GROWTH ACCOUNTING AND PRODUCTIVITY MEASUREMENT*

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This paper compares the growth accounting approaches to aggregate productivity measurement and analysis of three major researchers: E. F. Denison, D. W. Jorgenson, and J. W. Kendrick. The investigators are compared in terms of their treatment of a number of crucial elements, including measurement of output and of capital and labor inputs (including composition or quality changes), total factor productivity growth, economies of scale, and intensity of demand (for output). Judged by the standard of the neoclassical economic theory of production—the only generally accepted basis for input aggregation—Denison departs significantly from the production theory framework in his measurement of output and capital input, Kendrick to some degree in his measure of capital input, and Jorgenson not at all. The effects of these departures are illustrated with reference to the recent productivity slowdown. The probable near-term future utility of growth accounting methods for productivity analysis is assessed, and some related econometric modeling issues are noted.

I. INTRODUCTION

This paper compares the methods used by three prominent researchers—Edward Denison, Dale Jorgenson, and John Kendrick—in measuring and analyzing total factor or multifactor productivity. We point out the differences in their methods of aggregate productivity measurement, and examine some of the implications of these differences in methods for the resulting measures.

It is appropriate for several reasons to examine and assess the frameworks against the standard of the neoclassical theory of production used by these authors. They are widely cited in academic journals, and in policy discussions of energy, capital formation, the productivity slowdown, tax policy, and so forth. Developments in the last decade have shown the limitations of the "growth accounting" approach to productivity analysis, because the national accounts framework obliterates the structure of input factor demands by netting out energy and other intermediate goods. Further, the importance of dynamic issues such as lagged adjustment of capital input and the role of price expectations is recognized increasingly, while standard measurement methods rest on the assumption that equilibrium conditions hold for every data point. It may be excessively optimistic to expect establishment of a new paradigm for the neoclassical theory of production in the near future, but challenges to the existing paradigm are widespread. It therefore seems appropriate to provide a critical summary of the equilibrium version of the theory to provide a useful basis for comparison and assessment of new methods.

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Moreover, nearly 15 years have passed since the appearance of Nadiri's (1970) excellent survey of the productivity literature in the *Journal of Economic Literature*. Denison, Jorgenson, and Kendrick have been prolific since that survey, and have clearly dominated the field. Much of the discussion about their different approaches has been spread among journals and conference volumes and is difficult to pull together. Also, their practices, and to some degree their underlying methodologies, have evolved through time. A nontechnical assessment and illustration of their approaches can be informative to the non-specialist in this increasingly important and popular subject.

The neoclassical theory of production, as developed in Alfred Marshall's *Principles of Economics* and extended by Sir John Hicks in *Value and Capital* and by R. G. D. Allen in *Mathematical Economics*, now constitutes the only consistent theoretical basis for aggregation of inputs into a measure of multifactor input. This approach depends critically upon the assumptions of cost minimization, competitive factor markets, and constant returns to scale.

The neoclassical framework is, in reality, the only basis for aggregation of the various factors of production into a measure of multifactor input. (In fact, the method of aggregation is such that only the rate of growth of all inputs combined and of multifactor productivity itself has meaning; the levels of multifactor input and productivity are interpretable only as indexes.) Consequently, insofar as the investigators depart from the neoclassical framework, they may be accused of using *ad hoc* procedures that will necessarily render their measurements inconsistent and incomparable with measurements using that framework.

The neoclassical model of production yields a simple relationship that expresses labor productivity growth in terms of the growth of the capital/labor ratio, changes in the composition of labor and capital inputs, and a multifactor productivity growth residual. This framework is used by all three investigators. Denison and Jorgenson investigate factors that affect the *effective* inputs of labor and capital. Denison and Kendrick also incorporate a number of other factors that partially explain the productivity growth residual: the difference between the growth rates of inputs and of output. Assessment of some particular factors is omitted from analysis by Jorgenson on the basis that their measurement is inconsistent with the neoclassical framework for measurement of inputs: for example, economies of scale. Jorgenson uses a parametric approach that goes outside his growth accounting exercise to assess other effects in econometric models. His analysis of the effect of changing energy prices on productivity growth is of this type. In principle, it is possible to incorporate into the framework effects that are measured outside, provided that there is no violation of the assumptions of growth accounting in the measurement of the effects. Kendrick's incorporation of the impact of research and development is an example.

The methodologies used by Denison, Jorgenson, and Kendrick have changed somewhat through the years. In general, the most recent comprehensive work of each is used as the basis for comparison. These are:

Denison, Edward F., *Accounting for Slower Growth*, Brookings, 1980.

Kendrick, John W. and Grossman, E. *Trends and Cycles in Productivity in the United States*, John Hopkins University Press, 1980, as elaborated in Kendrick (1980).

