from 1948 to 1986. The multifactor productivity measure is the ratio of output to combined capital and labor inputs.[2]

The cyclical pattern in the multifactor productivity measure has not been satisfactorily explained, although various factors that may contribute to such movements have been identified. Change in multifactor productivity is measured as the difference between the growth rate of output and the growth rate of labor and capital inputs.[3] Growth in this measure reflects increase in output due to factors other than growth in capital and labor inputs. One of these factors is technical change—the increased efficiency of production resulting from better management or organization of resources and improved technology. However, the multifactor productivity measure also reflects the impact on output of changes in capacity utilization, in the composition of labor, and in economies of scale. In addition, the measure can be affected by errors in the measurement of output and of capital and labor inputs.

One possible explanation for the cyclical pattern of multifactor productivity focuses on the measurement of capital input, specifically, the measurement of capital discards. Capital input in production is defined as the flow of services from the available stock of capital, which is composed of capital assets of various vintages. The stock of capital changes over time as a result of new investment in capital assets, discarding of capital assets, and decay or loss in economic value of existing capital assets. In the BLS framework, capital stock is measured using gross investment data and some assumptions about how capital assets decay and when they are discarded.[4] The assumption used to estimate when capital assets are discarded does not allow for increases and decreases in discards over the business cycle.[5] However, capital discards generally increase when the economy is experiencing a slowdown, and decrease when economic activity is at a peak.

Because this fluctuation in capital discards over the business cycle is not reflected by the capital input

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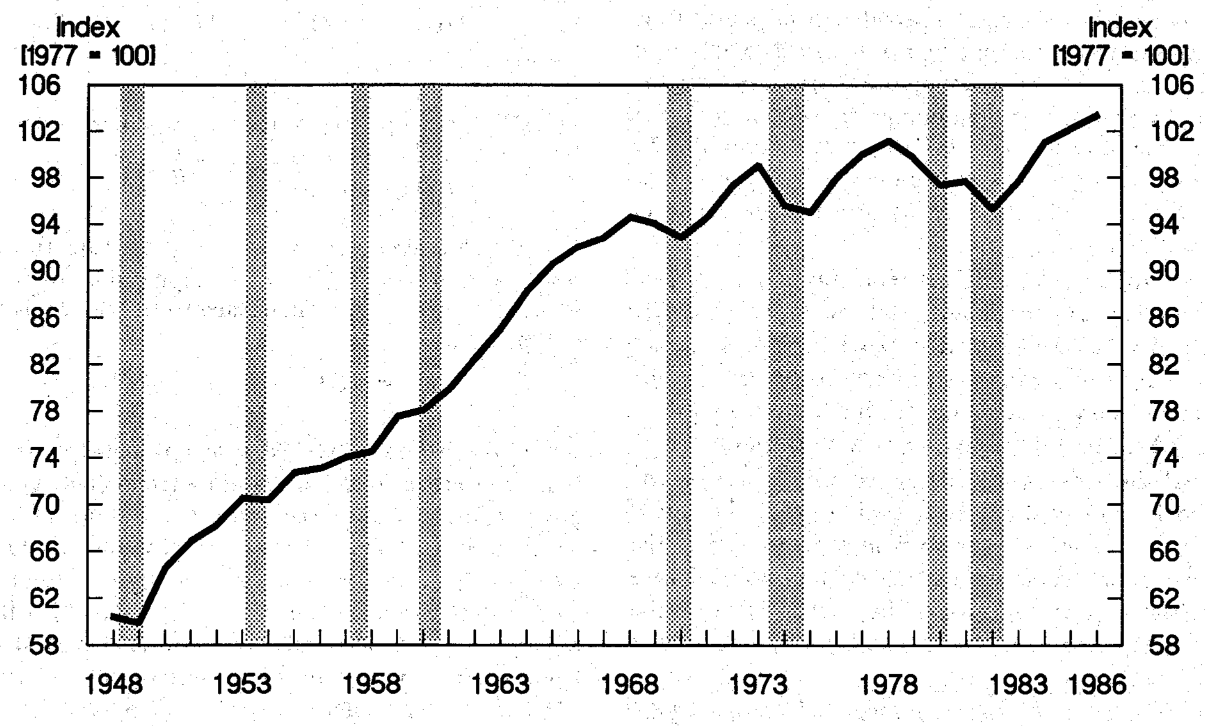
Chart 1. Index of multifactor productivity in the private business sector, 1948-86



NOTE: Shaded areas indicate recessionary periods, as designated by the National Bureau of Economic Research.

measure, variation in capital input over the business cycle may be understated. The capital input measure will reflect only cyclical movements in the gross investment series and changes in the distribution of the average age of assets over time. When multifactor productivity is measured using this smooth capital input series, cyclical movements in the output series may be more extreme than the understated cyclical movements in capital input. The result will be exaggerated cyclical movements in the multifactor productivity measure.

BLS has conducted research that develops direct measures of capital discards, in order to examine whether capital discards increase and decrease over the business cycle, and, if so, what implications this may have for cyclical movements in the multifactor productivity measure.[6] Direct capital discard measures are developed for each 2-digit Standard Industrial Classification (SIC) manufacturing industry, and for durable, nondurable, and total manufacturing, for the period 1963–81. The capital discard measures are constructed using data on the gross book value of depreciable capital assets.

