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The Slowdown in Productivity Growth: Analysis of Some Contributing Factors

LABOR PRODUCTIVITY in the private business sector grew at an annual rate of 1 percent from 1973 to 1978, about one-third of its rate of growth from 1948 to 1965. The effects of this slowdown were both substantially reduced economic growth and higher prices. A comprehensive analysis of recent economic growth has been made by Edward F. Denison, who examined the effects of regulation on growth in a framework that assesses the contributions from various potential causal factors.[1] Our approach is different from his in several respects, depending primarily on the definition of output and the measurement of capital input.[2] Several other studies have focused on particular issues in the productivity puzzle, such as analyses of the effects of capital formation, energy, labor force composition, and intersectoral shifts of labor.[3]

Note: The views expressed in this paper do not necessarily represent those of the U.S. Bureau of Labor Statistics or its staff. We thank the members of the Brookings panel for their especially helpful comments and criticism.

1. Edward F. Denison, "Effects of Selected Changes in the Institutional and Human Environment Upon Output Per Unit of Input," *Survey of Current Business,* vol. 58 (January 1978), pp. 21–44.

2. Edward F. Denison, *Accounting for United States Economic Growth, 1929–1969* (Brookings Institution, 1974).

3. For capital formation see Peter K. Clark, "Capital Formation and the Recent Productivity Slowdown," *Journal of Finance,* vol. 33 (June 1978), pp. 965–75; *Eco-*

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This paper investigates productivity in the private business sector for which quarterly labor productivity and cost statistics are published by the U.S. Bureau of Labor Statistics (BLS). The basic methodology weights growth rates of capital and labor inputs by their shares in gross domestic product of this sector. Although growth in labor productivity is the target for explanation, the framework includes the contribution of multifactor productivity growth—the Hicks-neutral residual. The measurement techniques draw primarily on the work of Denison and Dale W. Jorgenson, as outlined below.

The factors we examine as possibly contributing to the slowdown are limited to those that can be quantified and adapted for inclusion in a national accounts framework. Therefore, we do not explore such issues as deterioration of the work ethic, and any effect from such unmeasured phenomena will presumably appear in the residual of our analysis. In an alternative framework based on regression analysis, one could try to measure such phenomena because the standards for quantifying them could be relaxed.[4] However, the collinearity in single-equation regression models makes the coefficients associated with any single factor highly variable, depending greatly upon the other factors included in a particular specification. A multiple-equation, simultaneous model might be attempted; but it would be difficult to include a number of possible explana-

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nomic Report of the President, January 1978, pp. 48–58; and J. R. Norsworthy and Michael J. Harper, "The Role of Capital Formation in the Recent Productivity Growth Slowdown," Working Paper 87 (Bureau of Labor Statistics, January 1979). For energy see Edward A. Hudson and Dale W. Jorgenson, "Energy Prices and the U.S. Economy, 1972–1976," *Data Resources Review,* vol. 7 (September 1978), pp. 1.24–1.37; and George L. Perry, "Potential Output: Recent Issues and Present Trends," in Center for the Study of American Business, "U.S. Productive Capacity: Estimating the Utilization Gap," Working Paper 23 (Washington University, CSAB, December 1977), pp. 1–20 (Brookings Reprint 336). For labor force composition and intersectoral shifts of labor see Jack Beebe, "A Note on Intersectoral Shifts and Aggregate Productivity Change," *Annals of Economic and Social Measurement,* vol. 4 (Summer 1975), pp. 389–95; George L. Perry, "Labor Force Structure, Potential Output, and Productivity," *BPEA, 3:1971,* pp. 533–65; William D. Nordhaus, "The Recent Productivity Slowdown," *BPEA, 3:1972,* pp. 493–526; Michael Grossman and Victor R. Fuchs, "Intersectoral Shifts and Aggregate Productivity Change," in American Statistical Association, *Proceedings of the Business and Economic Statistics Section* (Washington, D.C.: ASA, 1972), pp. 66–75; and J. R. Norsworthy and L. J. Fulco, "Productivity and Costs in the Private Economy, 1973," *Monthly Labor Review,* vol. 97 (June 1974), pp. 3–9.

4. Robin Siegel, "Why Has Productivity Slowed Down?" *Data Resources Review,* vol. 8 (March 1979), pp. 1.59–1.65.

tory factors in a framework that allows for variable elasticities of substitution.

We examine, in addition, the existence and timing of the productivity slowdown and its pervasiveness among major industry sectors of the economy. And we estimate the contribution to this slowdown of changes in the composition of the labor force, changes in capital-labor ratios, trends in the ratio of hours worked to hours paid, interindustry shifts of capital and labor, capital expenditures for pollution abatement, and increases in energy prices. Most of these effects are analyzed by interpreting them as augmenting or abating the effective input of capital or labor.

A general point about the analysis of the slowdown needs to be made at the outset. For a particular phenomenon to contribute to a slowdown in productivity growth, its effects must be greater in the slowdown period than in the reference period. We therefore need data to estimate the effects in both periods in order to determine any contribution to the slowdown. It is not sufficient that a particular negative factor is at work during the slowdown; it must be working demonstrably harder than before.

The Dimensions of the Slowdown

Peter Clark, after adjusting the labor productivity series for cyclical movements, selected the time periods 1948–55, 1955–65, 1965–73, and 1973–77 for analysis.[5] The endpoint years, except for 1977, are peaks in Clark's cyclically adjusted labor productivity. The year 1965 has additional claims as a watershed year: it marked the onset of major Vietnam War deficit financing and increasing inflation. And at about that time the first cohort from the postwar "baby boom" entered the labor force. We adapted Clark's time periods (which were based initially on quarterly data) by combining the first two periods and extending the last one to 1978. The present evidence that real output is leveling off or declining during 1979 suggests that 1978 will be a reasonable endpoint for the analysis.