Jorgenson, Dale W. and Gollop, Frank M., U.S. Productivity Growth by Industry, 1947–1973, in Kendrick, J. and Vaccara, B., eds., *New Developments in Productivity Measurement,* National Bureau of Economic Research, 1980. (A somewhat revised treatment of capital is given in Fraumeni and Jorgenson, 1980.)

Table 1 presents a schematic comparison of the methods of the three investigators. Clear differences among them are pointed out descriptively in the comparison table and followed by an evaluative commentary. Further references are indicated in footnotes.

While this paper does not investigate the slowdown in productivity growth itself, the implications of growth accounting by the three investigators are used to illustrate the implications of the productivity analysis approaches they use. Because capital input measurement represents the point on which the three investigators differ most, a numerical illustration is provided to show the effects of different approaches on assessment of the role of capital formation in the productivity slowdown.

The fact that some effects are omitted from the comparison table that follows is not intended to imply criticism of those measures. Rather, their omission is a practical device to keep the basis of comparison to a manageable scale.

II. Summary of Comparisons Among Investigators

Denison departs from the neoclassical framework in several respects, most notably in his definitions of output and factor costs, but also in his treatment of economies of scale. In certain cases—as in measurement of the effects of changes in the composition of the labor force—he takes great pains to eliminate double counting of effects. In others, such as adjustment for intensity of demand—or cyclical effects—the adjustment seems incomplete because his residual shows a strong cyclical pattern in the late 1960s and thereafter. His treatment of capital—excluding depreciation from the cost of production and double counting part of depreciation which remains in the stock of capital—makes his framework unsuitable for an analysis of the effect of capital on economic growth or on labor productivity growth.[1] However, the breadth of his analysis of possible factors contributing to productivity growth and to the recent slowdown is enormous and constitutes a challenge to other analysts, although the additivity of the pieces may be suspect. The limitations of his method of growth accounting preclude complete analysis of, say, the role of energy or cyclical effects.

In all important respects, Jorgensen adheres to the neoclassical framework for input measurement and growth accounting.

Kendrick's basic approach is faithful to the neoclassical framework except for his simultaneous use of the gross stock of capital as the measure of capital input and depreciation as part of the cost of production. Where Kendrick imports measures of certain effects from Denison, the limitations inherent in those measures apply. Kendrick bases his measure of multifactor productivity growth

[1]In consequence, Denison's conclusion that the post-1973 slowdown in labor productivity is a "mystery"—while most other empirical studies find a major role for capital—is not surprising.

TABLE 1

COMPARISON OF METHODOLOGIES

Denison	Jorgensen	Kendrick
	MAJOR SECTOR COVERAGE	
Description of Method Nonresidential Business: Differs from Jorgenson's and Kendrick's measures by the output of tenant-occupied dwellings.	*Description of Method* Private Business Sector: Gross domestic product less housing product of owner-occupied dwellings, less general government (state, local and federal), less government enterprises, less nonprofit institutions and private households.	*Description of Method* Same as Jorgenson except that government enterprises are included.
	OUTPUT	
Description of Method Net national income at factor cost. Differs from gross domestic product by deduction of replacement investment—or depreciation—and of indirect business taxes. *Commentary* The economy is viewed as producing *income* rather than *output*. This leads to difficulties in measurement of the cost of output because net national income excludes depreciation, which is a real cost of production. This net output concept cannot be reconciled with the neoclassical economic theory of production, since the depreciation and discarding of capital are unequivocally part of the cost of production.	*Description of Method* Gross domestic product originating in the private business sector.	*Description of Method* Same as Jorgenson.

Denison	Jorgensen	Kendrick
	LABOR INPUT	
Description of Method Persons employed in nonresidential business, adjusted for part-time workers. Differs from Jorgenson's and Kendrick's measures because changes in hours per worker may make an hours of work measure move differently from employment. Denison considers hours per worker as an explanation of productivity growth.	*Description of Method* Unadjusted hours worked as published by the Bureau of Economic Analysis, with adjustment to Bureau of Labor Statistics' (BLS) definition of private business sector.	*Description of Method* Unadjusted hours paid for labor input as reported by the Bureau of Labor Statistics for the private business sector.
	COMPOSITION OF LABOR FORCE	
Description of Method Adjustment for age and sex effects includes interaction between these classifications. A separate adjustment is made for education, given age and sex. No adjustment is made for the occupational structure of the labor force. Only farm-to-nonfarm inter-industry effects are included.[a] *Commentary* Compensation weights for 1957 and 1967 are used in aggregation, with many complex adjustments to approximate the effects of changing weights in other years. Use of annually changing compensation weights would simplify the computation process.	*Description of Method* Adjustment to labor input is made for productivity effects of 107,000 categories of labor input in cross-classification of hours and compensation by six dimensions of labor input: age, sex, education, occupation, class of worker (employee or self-employed/unpaid family workers) and industry. All interactions among dimensions are adjusted for. Compensation weights for each category for each year are used in aggregation to yield effective labor input. The effects of labor force composition change (or "labor quality" as it is sometimes called) are computed as the difference between the unadjusted and adjusted—Divisia aggregated—quantities of labor input. See Gollop and Jorgenson (1980). *Commentary* For age, sex, and education effects, the Denison and Gollop-Jorgenson results are similar, and thus tend to confirm each other.	*Description of Method* In his analysis of other factors affecting productivity growth, Kendrick adopts and updates Denison's age, sex, and education estimates. He also includes a measure of the effects of training per worker which, however, is the same throughout the post World War II period.[b]