Gross book value measures

For a firm in a particular year, the gross book value of capital is defined as the sum of the original purchase cost of all existing capital assets. When a company discards capital assets, the gross book value is reduced by the original cost of the asset. Data on the gross book value of capital, then, directly reflect actual capital discards as they occur. The method used to obtain the direct measures of discards is described below.

This research provides a sensitivity test for the impact that an assumed smooth pattern of capital discards may have on business cycle movements in capital input and in multifactor productivity.[7] The direct capital discard measures are compared to the smoothed measures to assess the implications of increases and decreases in discards over the business cycle. The gross book value data, which are in historical dollars, are deflated to obtain constant-dollar gross book value measures. These gross book value capital stock measures reflect actual movements in capital discards over time and are developed for each 2-digit SIC industry for the years 1962–81.

Next, the gross book value capital stock series, which reflect increases and decreases in discards over the business cycle, are used to construct multifactor productivity measures for each industry for 1962–81. Finally, for each industry, the capital discard, gross book value capital stock, and multifactor productivity measures that reflect actual capital discards are compared to corresponding measures that reflect a static capital discard assumption.

Measurement of capital discards

Capital may be discarded for a variety of reasons.[8] The physical condition of capital assets deteriorates over time and as the result of wear and tear from use. The benefit to a firm of keeping an asset in use eventually may be eclipsed by the cost of maintaining the asset. The asset may become obsolete, or a company may discontinue the production of a good or service for which the asset was required. Capital also may be discarded as the result of accidental destruction.

Discarding an asset involves removing the asset from useful service. A discarded asset may be physically removed from a plant or left in place but not used. An asset no longer in use is considered to be discarded when the firm's account of the value of capital assets in service is adjusted to remove the original cost of the asset.

Capital discards can be measured using data on the gross book value of depreciable capital assets. The gross book value of capital for a firm in a given year is the historical dollar value of existing capital assets. These data reflect capital discards as they occur, because the original cost of an asset is removed from the gross book value when the asset is retired.

This research developed a measure of actual capital discards by deflating historical dollar gross book value data to obtain gross book value capital stock measures. The gross book value capital stock measure for a given year may be expressed as:

$$GBV_t = GBV_{t-1} + GI_t - DI_t$$

where:

GBV_t is the gross book value of capital stock in period t;
GI_t is gross investment in period t; and
DI_t is discards in period t.

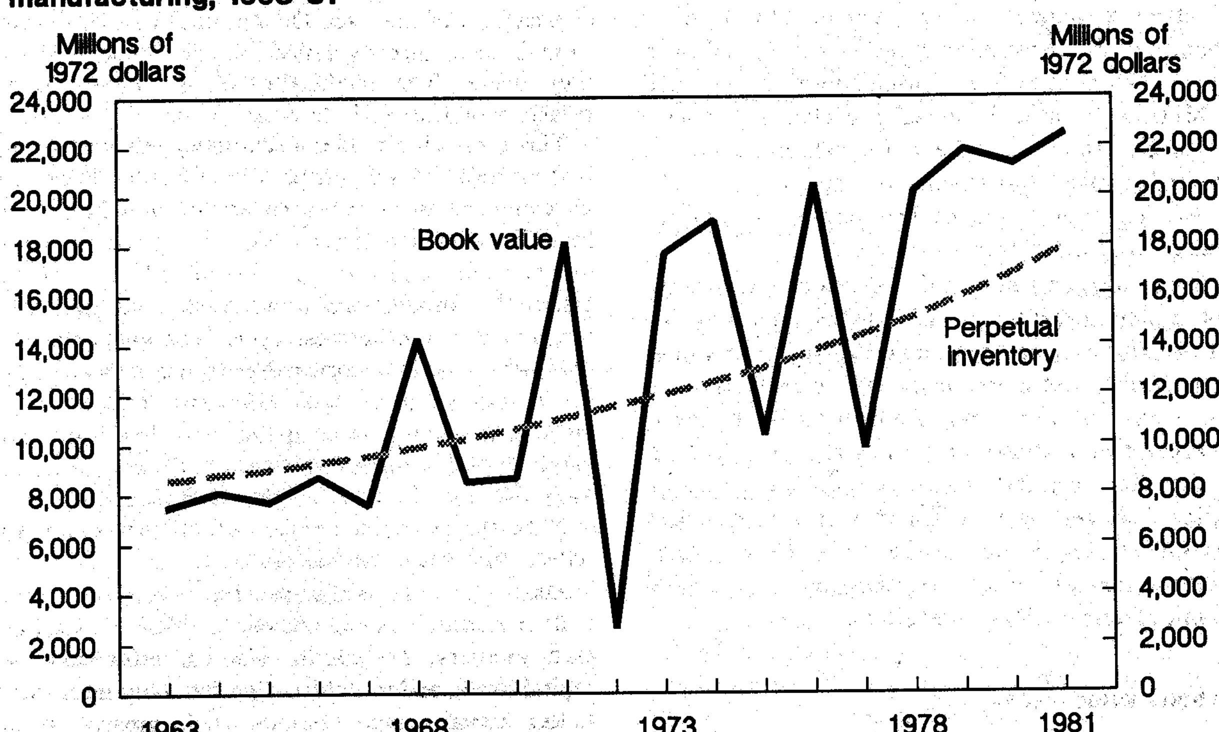
When the expression for gross book value capital stock is rearranged, a measure of actual capital discards can be defined in terms of gross investment and gross book value capital stock:

$$DI_t = GI_t - (GBV_t - GBV_{t-1})$$

For the period 1963–1981, capital discards for each industry were measured using this expression and data on gross investment and the gross book value of capital stock.[9] Census Bureau data on new capital expenditures were used for the gross investment series. Gross book value capital stock measures were developed by deflating data on the gross book value of depreciable capital assets from *Annual Survey of Manufactures* and *Census of Manufactures*, published by the Census Bureau.

The capital discard measures derived using the gross book value data reflect the actual cyclical pattern of

Chart 2. Discard measures by type of gross capital stock estimate, total manufacturing, 1963-81



capital discards. This contrasts with the smooth pattern of capital discards that underlies the BLS capital stock measures. The BLS uses the perpetual inventory method to construct net capital stock measures, that is, measures of capital stock net of the decay in the productive efficiency of existing capital assets.[10] The perpetual inventory method measures net capital stock as the cumulated value of investment minus cumulated discards and cumulated decay of capital assets. Under the perpetual inventory method, capital discards are determined by a static assumption, and this results in a smooth pattern of capital discards over the business cycle.

For each industry, gross capital stock measures are constructed using the perpetual inventory method, and are used to derive the capital discard series implied by the method's discard assumption for the years 1963 to 1981. Gross, rather than net, capital stock measures are created, to facilitate comparison with the gross book value capital stock measures.[11] Under the perpetual inventory method, gross capital stock is defined as the cumulated value of investment, minus the cumulated value of discards. This measure can be expressed as:

$$GPIM_t = GPIM_{t-1} + GI_t - DI_t^*$$

where:

$GPIM_t$ is the gross perpetual inventory method capital stock in period t;

GI_t is gross investment in period t; and

DI_t^* is capital discards in period t.

Capital discards, implicit in the gross perpetual inventory capital stock measure, can be defined in terms of gross investment and the gross capital stock measure:

$$DI_t^* = GI_t - (GPIM_t - GPIM_{t-1})$$

This measure of capital discards is computed for each industry. The gross investment series is measured using gross investment data from the Commerce Department's Bureau of Economic Analysis. The gross perpetual inventory capital stock measures are developed using the gross investment data, and the discard assumption used in BLS methods.

Measurement of capital stock

Gross book value estimates. Gross book value capital stock is measured for each industry for the years 1962–81, and used to compute the discard measures described above. The gross book value capital stock measures are also useful because movements in these measures over time can be compared, by industry, to movements in the gross perpetual inventory capital stock measures. This comparison is made to determine whether the use of gross book value data to reflect actual capital discards significantly affects cyclical movements in capital stock. The sensitivity of the multifactor productivity measure to movements in discards is also studied using the book value capital measures. Multifactor productivity is computed for each industry using the gross book value capital stock measures, and compared to multifactor productivity measures computed using the gross perpetual inventory method measures of capital stock.

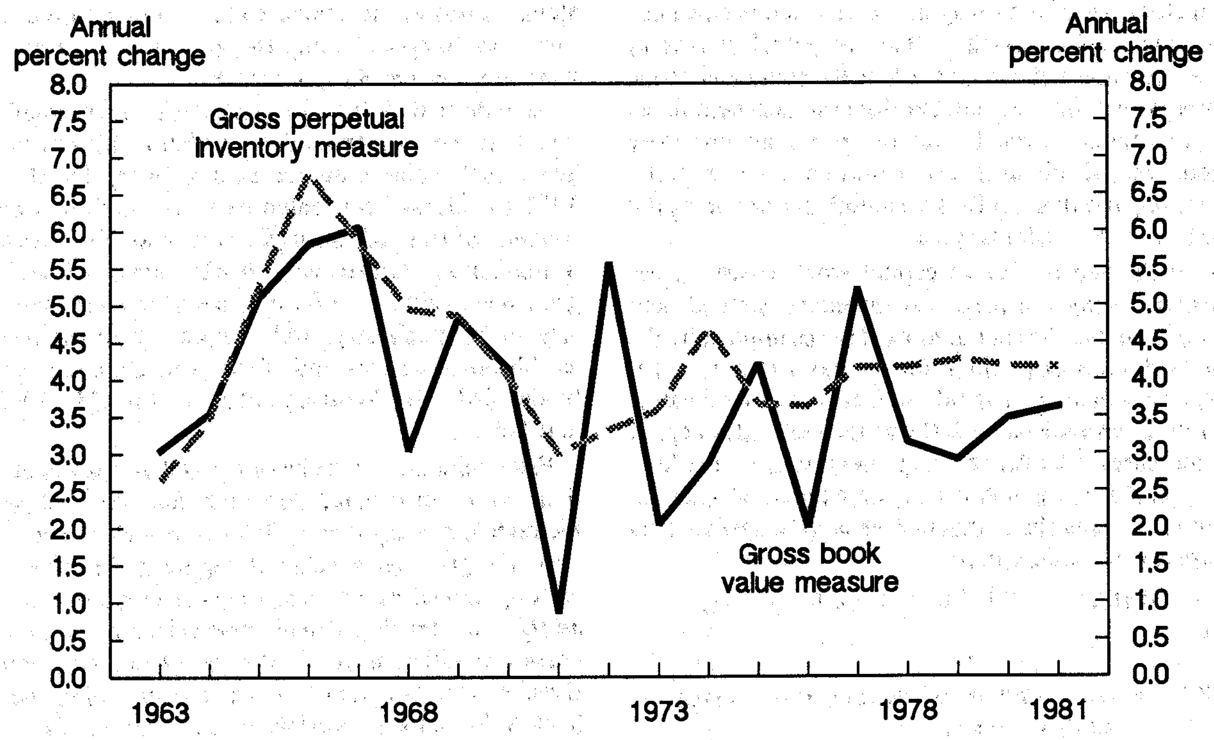
As indicated earlier, the gross book value capital stock measures are constructed by deflating historical-dollar gross book value data for each industry for the years 1962–81. Gross book value data are obtained from the *Annual Survey of Manufactures* and the *Census of Manufactures*. Census gross book value is defined as the gross book value of all fixed depreciable assets (buildings, structures, machinery, and equipment) on the books of establishments at the end of the year. Data are available by detailed manufacturing industry[12] for 1957, 1962–64, and 1967–81.