For each of our reference periods, table 1 shows the rates of growth of output, labor and capital input, and labor productivity in the private business sector—the largest sector for which the BLS publishes productivity statistics. The slowdown in the growth of labor productivity is evident in

5. Clark, "Capital Formation."

Table 1. Rates of Growth of Labor Productivity, Output, Capital, and Hours, and Ratio of Investment to Output, Private Business Sector, Selected Periods, 1948–78[a]
Annual average, in percent

Item	*1948–65*	*1965–73*	*1973–78*
Labor productivity	3.32	2.32	1.20
Gross domestic product	3.71	3.77	2.62
Net capital stock[b]	2.62	3.67	2.05
Total hours of labor input[c]	0.38	1.44	1.42
Ratio of gross private domestic investment to gross domestic product	12.3	13.5	12.8

Source: Computed by authors using data from the U.S. Bureau of Economic Analysis and the U.S. Bureau of Labor Statistics.
a. Output, investment, and the capital stock are measured at 1972 prices.
b. The method of aggregation used is direct aggregation. See table 4.
c. Measured as hours paid.

the last two periods. The growth of the capital stock is examined carefully below. It is worth noting here that it slowed substantially in the last period, even though the ratio of investment to gross product was slightly higher than in 1948–65. The growth rate of output does not explain variations in this investment fraction the way a simple accelerator model would predict. However, accelerator effects might help to explain part of the slowdown in capital formation between the last two periods.

Some investigators have chosen to examine the productivity slowdown as a *single* phenomenon beginning in the middle to late 1960s. The argument for a break at the business cycle peak in 1973 seems compelling, however. In addition to the sharp jump in energy prices that occurred, the patterns of productivity growth rates—or slowdowns—in 1965–73 and 1973–78 are quite different. And Norsworthy and Harper have found sharply different patterns of capital formation before and after 1973.[6] We therefore examine the productivity slowdown in two phases: 1965–73 and 1973–78.

By choosing our periods with endpoints that are years of relatively high resource utilization, we avoid the need to make cyclical adjustments in our data. Cyclical adjustment of output and input is an issue closely related to the choice of time periods for analysis. Clearly, productivity growth is slower—and for quarterly measurements it is negative—during economic recession. Measurement of average growth rates in output and

6. Norsworthy and Harper, "Role of Capital Formation."

input between peaks or over relatively long periods implicitly assumes that the various time periods between the endpoints are comparably affected by negative cyclical influences. But this is clearly not true in the time periods we analyze—the years 1973–78 encompass a far more severe recession in fewer years than did 1965–73. Only insofar as these recession effects are captured in the factors we consider—for example, slower growth of the capital-labor ratio—will they be captured in our analysis. Nadiri and Rosen and Mohr have shown that the adjustment of any factor input to changes in output depends not only on the output change itself, but on the disequilibrium in other inputs.[7] That is, with n inputs, there are n^2 coefficients that describe the adjustment process. Particularly when output changes are accompanied by substantial changes in relative prices, as in 1973–74, the adjustment process may extend beyond the next cyclical peak. At present, the cyclical adjustment issue probably cannot be dealt with in a satisfactory way except in the context of an elaborate model incorporating lagged simultaneous adjustment of inputs. Sufficient evidence exists to suggest that any relatively simple method is inaccurate.

The distribution of the slowdown in labor productivity among major industrial divisions shown in table 2 reveals different patterns in 1965–73 and in 1973–78.[8] In manufacturing, the slowdown was about the same magnitude in each period. Mining productivity began to decline in 1969 when the Federal Coal Mine Health and Safety Act was passed, and productivity has continued to decline in recent years as energy prices have risen and coal has played a larger role relative to petroleum mining. Productivity growth in transportation slowed only slightly in 1965–73, but fell much more in the recent period when energy prices may have retarded

7. M. Ishag Nadiri and Sherwin Rosen, "Interrelated Factor Demand Functions," *American Economic Review*, vol. 59 (September 1969), pp. 457–71; M. F. Mohr, "A Quarterly Econometric Model of the Long-Term Structure of Production, Factor Demand, and Factor Productivity in 10 U.S. Manufacturing Industries," Staff Paper 9 (Bureau of Labor Statistics, 1978).

8. Output is based on gross product originating in the private domestic business portion of each sector. Output and labor and capital inputs for nonprofit institutions and household workers are excluded because output for those sectors is measured in the national accounts by deflated labor compensation—thus productivity growth is necessarily zero. This deduction is largely from the services sector. We also exclude the imputation for rental value of owner-occupied dwellings both because the labor input of homeowners and their families is not measured, and because final demand categories such as home maintenance and repair and some utilities consumption should properly be considered as intermediate inputs to the imputed output. This exclusion affects the finance, insurance, and real estate sector.

Table 2. Growth of Labor Productivity and Share of Labor Input in the Total Private Business Economy, by Sector, Selected Periods, 1948–78

Annual average, in percent

	Growth of labor productivity			*Share of total labor hours*		
Sector	*1948–65*	*1965–73*	*1973–78*	*1948–65*	*1965–73*	*1973–78*
Private business	3.2	2.3	1.1	100	100	100
Agriculture, forestry, and fisheries	5.5	5.3	2.9	12	6	5
Mining	4.2	2.0	−4.0	1	1	1
Construction	2.9	−2.2	−1.8	6	7	7
Manufacturing	3.1	2.4	1.7	30	32	30
Durable goods	2.8	1.9	1.2	17	19	18
Nondurable goods	3.4	3.2	2.4	13	13	12
Transportation	3.3	2.9	0.9	5	5	4
Communication	5.5	4.8	7.1	1	2	2
Electric, gas, and sanitary services	6.2	4.0	0.1	1	1	1
Trade	2.7	3.0	0.4	23	25	26
Wholesale	3.1	3.9	0.2	6	7	7
Retail	2.4	2.3	0.8	17	18	19
Finance, insurance, and real estate	1.0	−0.3	1.4	5	6	6
Services	1.5	1.9	0.5	12	14	16
Government enterprises	−0.8	0.9	−0.7	2	2	2

Source: Bureau of Labor Statistics. Productivity data for services, construction, and finance, insurance, and real estate are unpublished.

an advance in productivity. Productivity growth in communications slowed slightly in 1965–73 and then accelerated in 1973–78. (This industry is clearly not part of the productivity problem.) Utilities showed a reduction in productivity growth in 1965–73 and a virtual halt in 1973–78. Energy prices, oil and gas shortages, and environmental regulations are commonly cited as affecting this industry. Productivity growth accelerated in the trade industries in 1965–73 and fell off sharply in 1973–78. In government enterprises, productivity declined in the base period, grew slightly in 1965–73, and declined again in 1973–78. Agricultural productivity growth slowed in 1973–78.