TABLE 1 (*continued*)

Denison	Jorgensen	Kendrick
CAPITAL INPUT AND CAPITAL QUALITY CHANGE[c]		
Description of Method BEA stocks of equipment, structures and inventories are used. Gross and net stocks are weighted by 0.75 and 0.25 respectively to give an estimate of net capital stock because Denison believes that the national income accounts substantially over-state depreciation of the capital input. Stocks are aggregated directly. Changes in the composition of the capital stock—*capital quality*—is not measured except for farm-to-nonfarm shifts. *Flows of capital services* are assumed proportional to stocks. *Capacity utilization* is not considered, although a similar concept, an adjustment for intensity of demand, is categorized and measured separately.[a] Nonlabor payments less depreciation adjusted for the difference between historical and replacement costs are considered as the *total cost of capital.*	*Description of Method* Investment series from the Bureau of Economic Analysis are used as the basis for creating net stocks of equipment and structures, based on geometric depreciation. Land measures are developed based on Goldsmith (1962). The price of capital services for each asset type is computed from the current asset price: rate of return, rate of depreciation, and capital gains; corporate income, capital gains and indirect business taxation; accelerated depreciation and investment tax credits. *Flows of capital services* are assumed proportional to stocks.[e] Adjustment for capacity utilization is implicit. Based on these quantities and prices, shares in total capital compensation for each asset class in each year are used to aggregate capital input across and within sectors to a Divisia index of adjusted capital input. As with labor, the measure of *capital quality* change is the difference between the growth rates of adjusted and unadjusted capital aggregates.[f] Nonlabor payments—gross product originating less labor compensation—is considered the *total cost of capital input.*	*Description of Method* BEA gross stocks are used. Stocks are aggregated directly. *Capital quality* is not measured except for the farm-to-nonfarm shift. *Flows of capital services* are assumed to be proportional to stocks. Adjustment for *capacity utilization* is only implicit; as in the Jorgenson approach, peaks of business cycles are selected as terminal points for the time periods analyzed. *Nonlabor payments* are considered as the *total cost of capital*, as in the Jorgenson method.
Commentary The treatment of capital cost is consistent with exclusion of replacement investment from the output measure. However, it is inconsistent with the neoclassical framework for analysis of production in that a major part of the cost of production—depreciation—is excluded from that measure.	*Commentary* The treatment of capital input and its valuation conform to the framework of the neoclassical theory of production.	*Commentary* In using gross stocks, together with the total nonlabor payments as the cost of production, Kendrick counts the portion of replacement investment that goes to compensate depreciation as *both* a cost of production *and* as an input as part of the flow of services from the gross stock of capital. In general, if depreciation is charged off as a cost of capital—and thus incorporated in the weight—it is the net (of depreciation) rather than the gross stock that should be used as the measure of factor input. Only the cost of replacing discards from the capital stock should appear in the cost of capital. if gross capital stock is used.

Denison	Jorgensen	Kendrick
	AGGREGATION TO MULTIFACTOR INPUT	
Description of Method Labor input is weighted by labor compensation and capital input is weighted by nonlabor payments less depreciation and indirect business taxes. This approach is consistent with Denison's definition of output as net national income.	*Description of Method* Labor and capital shares in total cost are used to aggregate the growth rates of labor and capital input to a measure of the growth of multifactor (capital-labor) input. Current year shares are used in the aggregation.	*Description of Method* Labor and capital shares are weighted by labor compensation and nonlabor payments respectively in 1972; that is, fixed weights are used. Nonlabor payment is not an appropriate weight for Kendrick's capital input, which is the gross stock, because depreciation—the difference between the gross and net stocks—is counted as part of the cost of capital.
Commentary Because a substantial part of the cost of capital—depreciation—is excluded from capital's share in the total cost of production, the weight for capital is smaller than called for by the economic theory of production. Consequently, growth in total factor input is different from what it should be. Since capital input grows more rapidly than labor input, the effect is to bias downward the growth in multifactor input. This probably results in an upward bias in the measure of output per unit of multifactor input—Denison's semi-residual.		*Commentary* Accounting as well as economic principles are violated if depreciation on an asset is charged as part of costs, while the value of the asset in production is undiminished.[g]