Price deflators for the historical-dollar gross book value data were constructed for each industry following a methodology suggested by John Kendrick.[13] For a given year, the gross book value of capital is the value of the existing capital assets, based on the original cost of the assets. The existing capital assets include capital purchased in different years, that is, of different vintages. Development of a capital stock measure using the gross book value data is possible if the value of the various vintages of capital assets can be expressed in constant dollars. This requires a price deflator that considers the vintage distribution of assets in the gross book value for a given year, and adjusts the valuation of capital assets from historical dollar to constant dollar, based on this vintage distribution. The price deflators developed reflected estimates of the vintages of capital included in a specific year's gross book value data, and the proportion of investment in each vintage, in the form of Bureau of Economic Analysis gross investment data and average useful life estimates.[14]

Perpetual inventory method estimates. Gross perpetual inventory method capital stock measures were created for each industry for the years 1962–81. As indicated above, the perpetual inventory method measures net capital stock as cumulated new capital investment adjusted for decay and discarding of previously accumulated capital stock. For a gross capital stock measure, cumulated new investment is adjusted for the cumulated value of discarded investment, but not for decay.

Constructing a gross perpetual inventory capital stock measure requires a long historical series of new capital investment data for each year in the capital series and an assumption regarding capital discards. The capital investment data used were Bureau of Economic Analysis constant-dollar gross investment data by asset type for each industry, from 1880–1981.

Chart 3. Growth rates of alternative capital stock measures, total manufacturing, 1963-81



The discard assumption used was identical to the BLS discard assumption. In using the perpetual inventory method to measure capital, BLS assumes capital assets are discarded as a function of the average useful life of an asset.[15] For each industry, capital assets of similar characteristics are grouped into asset-type categories. An average useful life for each type of asset is estimated by the Bureau of Economic Analysis. Because each type contains many different, although similar, assets, a particular asset may have a slightly different average useful life than that determined for its asset type. In addition, capital assets of a given description may exhibit variation in their useful lives as a result of random variations in breakage, loss, or obsolesence. Because of this, discards are assumed to be normally distributed around the average service life.

Initially, gross perpetual inventory capital stock measures were constructed for each detailed asset type within each 2-digit SIC manufacturing industry. The detailed asset-type measures in each industry were then summed to obtain the 2-digit industry gross capital stock measure. The durable, nondurable, and total manufacturing industry gross capital stock measures were similarly obtained by summing the appropriate 2-digit SIC manufacturing industry measures.[16]

Measurement of multifactor productivity

The impact on multifactor productivity of using a static assumption to estimate capital discards was examined by comparing alternative measures of multifactor productivity. The measures were constructed by methods similar to those used in constructing the BLS published multifactor productivity measures for major sectors.[17] The growth rate of multifactor productivity for each industry is defined as the growth rate of output minus the weighted growth rates of labor and capital inputs, where the weights are the cost shares of the respective inputs in total cost.[18] Multifactor productivity was measured using first the gross book value capital stock measure and, alternatively, the gross perpetual inventory capital stock measure for each industry for the years 1962–81.