Measures of output in the remaining three sectors are unreliable, and they are included in the table only to complete the productivity picture in the private business sector. The GNP Data Improvement Project—the Creamer report—urged that output measures for construction be improved because output is now essentially measured as deflated inputs (labor and materials). Construction productivity, as measured, fell in 1965–73 and declined slightly less rapidly in 1973–78, after growing in 1948–65 at near the average rate for the private business sector. A report by the U.S. Department of Commerce found no discernible cause for the productivity decline.[9] Within the finance, insurance, and real estate sector, output is measured by labor input in the banking sector, where electronic data processing has made major inroads. Any quality changes resulting from this technological change are therefore not reflected in the output measures for the sector. Measured productivity in that sector fell slightly in 1965–73 after slow growth in 1948–65, and rose again in 1973–78. In the services sector, output is measured by labor input in several constituent industries, and inadequate deflation to account for quality change is commonly cited as a problem. Measured productivity growth increased in 1965–73 and declined in 1973–78.[10]

The U.S. Bureau of Economic Analysis (BEA) does not publish data on capital stocks for federal, state, and local government enterprises. Consequently, we excluded output and labor input for government enterprises from the private business and private nonfarm business sectors. Table 3

9. H. Kemble Stokes, Jr., "An Examination of the Productivity Decline in the Construction Industry" (U.S. Department of Commerce, Office of the Chief Economist, March 1979).

10. Interindustry shifts within the service sector account for a major part of measured productivity change.

Table 3. Rates of Growth of Labor Productivity for the Private Business and Private Nonfarm Business Sectors, Total and Excluding Government Enterprises, Selected Periods, 1948–78

Annual average, in percent

	Private business		*Private nonfarm business*	
Period	*Total*	*Excluding government enterprises*	*Total*	*Excluding government enterprises*
1948–65	3.20	3.32	2.63	2.77
1965–73	2.25	2.32	1.95	2.02
1973–78	1.12	1.20	1.01	1.09

Sources: Computed by authors using data from the Bureau of Economic Analysis and Bureau of Labor Statistics.

shows the effects of the exclusion on the growth of labor productivity in those sectors.

In summary, the pervasiveness of the slowdown suggests that an examination of major economic aggregates may be fruitful. At the same time, growth in labor productivity by industry shows substantial differences between the 1965–73 and 1973–78 periods. An analysis that fails to separate these two periods may miss important causal patterns. We therefore attempt to account for the slowdown in two phases: a slowdown of 1.00 percentage point a year in 1965–73 and a further slowdown of 1.12 percentage points a year in 1973–78.

Framework for Analysis

Our analysis separates growth in labor productivity into growth attributable to changes in the capital-labor ratio, selected factors that alter the effectiveness of measured capital and labor inputs, and residual or otherwise unexplained growth, which may be considered as corresponding to total-factor productivity.

We begin by aggregating the growth rates of labor and capital inputs weighted by their respective shares in output measured at current prices. That is, the weight associated with the labor aggregate, w_L, is the ratio of total labor compensation to nominal output. Similarly, the weight associated with the capital aggregate, w_K, is the ratio of nonlabor payments to nominal output. The measures of output in current and constant prices, labor compensation, nonlabor payments, capital stock, and labor input are based on the national income and product accounts published by the Department of Commerce. The flow of capital services is assumed to be proportional to the net capital stock. The price of capital services is computed as reported by Norsworthy and Harper.[11]

From the definition of total-factor productivity, A, we have

$$A = O \Big/ \sum_{i=1}^{n} w_i X_i,$$

where O is output; w_i is the share of input i in total-factor cost, with $\Sigma w_i = 1$; and X_i is the quantity of input i used in producing O. Using lowercase letters to denote percentage change, we obtain productivity growth, a, from

$$a = o - \sum_{i=1}^{n} w_i x_i.$$

Thus when capital and labor are the only inputs,

$$a = o - w_K k - w_L l.$$

Factors such as composition or quality change can make the effective input of capital or labor differ from the measured input. Designating q_K as the change in factors influencing effective input of capital services and q_L as the change in factors influencing effective input of labor services, we have

$$a = o - w_K k - w_L l - w_K q_K - w_L q_L.$$

To focus on the growth in labor productivity, we rearrange terms to obtain

$$o - l = w_K(k - l) + w_K q_K + w_L q_L + a.$$

The growth in labor productivity thus depends on growth in the capital-labor ratio, factors of composition or quality change, and change in total-factor productivity. If all other factors are unchanged, labor productivity will grow at the same rate as total-factor productivity.

A key assumption that underlies this approach to accounting for growth in labor productivity is that the returns to various types of labor and capital equal their contributions to output—that is, equal their margi-

11. Norsworthy and Harper, "Role of Capital Formation."

nal products. This assumption, although questionable for any particular point in time, is widely used in accounting for productivity growth, and is more reasonable as a description of trends over longer periods of time than a single year.

The particular factors whose contribution to labor productivity we analyze can be described briefly. To measure the effect on labor productivity of shifts in labor among sectors, q_{LI}, the growth rates of hours of labor input in the sectors are aggregated using the proportion of total labor compensation in each sector as weights. The effects of changes in the composition of the labor force are computed by Divisia aggregation of various categories of labor input—disaggregated by age, sex, education, occupation, and class of worker. Divisia aggregation sums the growth rates of each category of input, weighting each by its share of total labor input. The index of the change in labor composition, q_{LC}, is then the difference between the growth of the Divisia aggregate and the growth of the directly aggregated (unweighted) labor input. The effect of shifts in the capital stock among asset types, q_{KC}, is measured by aggregating the growth rates of each type of capital asset weighted by each asset's share in total nonlabor payments in the sector. The effect of intersectoral shifts in capital, q_{KI}, is measured by aggregating the growth rates of the capital stock in each sector using the sector's share of total nonlabor payments as a weight. The effect of pollution abatement capital on the growth of the capital stock, k_{PA}, is also a kind of shift effect, and is treated as a deduction from the capital stock.