TABLE 1 (*continued*)

Denison	Jorgensen	Kendrick
	MULTIFACTOR (KL) PRODUCTIVITY GROWTH	
Description of Method Denison measures multifactor productivity growth as net national income per unit of combined capital and labor input, which Denison terms the semi-residual. Another residual after a list of twenty-odd factors contributing to productivity growth is designated "advances in knowledge." The effects of changes in labor force composition are included in input and thus excluded from the explanation of change in the semi-residual.	*Description of Method* Jorgenson measures multifactor productivity growth as the change in output less the weighted average of quality-adjusted (i.e. adjusted for composition change) capital and labor inputs Thus his residual is the same as his measure of multifactor productivity growth.	*Description of Method* Kendrick measures the growth in multifactor productivity as the growth in output per unit of growth in unadjusted aggregate factor input. *Commentary* While this approach violates the tenets of pure theory—because the labor and capital input aggregates do not exist except as they are affected by composition change—the idea of a common starting point is very appealing. Estimates of growth in output per unit of combined capital and labor inputs unadjusted for composition change would make it easier to compare the results of various researchers. The composition effects would be considered along with others as contributing to the explanation of productivity growth. Besides, in practice, the effects of composition change are determined by the degree or disaggregation in the data an investigator works with, so that the unadjusted capital or labor input really is a common starting point. See Mark and Norsworthy (1980).

Denison	Jorgensen	Kendrick
	ECONOMIES OF SCALE	
Description of Method Based on a paper by Scherer (1975), Denison assumes economies of scale of 12% throughout the period of analysis. *Commentary* The techniques for measuring labor, capital, and multifactor input used by all three investigators assume constant returns to scale. To the extent that economies of scale do exist, the effects will be spread among the measures of labor, capital and multifactor inputs and the residual. Denison acknowledges the inconsistency of measuring inputs as he does and simultaneously measuring economies of scale, but does so nonetheless.	*Description of Method* Jorgenson does not measure the effects of economies of scale.	*Description of Method* Kendrick adopts Denison's measure of economies of scale. *Commentary* The limitations of the Denison estimate apply.

TABLE 1 (*continued*)

Denison	Jorgensen	Kendrick
	INTENSITY OF DEMAND	
Description of Method Denison's estimates of demand intensity are based primarily on the proportion of nonlabor payments in total national income. Intensity of demand falls as this quantity falls and conversely. *Commentary* Two factors at work in the last 15 years impart a secular trend to Denison's measure of demand intensity: the change in composition of the capital stock toward more equipment and the inflationary impact that raises replacement cost of depreciable capital. Thus Denison finds 1968 to represent a higher intensity level than 1969, and 1973 to lie below 1972 *and* all years prior to 1970. 1976 also represents a year of greater demand intensity than 1973[h] in Denison's analysis. These aspects of Denison's intensity adjustment make it implausible. See the footnote to Denison's treatment of capital above.	*Description of Method* Jorgenson makes no estimates of the effects of demand intensity or capacity utilization, a closely related concept.	*Description of Method* Kendrick makes an adjustment for demand intensity based on the ratio of potential to actual GNP from the Council of Economic Advisors. *Commentary* The neoclassical productivity accounting framework is based on the assumption that all factors are compensated in accordance with their marginal products. Implicit partial adjustment for the business cycle is made by all three investigators by considering time periods for analysis only between peaks in labor productivity growth.[i,j] Kendrick's adjustment for demand intensity is consistent with the framework.

Denison	Jorgensen	Kendrick
	RESEARCH AND DEVELOPMENT	
Description of Method Denison does not separately measure the effects of research and development on productivity growth. These effects as well as others are treated collectively as part of "advances in knowledge," Denison's final residual after all other factors have been considered.	*Description of Method* Jorgenson does not measure the effects of research and development on productivity growth.	*Description of Method* Kendrick finds a large contribution to productivity growth from research and development, based on his measure of the stock of technological knowledge. *Commentary* The size of the research and development effect is at least partly the result of Kendrick's measurement method: he regresses multifactor productivity growth—which is large because he measures it inclusive of effects of composition changes in capital and labor inputs to begin with—on the stock of technological knowledge. If multifactor productivity growth were first adjusted for all other effects and *then* regressed, the results would be more convincing. There is likely to be double counting of research and development and other effects in Kendrick's approach.[k]

TABLE 1 (*continued*)