Results

As noted, actual capital discards, derived from the gross book value data, increase and decrease substantially with economic slowdowns and expansions, respectively, in each industry studied.[19] This is in contrast to the smooth capital discard pattern assumed in the BLS capital measures. For each industry, the growth rate of gross book value capital stock showed substantially more movement over the business cycle than did the growth rate of the perpetual inventory-based stock. In contrast, multifactor productivity based on the gross book value capital stock measure, which reflects actual capital discards, displays virtually the same cyclical pattern as multifactor productivity computed using the gross perpetual inventory capital stock measure, which reflects a smooth pattern of capital discards. Thus, even though capital discards do vary over the business cycle, and incorporating these variations into the capital stock measure does increase the cyclical movement of that measure, this pattern of capital discards is not an important factor in explaining cyclical variation in the multifactor productivity measures.

A measure summarizing cyclical movement in the book value and perpetual inventory method series on capital discards, capital stock, and multifactor productivity was computed for each industry. This measure uses the deviation of the actual series values from trend values as a proxy for the cyclical movement in the series. The summary measure of cyclicality is the absolute value of the percentage difference between the actual and the trend values of a series, summed over the years 1969 to 1981.[20] Those years respectively contained the initial and the final business cycle peaks occurring during the study period. A higher value of the measure indicates that a series has more extreme movements over the business cycle than a series with a lower value. The summary measures of cyclicality for each industry are presented in table 1.

Actual capital discards in each industry vary substantially over the business cycle, compared to capital discards implied by the gross perpetual inventory capital stock measures. The summary measure of cyclicality for capital discards based on the gross book value data, as shown in table 1, is consistently of a much higher magnitude than the same measure based on the static perpetual inventory discard assumption.

The second set of columns in table 1 presents the summary measures of cyclicality for gross book value and gross perpetual inventory capital stock in each industry. Although the perpetual inventory capital stocks do exhibit some cyclical movements as a result of variation in gross investment over the business cycle, the book value measures in each industry consistently exhibit more extreme cyclical movements. The book value capital stock measures reflect variation in capital discards, as well as gross investment, over the business cycle.

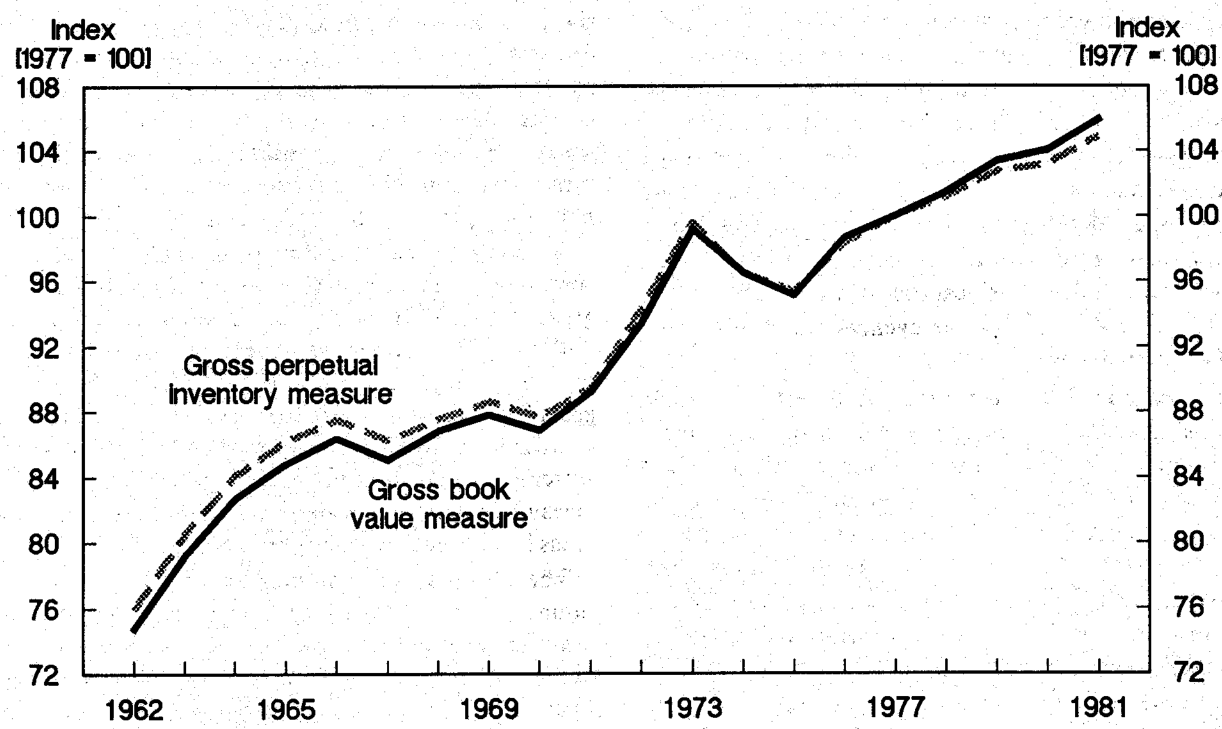
The third set of columns in table 1 presents the summary measures of cyclicality for the alternative measures of multifactor productivity. Multifactor productivity is first measured using gross book value capital stock, and then using gross perpetual inventory capital stock. The resulting multifactor productivity measures demonstrate similar patterns of cyclical variation, as evidenced by the small difference between the summary

Table 1. Summary measures of cyclicality in alternative measures of capital discards, growth rates of gross capital stock, and multifactor productivity, by industry, 1969–81