Each of these factors affecting measured capital and labor inputs is multiplied by the shares of labor and capital in nominal output—w_L and w_K—to compute the associated impacts on growth in labor productivity. The framework for analyzing the effects of changes in various factors contributing to growth in labor productivity thus can be expressed as

$$o - l = w_K(k - l) + w_K q_{KC} + w_K q_{KI} + w_K(-k_{PA}) + w_L q_{LC} + w_L q_{LI} + w_L q_{LH} + a,$$

where

$(k - l)$ = rate of growth of the capital-labor ratio
q_{KC} = effect of changes in the composition of capital
q_{KI} = effect of intersectoral shifts in capital
k_{PA} = rate of growth of pollution abatement capital

q_{LC} = effect of changes in labor force composition
q_{LI} = effect of intersectoral shifts in labor
q_{LH} = effect of changes in the ratio of hours worked to hours paid
a = change in total-factor productivity (residual).

The residual or unexplained growth in labor productivity, *a,* is computed as the difference between observed growth in labor productivity and the contributions of the other effects. Thus it contains the effects of any errors in measurement and of other factors not accounted for in the analysis.

The approach used here to measure sources of growth in labor productivity is similar to the approaches used by Denison and by Frank M. Gollop and Jorgenson in one respect—all depend on a share-weighting scheme to estimate the contributions of various factors to productivity growth.[12] The focus on growth in labor productivity in this paper is an expansion of a similar framework used by Christensen, Cummings, and Jorgenson.[13] Certain differences between our approach and the others should be noted, however. Those relating to measurement of capital and labor input are discussed in the appropriate sections below. Our concept of output measurement is similar to that of most other investigators except Denison. He measures output as net national income at factor cost and thus excludes replacement investment from real output. Consistent with this practice, he also excludes depreciation from the cost of capital, and hence from the share of capital in the nominal value of output. To measure output in this way seems less desirable than to include replacement investment because it is equivalent to assuming that the output that goes to replacing the capital stock could not be diverted elsewhere. Even at the aggregate level, this is untrue—during the 1930s, net investment measured in the national income accounts was negative in at least one year. And at the industry level, negative net investment in a given year is common. Denison's approach reduces the measured effect of capital's contribution to productivity growth because, as noted above, the share of capital is considerably smaller. In addition, the impact of productivity growth on

12. Denison, *Accounting for United States Economic Growth,* and Frank M. Gollop and Dale W. Jorgenson, "U.S. Productivity Growth by Industry," in John W. Kendrick and Beatrice N. Vaccara, eds., *New Developments in Productivity Measurement* (National Bureau of Economic Research, forthcoming).

13. Laurits R. Christensen, Diane Cummings, and Dale W. Jorgenson, "Economic Growth, 1947–1973: An International Comparison," in Kendrick and Vaccara, eds., *New Developments.*

prices cannot be directly observed in Denison's framework because output prices include the full cost of capital. In a period such as 1965–73, when the share of equipment in total investment and hence in the total capital stock was rising, replacement investment was also rising because depreciation occurs faster for equipment than it does for structures. Thus output in the private business sector would rise more rapidly in our accounting framework than in Denison's, other things being equal.

THE CAPITAL STOCK

A number of issues arise in measuring the effects of capital input on the growth of labor productivity. These include how to aggregate the capital stock; whether to use net or gross stocks; whether to include land, inventories, and tenant-occupied housing; and whether to adjust for capacity utilization. These issues are discussed extensively by Norsworthy and Harper.[14] Only the main outline of that argument is summarized here.

Issues in Measurement. Disagreement about the appropriate techniques for aggregation of the capital stock—and, indeed, inputs in general—for productivity analysis has characterized the discussion of production theory in the economics literature.[15] This particular type of index-number problem turns on the validity of direct aggregation of the components of the capital stock, measured in constant prices, as contrasted with translog or Divisia aggregation, which are both based on aggregation of the growth rates of the components weighted by their shares in total capital cost.[16] In terms of the production function, direct aggregation

14. Norsworthy and Harper, "Role of Capital Formation."

15. The disagreement figures prominently in the debate between Edward F. Denison, Dale W. Jorgenson, and Zvi Griliches, which is reproduced in "The Measurement of Productivity," *Survey of Current Business,* vol. 52 (May 1972), pt. 2, pp. 1–111.

16. The term "Törnquist index" is also used. The Divisia index, properly speaking, is a continuous index, and some of the superior mathematical properties claimed for it apply only in the continuous form. See D. W. Jorgenson and Z. Griliches, "The Explanation of Productivity Change," *Review of Economic Studies,* vol. 34 (July 1967), pp. 249–83. The application of the aggregation technique in time-series analysis necessarily involves a discrete approximation to the continuous Divisia form. The particular approximation—more than one is possible—used by Jorgenson and his associates is based on the maintained hypothesis of a translog production or cost function and thus seems best called a translog index. See Laurits R. Christensen, Dale W. Jorgenson, and Lawrence J. Lau, "Transcendental Logarithmic Production Frontiers," *Review of Economics and Statistics,* vol. 55 (February 1973), pp. 28–45.

is exact for the Cobb-Douglas specification, which requires strong separability of the inputs being aggregated from other inputs appearing in the production function. Translog aggregation, which is exact for a homothetic translog production function, requires weak separability of the inputs.

We performed econometric tests for each specification. The test for the conditions required for direct aggregation failed by a wide margin for all three sectors, while the test for translog aggregation passed for the private nonfarm and private nonfarm business sectors and failed narrowly for manufacturing.[17] We therefore chose to use translog aggregation in this study.