Denison	Jorgensen	Kendrick
	EFFECTS OF REGULATION AND CRIME	
Description of Method Denison estimates the effects of three regulatory activities on output per unit of input, including pollution abatement, employee health and safety and dishonesty and crime. *Commentary* The analysis is for the period 1973–76, and the effects, which are rather large, may partly reflect incomplete adjustment for cyclical movements. See the discussion of intensity of demand above.	*Description of Method* Jorgenson makes no estimate of the effects of regulation and crime.	*Description of Method* The basis for part of Kendrick's estimation of regulatory effects is unclear, but it seems largely to follow Denison.
	RESIDUAL	
Description of Method The Denison residual is called "advances in knowledge and (effects) not elsewhere classified." *Commentary* There is sometimes a confusion between the residual nature of this measure and the active contribution that advances in knowledge can make through technology, managerial innovation, etc. Since Denison's is a true residual, it is not appropriately treated as an *active* influence as in the statement: Advances in knowledge contributed less in period one than in period two.	*Description of Method* The Jorgenson residual, which is labelled "total factor productivity growth," includes all influences not captured in explicit estimates of capital or labor augmenting effects.	*Description of Method* Kendrick's final residual is measured net of all explanatory factors. This residual is negative for all time periods reported. *Commentary* This negative result throughout the period of the analysis strongly suggests overcounting. An important source of bias may be Kendrick's treatment of "advances in knowledge" as an *active* category which includes the effects of research and development.[1] (See commentaries on Kendrick's treatment of research and development above, and on Denison's treatment of the residual.)

[a]The farm-to-nonfarm shift of labor and capital is categorized as "reallocation of resources" in Denison's work.

[b]The training effect is based on Kendrick's broad-based study measuring human and nonhuman aggregate stocks of capital. (See Kendrick, 1976.)

[c]Considerable current research is directed towards determination of appropriate net capital stock measurement methods. Properly speaking, the "net-gross" controversy insofar as it makes sense at all is really a discussion of *which* net stock measure to use: some hold that the gross stock as measured by the Bureau of Economic Analysis (BEA) is a better approximation to the true net stock because the BEA net stock is depreciated too rapidly. The method of depreciation appropriate for productivity analysis need not be the same as that used for national income accounting in measuring GNP. (See Hulten and Wykoff, 1981.)

[d]Denison has correctly pointed out that attempts to measure capacity utilization are typically based on measurement of other inputs, e.g. kilowatt hours used by machinery, or hours worked by the labor force. The procedures used by Jorgensen and Griliches (1967), which he criticized, were subsequently modified to eliminate this method. Denison's adjustment is not subject to that defect. However, it appears to have other shortcomings as noted under *Intensity of Demand* below.

[e]The details of the methods used are reported in Christensen and Jorgensen (1970), with subsequent modifications as described in Gollop and Jorgensen (1980) and Fraumeni and Jorgensen (1980).

[f]Econometric tests have been undertaken by Norsworthy and Harper (1981) to determine whether the required conditions for Divisia aggregation of the capital stock are met, as well as those for direct aggregation of the capital stock as practiced by Denison and Kendrick. The former tests generally pass, while the latter always fail. The quantitative difference is quite significant. Norsworthy, Harper and Kunze (1979) find that in 1965–73, about 30 percent of the growth rate of the capital stock was attributable to changes in quality, and that the estimate of the quality or composition effect is even more dramatic when equipment and structures alone are considered. Thus, use of the Divisia method for aggregation of the capital stock is strongly supported by empirical analysis.

[g]See Mark and Norsworthy (1980). See also the commentary on Kendrick's capital stock measurement above.

[h]All major measures of capacity utilization show 1973 at or near a post-war high level. The unemployment rate for prime age males shows the same pattern, as does the National Bureau of Economic Research index of coincident economic indicators. All also show 1976 well below 1973. While it is difficult to see how an adjustment for demand intensity should be constructed, Denison's measure—which peaks in 1972 and declines in 1973, and shows 1976 substantially above 1973—is simply implausible.

[i]This choice of time periods is discussed further in Norsworthy, Harper and Kunze (1979).

[j]See Kendrick (1980).

[k]See Kendrick (1976).

[l]See Kendrick (1980) and Mark and Norsworthy (1980).

on unadjusted capital and labor inputs, an approach that has great practical value as a zero baseline for comparison among different investigators; changes in labor force composition and the capital stock are then viewed as part of the explanation of growth. There is probably considerable double counting among the quantitative effects he assigns to various causes.

Both Jorgenson and Kendrick extend their productivity measurement methods to disaggregated data. Jorgenson's sector level analysis (Gollop and Jorgenson, 1980) is based on a gross output definition of output since he includes intermediate goods, while Kendrick carries his value-added measurement framework to the sectoral level. Denison, whose method is more strongly rooted in macro-economics generally, and in the national income and product accounts in particular, does not extend it to disaggregated data.