Standard Industrial Classification code	Industry	Capital discards			Capital stock growth rates			Multifactor productivity indexes		
		Book value basis	Perpetual inventory basis	Difference	Book value basis	Perpetual inventory basis	Difference	Book value basis	Perpetual inventory basis	Difference
	Total manufacturing	3.56	.05	3.51	3.74	1.15	2.59	.17	.17	.00
	Nondurable manufacturing	2.92	.04	2.88	3.56	1.12	2.44	.18	.18	.00
20	Food and kindred products	2.62	.13	2.49	4.86	1.19	3.67	.28	.26	.02
21	Tobacco manufactures	5.88	.01	5.85	10.17	5.20	4.97	.50	.39	.11
22	Textile mill products	4.47	.12	4.35	18.58	5.31	13.27	.52	.51	.01
23	Apparel and other textile products	22.72	.01	22.71	51.66	2.16	49.50	.30	.33	−.03
26	Paper and allied products	5.05	.05	5.00	4.24	2.74	1.50	.39	.40	−.01
27	Printing and publishing	4.35	.04	4.31	7.50	1.88	5.62	.21	.21	.00
28	Chemicals and allied products	4.24	.11	4.13	5.21	2.49	2.72	.31	.29	.02
29	Petroleum and coal products	7.86	.06	7.80	7.48	2.89	4.59	.44	.45	−.01
30	Rubber and miscellaneous plastics products	17.86	.02	17.84	10.36	2.83	7.53	.31	.36	−.05
31	Leather and leather products	2.62	.02	2.60	26.46	4.22	22.24	.33	.34	−.01
	Durable manufacturing	4.40	.05	4.35	4.04	1.48	2.56	.15	.16	−.01
24	Lumber and wood products	14.75	.02	14.73	14.09	2.78	11.31	.24	.17	.07
25	Furniture and fixtures	5.58	.02	5.56	10.34	3.55	6.79	.36	.37	−.01
32	Stone, clay, glass, and concrete products	6.60	.04	6.56	11.06	2.84	8.22	.27	.28	−.01
33	Primary metal industries	2.09	.02	2.07	5.94	2.53	3.41	.53	.54	−.01
34	Fabricated metal products	15.49	.06	15.43	7.85	1.75	6.10	.31	.32	−.01
35	Machinery, except electrical	3.16	.13	3.03	2.42	1.49	.93	.22	.21	.01
36	Electric and electronic equipment	4.11	.03	4.08	4.30	2.12	2.18	.37	.39	−.02
37	Transportation equipment	5.27	.04	5.23	6.47	2.28	4.19	.53	.53	.00
38	Instruments and related products	34.22	.07	34.15	5.24	2.13	3.11	.34	.35	−.01
39	Miscellaneous manufacturing, industries	4.75	.07	4.68	12.14	2.37	9.77	.33	.33	.00

[1] The summary measure is the sum of the absolute values of the percentage differences between actual and trend values for the specified series, for the years 1969–81.

Chart 4. Indexes of alternative multifactor productivity measures, total manufacturing, 1962-81



measures of cyclical variation for the alternative multifactor productivity measures in each industry.

These results are illustrated for total manufacturing in charts 2, 3, and 4. Chart 2 shows actual capital discards with implied capital discards derived from the gross perpetual inventory capital stock measure. For total manufacturing and for detailed manufacturing industries, actual capital discards derived from gross book value data increase and decrease over the business cycle, while discards implied by the perpetual inventory discard assumption have a smooth, upward-trending pattern. Chart 3 shows that, while the perpetual inventory capital stock measure does vary over the business cycle, the book value measure exhibits more extreme cyclical variation. Chart 4 compares two alternative multifactor productivity measures, one based on the gross book value capital stock, and a second based on the gross perpetual inventory capital stock. The two multifactor productivity measures show similar patterns of cyclical movements.

Accounting for increases and decreases in capital discards over the business cycle demonstrates that variation in capital discards is a minor factor in explaining the cyclical pattern exhibited by multifactor productivity measures. This finding supports the conclusion that the BLS technique of measuring capital stock using the static discard assumption in the perpetual inventory method does not create a large cyclical bias in the multifactor productivity measure. However, the issue of explaining the relationship between multifactor productivity and the business cycle remains open. Possible explanations include fluctuations over the business cycle in the rates of capital and labor utilization, which are not accounted for by the capital or labor input measures. BLS is conducting further research investigating these and other factors that may explain the cyclical fluctuations in multifactor productivity measures. □

——*FOOTNOTES*——

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[1] In the private business sector, growth in labor productivity—output per unit of labor input—decreased from a rate of 2.9 percent annually in 1948–73 to a rate of 1.0 percent in 1973–86. Growth in multifactor productivity—output per unit of combined capital and labor input—decreased from a rate of 2.0 percent in the earlier period to a rate of 0.3

percent in 1973–86. For further information on trends in multifactor productivity, see *Multifactor Productivity Measures, 1986*, USDL 87-436 (Bureau of Labor Statistics, Oct. 13, 1987).