The choice of net or gross capital stocks of equipment and structures is another issue in the measurement of the growth of the capital stock. For productivity analysis, the issue comes down to whether net or gross capital stock—or, indeed, some other measure—is the better indicator of real capital input. In accounting terms, the difference between the gross and net capital asset measures is the accumulated depreciation on the asset. The method of depreciation and the service life of the capital asset are the determinants of depreciation. There is precedent for using gross capital stock, net capital stock, and a linear combination of the two.[18] Denison uses a linear combination of the net and gross capital stocks to measure real capital input, whereas we use the net stock. Although the service lives of capital assets are difficult to obtain, there is evidence that the net capital stock from the national income accounts understates and the gross stock overstates real capital input.[19] The evidence is incomplete, but Denison's measure may be nearer to real capital input than that used here.

Evidence indicates that the results for 1965–73 are not sensitive to the choice of measures: the net stock of equipment and structures in the private nonfarm business sector grew at an average annual rate of 3.1 percent

17. These tests are described in Norsworthy and Harper, "Role of Capital Formation."

18. For gross capital stock see John W. Kendrick, *Postwar Productivity Trends in the United States, 1948–1969,* General Series, 98 (National Bureau of Economic Research, 1973); for net capital stocks see Laurits R. Christensen and Dale W. Jorgenson, "U.S. Real Product and Real Factor Input, 1929–1967," *Review of Income and Wealth,* series 16 (March 1970), pp. 19–50; for a linear combination see Denison, *Accounting for United States Economic Growth.*

19. Charles R. Hulten and Frank C. Wykoff, "Economic Depreciation and the Taxation of Structures in U.S. Manufacturing Industries: An Empirical Analysis," in Dan Usher, ed., *The Measurement of Capital* (National Bureau of Economic Research, forthcoming).

in 1948–65 and 4.4 percent in 1965–73, while the gross stock grew at rates of 2.7 and 3.9 percent in the respective periods. The changes in the rates of growth therefore differ by only one-tenth of 1 percentage point. The 1973–78 results, however, are sensitive to the choice between net and gross measures.

In simplest terms, the translog aggregation of the capital stock that we use is a method of correcting for aggregation bias because of changes in the composition of the capital stock. The reasoning underlying the use of the technique depends on the assumption that each asset type is used in each sector in such quantity that its marginal product—the value of asset services—is just equal to the price of the services of the asset. The price of those services depends upon the purchase price of the asset, the corporate tax rate, the service life of the asset (or the rate of depreciation), other special tax treatment (such as capital gains or investment tax credit), and the debt-equity structure of corporate liabilities.[20] For example, a shift in the composition of the capital stock from structures to equipment (such as the one that took place from 1965 through 1977) represents an increase in the "quality" of the capital stock because the service life of equipment is shorter than that of structures. Thus the depreciation rate for the aggregate stock is higher, and the cost of capital services is higher. The marginal productivity of the capital stock as a whole is therefore higher, and the flow of capital services in economic terms is greater.

The interindustry mix of the capital stock reflects differences in the rate of return on assets among industries. Because we only consider four asset categories, whereas the BEA capital stock information is based on more than twenty classes of equipment alone, there may also be systematic differences in depreciation rates among industries reflecting the different average service lives of the stocks of equipment and structures. Even in the equilibrium model on which this aggregation technique is based, such differences may occur in the average price of capital services across industries reflecting different capital stock composites. Therefore differential rates of growth of the capital stock by industry can lead to changes in the value of the flow of aggregate capital services. As noted below, the asset and industry dimensions of changing capital stock composition can be separated in the translog aggregation process, and reported and analyzed separately.

20. See Christensen and Jorgenson, "U.S. Real Capital and Real Factor Input."

The translog aggregation procedure makes it possible to isolate the separate contributions of changes in asset type and changes in interindustry composition of the capital stock to the growth of the capital aggregate. We may express the growth rate of the translog index for the capital aggregate, k_T, as

$$k_T = k + q_{KA} + q_{KI},$$

where

k = growth rate of the capital stock directly aggregated

q_{KA} = growth contributed by changes in the asset mix (among equipment, structures, land, and inventories)

q_{KI} = growth contributed by changes in the industry mix of the capital stock.[21]

An additional term, not shown in the expression for k_T above, accounts for the interaction between q_{KI} and q_{KA}. Where it is not shown explicitly, we distributed the value of this term between the values of q_{KI} and q_{KA} in the tables presented below.

Direct and translog aggregation of the capital stock for the private business sector are compared in table 4. The translog aggregate grows more rapidly in all time periods, particularly in 1965–73 when there was a substantial shift to equipment purchases in the manufacturing sector, presumably in response to the investment tax credit. Assets and interindustry shift generally follow the annual growth rates in magnitude. The size of the total capital composition, or quality effect, is important; it provides between 10 and 20 percent of the average annual growth rate in each period. The notion that aggregation effects of this sort can be ignored seems to be refuted effectively. The rates of growth changed and so did their intertemporal pattern: the increase in the rate of capital formation in 1965–73 is greater for the translog aggregate.

In measuring total real capital input for productivity analysis, it is important to include land and inventories as well as measures of equipment and structures.[22] Stocks of inventories measured in current and constant

21. Only three industry sectors are recognized in the capital stock and investment data available from the U.S. Bureau of Economic Analysis: manufacturing, farm, and nonfarm nonmanufacturing. Because the definition of asset is a general one, finer detail for each industry typically leads to a reallocation of capital "quality" change—as the sum of the q terms above is often called—from asset to industry. See Gollop and Jorgenson, "U.S. Productivity Growth."