Major differences in methods of measurement of capital input and its growth effects between Denison and Jorgenson result in substantially different conclusions about the role of capital formation in the post-1973 productivity slowdown. Kendrick's approach and results are intermediate between the others.

III. Effects on Growth Accounting of Different Capital and Output Measures

The measurement techniques of the three investigators are most important for the growth accounting results in two areas: output measurement, where Denison differs from the other two investigators, and capital input measurement, where all three differ. It would be desirable to show the methods of all three investigators applied to a common body of data. However, to do so would involve virtually redoing the three volumes cited above, because the authors' respective techniques were applied to different "vintages" of data from the national accounts, and also because Denison and Jorgenson extensively use unpublished data on which the national accounts are based. In consequence, the comparisons that follow, while they illustrate the several differences, cannot be combined in a fully consistent way.

Table 2 shows the effect of output measurement as practiced by Jorgenson and Kendrick—column 1—and by Denison—column 2. The differences are not large—a difference of only one-tenth of one percent per year is introduced into the measurement of the output slowdown in 1973–78. The difference would be smaller still if Denison deducted from gross product originating only that portion of depreciation—0.25—that he deducts from the capital input. (Recall that Denison measures capital input as proportional to $\frac{3}{4}$ of the gross stock plus $\frac{1}{4}$ of the net stock.)

Table 3 shows the growth rates of the net and gross stocks of fixed investment (equipment and structures) for the corporate sector, and the Denison $\frac{1}{4}$–$\frac{3}{4}$ combination. The growth rates are based on the stocks of equipment and structures only. Land and inventories are included in the investigator's estimates of capital input, so that the net-gross differential would be smaller than that shown in the table. While Jorgenson does not use the BEA net stocks directly, he uses a geometric approximation to the BEA stocks, so that the table illustrates his approach reasonably well. The slowdown in growth of the capital stock (and hence the

TABLE 2

OUTPUT MEASUREMENT

	Average Annual Rates of Growth	
Year	Gross Product Originating[a]	National Income[b]
1948–65	3.75	3.70
1965–73	3.71	3.55
1973–78	2.83	2.58
Slowdown 1965–73 to 1973–78	−0.88	−0.97

Source: Computed using data from the national income and product accounts reported in *The National Income and Product Accounts of the United States, 1929–76 Statistical Tables* and *Survey of Current Business*, July 1982.

[a]Jorgenson and Kendrick.

[b]Denison.

TABLE 3

NET AND GROSS CAPITAL STOCK MEASUREMENT

	Average Annual Rates of Growth		
Year	Net Capital Stock[a]	Gross Capital Stock[b]	0.25 Net plus 0.75 Gross[c]
1948–65	3.64	3.11	3.24
1965–73	5.10	4.60	4.73
1973–78	3.26	3.78	3.65
Slowdown 1965–73 to 1973–78	−1.84	−0.82	−1.08

Source: Based on corporate capital stocks in constant 1972 prices from *Fixed Reproducible Tangible Wealth in the United States, 1925–79*. Bureau of Economic Analysis, U.S. Department of Commerce, March 1982.

[a]Jorgenson (approximately—see text).

[b]Kendrick.

[c]Denison.

growth of capital input since all investigators assume that the flow of capital services is proportional to the capital stock) is clearly much less when the gross stock is used. This difference undoubtedly accounts for Kendrick's finding of a smaller (although still substantial) impact of capital on labor productivity growth than that shown by Jorgenson and Fraumeni (1980) or Norsworthy, Harper, and Kunze (1979). The Denison method results in an intermediate measure of the slowdown in capital growth as would be expected.

Table 4 shows the growth of the capital inputs according to direct and Divisia aggregation[2] for the private business sector of the U.S.[3] In each period, the Divisia

[2]In principle, the Divisia aggregate is preferred for two reasons: it recognizes that the marginal productivity of capital may change both through time and across asset types. See Hulten (1973) and Norsworthy and Harper (1981).

[3]This is the major aggregate sector investigated by Jorgensen and by Kendrick. The data for the illustration are from Norsworthy, Harper, and Kunze (1979).

TABLE 4

GROWTH OF CAPITAL AND ITS PRODUCTIVITY

	Average Annual Rates of Growth				
	Method of Measurement		Capital Productivity Based on:		
Year	Direct Aggregate of Capital Stock[a]	Divisia Aggregate of Capital Input[b]	Difference: Growth in Capital Quality	Direct Aggregate[a]	Divisia Aggregate of Capital Input[b]
1948–65	2.62	3.14	0.51	1.09	0.57
1965–73	3.67	4.48	0.82	0.10	−0.74
1973–78	2.05	2.31	0.24	0.57	0.31
Slowdown 1965–73 to 1973–78	−1.62	−2.17	−0.58	0.47	1.05

Source: Based on the private sector capital stocks of four assets: structures, equipment, land, and inventories from Norsworthy, Harper and Kunze (1979).