[2]A detailed explanation of the multifactor productivity measure published by BLS is available in *Trends in Multifactor Productivity, 1948–81*, Bulletin 2178 (Bureau of Labor Statistics, September 1983).

[3]Output is defined as real gross product originating in a given industry, which is net of its intermediate inputs. The multifactor productivity measurement formula is derived from an assumed production relationship: $Q(t) = A(t)f(K(t),L(t))$, where $Q(t)$ is real output, $K(t)$ is real capital input, $L(t)$ is real labor input, and $A(t)$ is an index of neutral technological progress, or multifactor productivity. Taking the logarithmic differential of this production function with respect to time, and assuming perfect competition and constant returns to scale, a measure of multifactor productivity growth can be derived from observed input and output quantities and prices:

$$\frac{\dot{A}}{A} = \frac{\dot{Q}}{Q} - \frac{P^L L}{PQ}\frac{\dot{L}}{L} - \frac{P^K K}{PQ}\frac{\dot{K}}{K}$$

where P^L is the price of labor services, P^K is the rental price of capital services, P is the price of output, and the "dot" notation refers to the rate of change of the variable over time. The growth rate of multifactor productivity is equal to the growth rate of output minus the cost-share-weighted growth rates of labor and capital inputs. The cost share of labor input is the expenditure on labor, calculated as the price of labor services multiplied by the quantity of labor services, $P^L L$, divided by total input cost, calculated as the price of output multiplied by the quantity of output, or PQ. Similarly, the cost share of capital input is calculated as expenditure on capital input, $P^K K$, divided by total input cost, PQ. Under constant returns to scale and perfect competition, total input cost is equal to the value of total output. That is,

$$PQ = (P^L L + P^K K)$$

[4]The BLS measures capital stock using the perpetual inventory method. This method is described below.

[5]BLS estimates capital discards using a constant discard pattern based on the estimated average useful lives of capital assets. An assumption of a constant discard pattern has generally been made when measuring capital stock using the perpetual inventory method. For example, see L. Christensen and D. Jorgenson, "The Measurement of U.S. Real Capital Input, 1929–1967," *Review of Income and Wealth*, 1969, pp. 293–97; E. Denison, *Accounting for United States Economic Growth, 1929–1969* (Washington, The Brookings Institution, 1974), pp. 156–57; D. Jorgenson and Z. Griliches, "The Explanation of Productivity Change," *Survey of Current Business*, May 1969, pp. 31–38; *Fixed Reproducible Tangible Wealth in the United States, 1925–79* (U.S. Department of Commerce, March 1982), pp. T-1—T-15; *Capital Stock Estimates for Input-Output Industries: Methods and Data*, Bulletin 2034 (Bureau of Labor Statistics, 1979), pp. 1–24; and *Trends in Multifactor Productivity, 1948–81*, pp. 40–45.

[6]This study, of course, does not attempt a complete analysis of the business cycle movements of capital discards, capital stock, and multifactor productivity. The focus of the empirical work performed is annual variation in capital discards, using alternative measures of discards, and the effects of the discard series on trends in multifactor productivity. Additional study of the capital discard data, and related data, within the context of the business cycle is contemplated. Some exploratory work has examined movements in capital discards over the business cycle by correlating the level of capital discards and the rate of growth of output for each industry. These correlations, performed using data for 1964–81, are negative for 18 of the 20 2-digit SIC manufacturing industries and for the durable, nondurable, and total manufacturing sectors. These results indicate a decline in the level of discards as the rate of growth of output increases during business cycle expansions and an increase in the level of discards as the rate of output growth declines during business cycle contractions.

[7]For further analysis and discussion of this issue, see Susan G. Powers, "Cyclical Variation in Capital Stock Measures: Implications for Multifactor Productivity," Ph. D. thesis (State University of New York at Binghamton, 1985).

[8]For a discussion of capital discarding, see A. Marston, R. Winfrey, and J. Hempstead, *Engineering Valuation and Depreciation* (New York, McGraw-Hill Book Company, Inc., 1953), pp. 139–42.

[9]Capital discards are measured for 1963–81, rather than 1962–81, because of the lagged term in the discard definition.

[10]Net capital stock measures are constructed by BLS using the perpetual inventory method. Capital in the current year is equal to capital in the previous year, plus new investment, minus capital discards and decay. Capital discards are determined based on the average useful lives of capital assets. Decay in the productive efficiency of assets is approximated using a hyperbolic functional form. The hyperbolic function is concave, implying slower decay during the early life of an asset and faster decay during the later years.

[11]Net capital stock measures are used more frequently than gross measures. However, net book value data often reflect an accounting, rather than an economic, concept of depreciation. Comparing gross book value and gross perpetual inventory, capital stock measures avoid the bias that might result from comparing net capital stock measures based on different depreciation concepts. Note that capital discards measured using the gross book value capital stock series reflect the original value of the capital asset, rather than the remaining value of the asset after adjusting for loss in productive efficiency of the asset over time. Similarly, discards implied by the gross perpetual inventory capital stock measures are not adjusted for loss in productive efficiency.