22. See Denison, *Accounting for United States Economic Growth;* Gollop and Jorgenson, "U.S. Productivity Growth"; and Kendrick, *Postwar Productivity.*

Table 4. Rates of Growth of Capital Stock, by Method of Aggregation, and Contributions to Growth from the Effect of Capital Composition, Private Business Sector, Selected Periods, 1948–78

Annual average, in percent

	Method of aggregation		*Effect of capital composition*			
Period	*Direct*	*Translog*	*Total effect*	*Asset composition*	*Inter-sectoral shifts*	*Interaction between asset composition and shifts*
1948–65	2.62	3.14	0.51	0.30	0.34	−0.13
1965–73	3.67	4.48	0.82	0.41	0.51	−0.10
1973–78	2.05	2.31	0.24	0.18	0.10	−0.04

Sources: Computed by authors. Net capital stock series for equipment, structures, and inventories are from the Bureau of Economic Analysis. Data on land are from John W. Kendrick, *The National Wealth of the United States: By Major Sector and Industry*, Report 698 (The Conference Board, 1976), extrapolated for 1975–78 by the authors.

prices and adjusted for price changes are reported by BEA. Corresponding measures of land input are not available from that source. In this paper we adopt the measures used by Kendrick in his estimates of the input of land for the aggregate sectors.[23]

It is important to measure the capital stock that corresponds as closely as possible to the output it produces. In his analysis of productivity growth in the nonfarm business sector, Clark used the capital stock for the private nonfarm sector of the economy and found that some slowdown in labor productivity was attributable to capital formation in 1965–73.[24] In table 5 that capital stock is adjusted to conform to the definition of the private nonfarm business sector by eliminating the capital in nonprofit institutions and including tenant-occupied residential capital.[25] These adjustments increase the acceleration in capital formation between 1948–65 and 1965–73 from 0.74 percentage point to 1.31 percentage points a year, enough to alter sharply Clark's verdict on the role of capital in the 1965–73 slowdown. Inclusion of land and inventories modifies the pattern only slightly. To adjust real capital input—the flow of capital services—for changes in capacity utilization means that part of the corresponding growth (or decline) in output can be traced to the change in capacity utili-

23. John W. Kendrick, *The National Wealth of the United States: By Major Sector and Industry*, Report 698 (The Conference Board, 1976).

24. Clark, "Capital Formation," p. 974.

25. Aggregates in table 5 are based on direct aggregation of capital stocks.

Table 5. Reconciliation of Nonresidential Equipment and Structures to Business Capital, Private Nonfarm Business Sector, Selected Years, 1948–78[a]

	Net stock (billions of 1972 dollars)				Rate of growth (percent)		
Item	*1948*	*1965*	*1973*	*1978*	*1948–65*	*1965–73*	*1973–78*
Nonresidential equipment and structures	304.41	597.08	867.47	991.86	4.05	4.79	2.72
Minus: Capital of nonprofit institutions	25.23	64.67	88.58	92.37	5.69	4.02	0.84
Equals: Nonresidential business equipment and structures	279.18	532.41	778.88	899.50	3.88	4.88	2.92
Plus: Tenant-occupied residential capital	128.42	156.73	197.46	202.00	1.19	2.93	0.46
Equals: Business equipment and structures	407.60	689.14	976.34	1,101.49	3.14	4.45	2.44
Plus: Land and inventories	158.11	261.09	358.47	388.25	3.03	4.05	1.64
Equals: Business capital	565.71	950.23	1,334.81	1,489.75	3.10	4.34	2.23

Source: Computed by authors using data from the Bureau of Economic Analysis. Figures are rounded.
a. The aggregates are based on direct aggregation of capital stocks.

zation. Denison argues extensively and convincingly that this cannot be done.[26] He also argues that adjustment of the entire capital stock by utilization rates in manufacturing is inappropriate because those rates inaccurately reflect utilization rates for other sectors, and for assets other than machinery. A careful reading of Denison's argument—which is too extensive to reproduce or even adequately summarize here—is compelling for us and presumably for Jorgenson, who revised his measurement technique to eliminate adjustment for capacity utilization.[27]

We also make no separate adjustment for technological improvement embodied in the capital stock. Insofar as these advances are reflected in a higher price for the asset, the adjustment for changes in the asset mix will capture the effect. If the improvements are achieved at no cost, the quantity of the asset used in production will be correspondingly adjusted so that the marginal product of the improved asset is equal to its service price, as noted above. Thus in either case the equilibrium nature of the model captures embodied technological change in the quantity or "quality" of the capital stock.

Effects of Capital Spending for Pollution Abatement. The effects of investment in pollution abatement capital (PAK) on productivity growth is assumed to operate only through the capital stock. A reliable estimate of the contribution to the 1965–73 slowdown cannot be made because data for investment in PAK are not available before 1968. The unofficial BEA estimates of PAK investment and net stock are sufficient to fill out the 1965–73 period, and this period can be used as a reasonably good baseline with which to judge the effects of PAK expenditures in 1973–78 on productivity growth.[28] Even the unofficial estimates begin in 1955. We quite arbitrarily projected the estimated investment growth back to 1948 to obtain a baseline for estimating the contributions to the 1965–73 slowdown. The data are poor and the technique mechanical; however, the re-

26. Edward F. Denison, "Some Major Issues in Productivity Analysis: An Examination of Estimates by Jorgenson and Griliches," *Survey of Current Business*, vol. 49 (May 1969), pt. 2, pp. 1–29.

27. Ibid., and Gollop and Jorgenson, "U.S. Productivity Growth."

28. A more complete discussion of the quality of PAK data and their meaning is found in John E. Cremeans, "Capital Expenditures by Business for Air and Water Pollution Abatement, 1973 and Planned 1974," *Survey of Current Business*, vol. 54 (July 1974), pp. 58–64; and his "Conceptual and Statistical Issues in Developing Environmental Measures—Recent U.S. Experience," *Review of Income and Wealth*, series 23 (June 1977), pp. 97–115.

Table 6. Rates of Growth of the Capital Stock, Total and Excluding Pollution Abatement Capital, by Sector, Selected Periods, 1948–78[a]
Annual average, in percent

Sector	1948–65 Total	1948–65 Excluding pollution abatement capital	1965–73 Total	1965–73 Excluding pollution abatement capital	1973–78 Total	1973–78 Excluding pollution abatement capital
Private business	3.14	3.11	4.48	4.37	2.31	2.05
Private nonfarm business	3.24	3.21	4.59	4.47	2.37	2.09
Manufacturing	2.93	2.86	3.93	3.64	2.16	1.47

Source: Computed by authors using data from the Bureau of Economic Analysis.
a. The aggregates are based on direct aggregation of capital stocks.

sulting changes in the rates of growth of the capital stock, shown in table 6, are so small for the earlier periods in all but the manufacturing sector that substantial changes in technique would make little difference. The effects on the growth of labor productivity in the private business, private nonfarm business, and manufacturing sectors are estimated by weighting the capital devoted to pollution abatement by the share of capital in total output in the sectors.