[a]Denison's and Kendrick's method.

[b]Jorgenson's method.

aggregate capital input grows faster than the directly aggregated capital input. The difference between growth rates, however, is not constant in the three time periods, nor is it roughly proportional to the rate of growth of the directly aggregated capital stock. Furthermore, the slowdown in the rate of growth of capital input is greater between the last two time periods. In principle, then, the last two columns in Table 4 show the growth of capital productivity based on the direct aggregate and Divisia aggregates. Because the Divisia-aggregated capital input grows more rapidly than the directly aggregated, the productivity of capital input grows more slowly, and even declines in the 1965–73 period.

A conventional way to analyze the sources of labor productivity growth is to express the growth of labor productivity in terms of growth of the capital/labor ratio and the growth of total factor productivity.[4]

Table 5 shows how differences in measurement of capital input leads to different analysis of the slowdown in U.S. productivity growth after 1973. The first part of the table shows how the growth in labor productivity can be partitioned

[4]This is a common variant on the conventional approach to growth accounting. The conventional growth accounting model represents total factor productivity growth as

$$\frac{\dot{A}}{A}=\frac{\dot{Y}}{Y}-w_K\cdot\frac{\dot{K}}{K}-w_L\cdot\frac{\dot{L}}{L}$$

when Y = output, K = capital input, L = labor input, A = total factor productivity and the "·" operator denotes the rate of change with respect to time.

This expression is rearranged algebraically to express the growth in labor productivity as a function of the capital/labor ratio and the growth in total factor productivity:

$$\frac{\dot{Y}}{Y}-\frac{\dot{L}}{L}=w_K\left[\frac{\dot{K}}{K}-\frac{\dot{L}}{L}\right]+\frac{\dot{A}}{A}.$$

The productivity growth accounting exercise then devolves into one of partitioning these two components according to sources of increase or decrease. See Norsworthy, Harper, and Kunze (1979).

TABLE 5

ROLE OF CAPITAL IN SLOWDOWN OF LABOR PRODUCTIVITY GROWTH

Year	Labor Productivity Growth	Contribution of Growth of Capital/Labor Ratio Based on:		Contribution of All Other Factors Based on:	
		Direct Aggregate	Divisia Aggregate	Direct Aggregate	Divisia Aggregate
1948–65	3.32	0.76	0.94	2.56	2.38
1965–73	2.32	0.75	0.99	1.57	1.33
1973–78	1.20	0.20	0.21	1.00	0.99
Slowdown from 1965–73 to 1973–78	−1.12	−0.55	−0.78	−0.57	−0.34

Source: Based on data from Norsworthy, Harper and Kunze (1979).

into two categories: a contribution from growth of capital input working through the capital/labor ratio and a residual contribution from other factors not accounted for—total factor productivity growth. The capital contribution in each of the first two time periods is greater allowing for the effects of changes in the composition of capital stock. Correspondingly, the contribution of unknown factors to labor productivity growth is smaller when the capital input is measured by the Divisia aggregate. The last line in Table 5 shows the contribution to the slowdown in labor productivity growth that took place after 1973. Jorgenson's approach to measurement of capital input leads to the conclusion that about 70 percent of the labor productivity slowdown is due to reduced growth in capital input, with only about 30 percent associated with other factors. By contrast, direct aggregation of capital leads to the conclusion that other factors contributed as much to the productivity growth slowdown as did slower growth in capital input.

There is another important dimension to the measurement of capital input in productivity analysis that derives from using an incorrect marginal productivity of capital input. Recall that according to the neoclassical measurement framework the marginal productivity of capital input is indicated by its service price. As noted above, Denison's analysis of productivity and economic growth excludes depreciation (and other smaller items) from output. Consistently, depreciation is excluded from the share of capital in the total cost of production. This latter step amounts to reducing the implied marginal product of capital substantially, and therefore it reduces the contribution of capital to the growth of output and to the growth of labor productivity by a significant proportion.

Table 6 shows how the measured impact of capital on the growth of real output varies in response to the exclusion of depreciation from the marginal productivity of capital. Data are again for the private business sector of the U.S. economy. The first two columns show how the weights vary from each other and through time. When depreciation is included as part of the capital cost of production the share is relatively stable through time. When depreciation is

TABLE 6

MEASUREMENT AND WEIGHTING OF THE GROWTH OF CAPITAL INPUT

Year	Average Annual Rates of Change					
	Share of Capital in Total Cost of Production Based on:		Impact of Capital on Output Growth:			
			Direct Aggregate		Capital Input	
	Marginal Productivity of Capital[a]	Marginal Productivity of Capital Excluding Depreciation[b]	Marginal Productivity of Capital[a]	Marginal Productivity of Capital Less Depreciation[b]	Marginal Productivity of Capital[a]	Marginal Productivity of Capital Less Depreciation[b]
1948–65	34.0	20.7	0.89	0.54	1.07	0.65
1965–73	33.8	18.3	1.24	0.67	1.51	0.82
1973–78	33.5	16.7	0.68	0.34	0.77	0.39
Slowdown 1965–73 to 1973–78			−0.56	−0.33	−0.74	−0.43