[12]These data are available for manufacturing industries at the 2- , 3- , and 4-digit levels of the Standard Industrial Classification of industries. The first year of available data, 1957, is not used. Values for the missing observations, years 1965 and 1966, were interpolated to complete the data series for 1962–81. The Census Bureau gross book value data were regressed on gross book value data series constructed using Bureau of Economic Analysis gross investment data and a discard assumption. The fitted values for the Census Bureau gross book value series in 1965 and 1966 from this regression were used as estimated values.

[13]This method is described in John Kendrick, *Improving Company Productivity: Handbook with Case Studies* (Baltimore, The Johns Hopkins University Press, 1984), pp. 42–46.

[14]Gross book value price deflators were developed for each industry from 1962–81. First, the deflators were constructed for each industry's individual asset types. Total gross book value price deflators for each industry were then constructed as weighted sums of the individual detailed-asset-type gross book value price deflators. The weights used to construct the industry gross book value price deflators were the sum of constant-dollar investment in asset i in years X-L to X, divided by the sum of constant-dollar investment in total assets in years X-L to X. L is the average service life of a capital asset. The weights constructed were variable weights, changing each year.

The individual-asset-type deflators for each industry were constructed using a method that considers the vintage composition of an industry's gross book value in any given year. The gross book value of capital for a given year is defined as the original cost valuation of existing capital assets, and so includes capital assets of different vintages. This method estimates the vintage distribution of assets included in a given year's gross book value figure. Vintages from the previous L years were assumed to remain in a given year's gross book value. The proportion of investment in each vintage within the gross book value figure was determined by the original level of gross investment in the vintage.

The method used can be summarized as follows. The gross book value price deflator value in year X is the sum of historical-dollar gross investment in years X-L to X, divided by the sum of constant-dollar gross investment in years X-L to X. This general formulation was constructed using data on each asset type for each industry. The historical- and constant-dollar gross investment data for each asset type in each industry were obtained from the Bureau of Economic Analysis, as were the average useful life values for each asset type by industry.

[15]The Bureau of Economic Analysis estimates of the average useful lives of assets, and a truncated normal distribution ranging from 2

percent to 198 percent of the average useful life of an asset L, are used by BLS in determining discards. Capital assets are discarded as a function of their average useful life. Variation in the discarding of capital assets around the average useful life is described by the truncated normal distribution. The value of discards in a given year, X, is calculated by summing the product of the constant-dollar value of a capital asset times the probability of the asset's retirement at that age, for capital assets ranging in age from 2 percent to 198 percent of the asset's average life. The truncated normal distribution includes two standard deviations or 95 percent of the area under the discard distribution. An expanded discussion of the discard assumption used by BLS is contained in *Trends in Multifactor Productivity, 1948–81*, appendix C.

[16]For each 2-digit SIC manufacturing industry, the gross perpetual inventory capital stock measure was obtained as an unweighted sum of the industry's detailed-asset-type gross perpetual inventory capital stock measures. This is similar to the methodology underlying the gross book-value capital stock measures for each industry, because an industry's total gross book value is an unweighted sum of the gross book value of existing capital assets. This approach also simplified the construction of the gross perpetual inventory capital stock measures.

[17]For further discussion of the methodology underlying the published BLS multifactor productivity measures, see Jerome A. Mark and William H. Waldorf, "Multifactor productivity: a new BLS measure," *Monthly Labor Review*, December 1983, pp. 3–15; *Trends in Multifactor Productivity, 1948–81;* and *Multifactor Productivity Measures, 1986.*

[18]Bureau of Economic Analysis data on output quantity were used in each industry, whereas labor services data were obtained from BLS 2-digit industry data sources. Labor income, capital income, and total income estimates were obtained from Bureau of Economic Analysis 2-digit industry data.

[19]For example, capital discards in total manufacturing increase during the peak-to-trough years, and decrease during the trough-to-peak years. This is particularly noticeable during the 1973–75 and 1980 recession periods. During the 1969–70 recession, discards increased slightly and then jumped substantially in 1971. For a graphical presentation of capital discards in total manufacturing for 1963–81, see chart 2.

[20]The summary measure of cyclicality for a given series was constructed using trend values which were estimated by regressing the actual series values on a constant, time, and time squared, and obtaining the fitted values from this regression. The measure was constructed using a sum over the years 1969 to 1981, in order to provide a peak-to-peak comparison of the measures.

Excessive hours and productivity

Economists have tended to assume that 1 hour of labor supplied by a worker is much like another. Karl Marx, who cited a variety of evidence to show that long hours of work were detrimental to health and to longevity, did not go on to deduce that those who worked long hours must, because of their poor health, produce less. The most fundamental connection between hours of work and production exists at this *physiological* level. People are able to sustain work for remarkably long continuous periods, and for remarkably high proportions of their total daily hours. But long hours are accommodated by an adjustment of pace or work intensity—by a slowing of movements and an interpolation of more pauses between movements. In addition, long hours (which must also be judged relative to the arduousness of the work) tend to give rise to a high rate of absence and sickness, which has particularly serious effects in production involving the interdependence of workers and complex planning and scheduling.

—MICHAEL WHITE
Working Hours: Assessing the Potential for Reduction (Washington, International Labour Office, 1987), pp. 40–41.