For the last period, the growth of the capital stock is affected noticeably by the adjustment for pollution abatement. For the periods before 1973, the table demonstrates that PAK expenditures had a minimal effect on the capital aggregates. The effects in particular sectors were obviously greater than what is shown in these aggregate data. Denison examines the proposition from a broader perspective and still finds no major impact, although his is an aggregate perspective also.[29]

ADJUSTMENT FOR THE COMPOSITION OF THE LABOR FORCE AND FOR INTERINDUSTRY SHIFT

We adapt the method used by Gollop and Jorgenson to analyze the effects of the composition of the labor force and interindustry shifts.[30] Our

29. Denison, "Effects of Selected Changes," p. 42. The effects of pollution abatement and health and safety regulations are analyzed by Denison in a different manner. He concludes that by 1975 the annual impact of these activities as well as private expenditures for crime prevention may have contributed as much as 0.26 percentage point a year to the slowdown measured from 1969 to 1975, reaching 0.47 percentage point from 1973 to 1975.

30. Gollop and Jorgenson, "U.S. Productivity Growth."

procedure also follows Denison's analysis closely.[31] Denison does not account for different occupation groups nor is he always able to weight all the separate characteristics by their specific relative wage as we do; however, this is because of a lack of data rather than a difference in approach.

The basic technique for translog aggregation of the various components of the labor force is the same as that for aggregation of the capital stock: each category of labor input is assumed to be paid the value of its marginal product in each year. Thus relative increases in the proportion of higher paid labor categories to total labor input are taken to represent increases in effective input. This assumption underlies the adjustment by Denison as well as by Gollop and Jorgenson for changes in effective labor input.

To account for changes in the composition of labor input, the total hours for each sector analyzed here—the private business, private nonfarm business, and manufacturing sectors—are disaggregated according to sex, age, education, occupation, and employment class of worker (self-employed or employee) for each year from 1948 to 1978. Total compensation for each sector was disaggregated in the same manner. In all, there are 1,600 disaggregations for each sector (two groups for sex, two for worker employment class, five for education, eight for age, and ten for occupation).

The interindustry disaggregation was based on the industry detail from the national income and product accounts: the private business sector is composed of sixty-two industries; the private nonfarm business sector, sixty-one industries; and the manufacturing sector, twenty-one industries. The raw data for the disaggregation was compiled from records of the U.S. Bureau of the Census, special labor force reports published by the BLS, and for the last years, from tapes from the Current Population Survey.[32]

The growth rate in the adjustment for labor composition, q_{LC}, is de-

31. Denison, *Accounting for United States Economic Growth*, pp. 30–50, 219–59. For a comparison of the analyses by Denison, Gollop and Jorgenson, and Kendrick, see Kent Kunze, "Evaluation of Labor Force Composition Adjustment," in *Measurement and Interpretation of Productivity* (National Academy of Sciences, forthcoming).

32. The disaggregation of the hours and compensation was resolved by use of a multiproportional matrix model. The annual hours and compensation are controlled at the industry level for employees, with only the hours and compensation for the self-employed and unpaid family workers adjusted according to the March Current Population Survey.

fined as the growth in labor services adjusted for all categories of labor, h, less the growth in unadjusted hours worked, l:

$$q_{LC} = h - l,$$

where labor services is a function of the various categories of labor input, L_i:

$$H = f(L_1, L_2, \ldots, L_N).$$

Assuming f is a linear homogenous logarithmic function, the growth in labor services is the derivative with respect to time:

$$h = \sum_{i=1}^{n} v_i l_i,$$

where

$$v_i = \frac{df}{dL} \qquad \text{and} \qquad \sum_{i=1}^{n} v_i = 1.$$

We further decompose labor services into q_{LC} and l. Adding and then subtracting the growth rate in unadjusted hours from the right-hand side yields

$$h = \sum_{i=1}^{n} v_i(l_i - l) + l.$$

The difference $(l_i - l)$ is interpreted as the growth rate of the proportion of total hours worked by the ith category of workers. The growth rate of labor services can thus be expressed as the sum of the rates of changes in q_{LC} and l. That is,

$$h = q_{LC} + l,$$

where

$$q_{LC} = \sum_{i=1}^{n} v_i(l_i - l).$$

The ratio of hourly compensation between categories is assumed to be equal to the ratio of marginal products for each category of labor.

Two sets of indexes are computed for each of the major sectors: one for changes in sex, age, education, occupation, and class of worker; the other for changes in labor input among industries, q_{LI}.

Table 7. Rates of Growth of Adjustments to Total Hours for Changes in Labor Composition and for Interindustry Shifts, by Sector, Selected Periods, 1948–78
Annual average, in percent

	Private business		*Private nonfarm business*		*Manufacturing*	
Period	*Labor composition*	*Interindustry shifts*	*Labor composition*	*Interindustry shifts*	*Labor composition*	*Interindustry shifts*
1948–65	0.17	0.23	0.18	−0.02	0.20	−0.03
1965–73	0.08	0.30	0.03	0.18	0.07	−0.03
1973–78	0.14	−0.11	0.06	−0.12	0.11	0.07

Source: Computed by authors as explained in the text, using the method described in Frank M. Gollop and Dale W. Jorgenson, "U.S. Productivity Growth by Industry, 1947–1973," in John W. Kendrick and Beatrice N. Vaccara, eds., *New Developments in Productivity Measurement* (National Bureau of Economic Research, forthcoming). The basic data are from the U.S. Bureau of the Census and the Bureau of Labor Statistics.

Separation of the industry adjustment from the adjustment for labor composition assumes independence between them. This assumption was investigated by calculating a measure of labor composition using industry as one of the characteristics. If independence exists, no difference occurs between this measure and the sum of the two measures we have used, q_{LI} and q_{LC}. There was virtually no difference for the private business and private nonfarm business sectors in either the 1948–65 or the 1965–73 periods.[33] This was not the case in the manufacturing sector, where a significant interaction seemed to occur between q_{LC} and q_{LI}. For all sectors, the measured interaction term was added to the adjustment for labor composition.