Based on Denison (1979) and Norsworthy, Harper and Kunze (1979).
[a]Jorgenson's method.
[b]Denison's method.

excluded, the share of capital declines substantially through time. This occurs because the composition of the capital stock in the U.S. changed to include a greater proportion of equipment, which depreciates faster than structures, and a smaller proportion of structures. (This change in composition was at least partially induced by the investment tax credits for equipment investment, but not for investment in structures. Various versions of the investment tax credit were in effect off and on from 1963 to 1981.)

It is easy to see that the smaller weight for capital reduces the measured effect of capital growth on economic growth, both when applied to a correct measure of capital input and also when applied to a direct aggregate of the capital stock. The fifth column of the table shows the measure of capital impact on economic growth that is based on the marginal product of capital applied to Divisia aggregated capital input. The fourth column shows the results when both Denison types of differences in the analysis of capital are introduced. These differences are important (especially compared against an annual rate of economic growth in the U.S. of three to four percent per year) and about equal in magnitude. Together they seriously understate the role of capital in the U.S. economic slowdown since 1973, when contrasted with the role implied by the neoclassical framework of analysis used by Jorgensen. Kendrick's method would lead to results intermediate between those of Denison and Jorgenson.

IV. Whither Growth Accounting?

The limitations of growth accounting methods based on the economic theory of production strictly construed are narrow: only those effects that can be expressed as contributing to effective inputs of capital and labor in a value-added framework, or to effective inputs of capital, labor, energy and materials, in a gross output framework,[5] may properly be included in a growth accounting analysis. However, this limitation is elastic in several senses. First, the growth accounting approach provides a filing system that is *complete*, in the sense that all phenomena that affect economic growth must do so through input factor quantities, relative factor intensities or total factor productivity growth, either singly or in combination. Second, the results of a growth accounting exercise may point to areas where parametric studies are likely to be fruitful. For example, the evidence from growth accounting that capital formation is important in the slowdown in labor productivity growth since 1973 immediately suggests an agenda for econometric research: energy-capital complementarity, the relative movements of the prices of capital and labor services, energy price-induced obsolescence of part of the capital stock, the effects of slower economic growth through an accelerator model of capital accumulation, etc. The change in growth of capital input can be apportioned among the several causes and thus incorporated into a growth or productivity accounting analysis. Finally, aggregate and sectoral measures can be consistently represented in a common framework, as detailed

[5]See, for example, Norsworthy and Malmquist (1983) and Berndt (1980) for application of the technique in a gross output framework. The technique is used in the value added case in Norsworthy, Harper and Kunze (1979) to incorporate *inter alia* the effects of pollution abatement capital spending on the growth of capital input, and changes in hours at the workplace on the growth of labor input.

in Gollop (1982). Application of the growth accounting approach to productivity analysis at the industry level may prove useful as a prelude to more elaborate modeling—again in an agenda-setting role. At a minimum the growth accounting model based on the neoclassical economic theory of production can be expected to play a kind of data analysis role, and also to serve as a filing system for integrating consistently its own results with those of econometric models constructed on the same basis.

This lower bound on the role of growth accounting may also be an upper bound. Many of the issues in productivity analysis that have emerged in recent years require econometric models for testing associated hypotheses—some of the topics related to capital formation illustrate this point: the role of energy, the effects of such tax incentives as investment tax credits and (in Japan) preferential treatment for income from certain types of savings, the research and development tax credit, the effects of high interest rates and "crowding out."

Some of the issues now being addressed in empirical applications of production theory move outside the collectively acknowledged boundaries of the equilibrium model. Brown and Christensen (1980); Caves, Christensen and Swanson (1980); and Gollop and Roberts (1979) estimate the effects of scale economies on productivity growth in various industrial settings. Berndt, Fuss and Waverman (1980), Morrison and Berndt (1981), as well as the Christensen citations above estimate explicitly dynamic disequilibrium models where the conditions for aggregation of the capital stock components into capital input are clearly violated. These models may be viewed as appropriate for exploratory purposes in those cases where the importance of the topic outweighs the adverse impact of methodological impurity on the results. More precisely, there is an implied quantitative judgment that the relationships that are illuminated by the *ad hoc* approach are less distorted than they would be in the equilibrium model based consistently on the economic theory of production. It will be especially helfpul if investigators using these methods address this issue directly, both theoretically and empirically.

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