Table 7 indicates the annual growth rates for adjusted labor composition and adjusted interindustry shifts as computed above. (These growth rates have not been weighted by labor's share, w_L.) The contribution to labor productivity provided by the changing composition of the labor force decreased by more than 50 percent for all sectors from the 1948–65 to 1965–73 period and increased in 1973–78. The contribution of interindustry shift, on the other hand, increased significantly from the first to second period for the private business and private nonfarm business sectors, then decreased substantially in 1973–78. Interindustry shift has had little effect in the manufacturing sector.

To obtain a better understanding of the cause for the changes in labor composition, we also examined the separate direct effects of age, sex, edu-

33. The data have not been developed at this time to measure the interaction for 1977 and years following. To use only the 1973–76 period would be inappropriate.

Table 8. Rates of Growth of Direct Effects of Labor Characteristics on Labor Composition, by Sector, Selected Periods, 1948–78
Annual average, in percent

Sector and period	*Sex*	*Employment class of worker*	*Age*	*Education*	*Occupation*
Private business					
1948–65	−0.11	−0.02	0.08	0.46	0.31
1965–73	−0.07	−0.00	−0.27	0.95	0.28
1973–78	−0.23	−0.13[a]	−0.23	1.05	0.25
Private nonfarm business					
1948–65	−0.06	−0.05	0.04	0.33	0.06
1965–73	−0.07	−0.05	−0.30	0.85	0.11
1973–78	−0.23	0.02[a]	−0.08	1.00	0.24
Manufacturing					
1948–65	−0.04	−0.03	0.17	0.49	0.30
1965–73	−0.08	0.00	−0.16	0.81	0.36
1973–78	−0.06	0.02[a]	−0.17	0.75	0.52

Source: Computed by authors as described in the text, using data from the Bureau of the Census and the Bureau of Labor Statistics.
a. Calculated for the 1973–76 period.

cation, occupation, and class of worker, as shown in table 8. These growth rates show the composition adjustment separately for the specific characteristics. The effects are not simply additive to q_{LC} because they are not independent; however, they do show which characteristics exhibited the largest effect on the change in the labor composition and the direction of the effects.

The growth rates presented in table 8 show that age was the major factor contributing to the downward adjustment from labor composition for the first period of slowdown. In all three sectors this characteristic went from a positive to a negative annual growth rate, corresponding directly to the large increase of young workers as the postwar baby-boom cohort entered the labor market. For the private nonfarm and private business sectors the age factor reversed itself in the third period, but the increase in female entrants to the labor force seemed to compensate for this reversal. Especially rapid entry of females took place in nonfarm-nonmanufacturing industries, an area that has historically shown a smaller increase in productivity. This development did not affect the manufacturing sector. However, the age factor did continue to depress the composition of the labor force in manufacturing for the third period. Educational attainment increased and added to effective labor input in the 1965–73 and 1973–78 periods for all sectors. Education and occupation are highly interrelated factors, so that adjusting for education alone also captures a significant amount of the contribution from the changing occupation mix.

HOURS WORKED VERSUS HOURS PAID

Labor productivity is generally measured using hours paid as the labor input measure. The data are taken from the current employment statistics (CES) program's survey of nonagricultural establishments, which has far greater coverage than any currently available survey of hours worked.[34] A 1976 report by the BLS found that no available survey provides data on hours worked that are sufficiently accurate to serve as a basis for quarterly or annual measures of labor productivity.[35]

Insofar as hours paid exceed hours worked, the level of labor productivity will therefore be understated. Measured growth in labor productivity will be affected only if the ratio of hours worked to hours paid changes through time; the measured slowdown in productivity growth will be affected only if the rate of change of that ratio is altered. Recent work by Stafford and Duncan,[36] based on quite small samples, shows that the divergence between hours worked and hours paid accounts for as much as one-third of the productivity slowdown. This suggests that it is worthwhile to use the best available data to attempt to quantify the effect.

The BLS report made rough estimates of hours worked from 1952 to 1965, based on exclusion of leave from the CES data on hours paid, and from 1966 to 1975, based on the Employer Expenditures for Employee Compensation survey.[37] From these data we estimated average annual

34. The ideal target concept is hours actually worked. In this paper we use the term to denote hours at the workplace, a concept that excludes paid leave (vacation, holiday, and sick leave).

35. Bureau of Labor Statistics, "Report of the BLS Task Force on Hours Worked" (BLS, March 1976). Modification of the survey to include the collection of data on hours worked is now planned.

36. Frank P. Stafford and G. I. Duncan, "The Use of Time and Technology by Households in the United States," in Ronald G. Ehrenberg, Orley Ashenfelter, and Ronald L. Oaxaca, *Research in Labor Economics*, vol. 3 (JAI Press, forthcoming).

37. The Employer Expenditures for Employee Compensation survey covered 6,000 establishments, primarily large ones, from 1966 to 1974. While the data are not comparable to the time-use diaries cited by Stafford and Duncan, the sample size and frequency is considerably larger. See ibid.

Table 9. Rates of Change in the Ratio of Hours Worked to Hours Paid, by Sector, Selected Periods, 1952–75

Annual average, in percent

Sector	*1952–65*	*1965–73*	*1973–75*
Private business	−0.08	−0.22	−0.14
Private nonfarm business	−0.06	−0.21	−0.12
Manufacturing	−0.06	−0.40	0.03

Sources: Computed by authors from data in Bureau of Labor Statistics, "Report of the BLS Task Force on Hours Worked" (BLS, March 1976).

rates of change in the ratio of hours worked to hours paid for 1952–65, 1965–73, and 1973–75 in private business, private nonfarm business, and manufacturing. The results, shown in table 9, are not striking. There is a small, persistent but variable decline in the ratio of hours worked to hours paid in each sector, except for manufacturing in the last period. The effects on growth of labor productivity were estimated by assuming that the average annual growth rates for 1952–65 and 1973–75 characterized the periods 1948–65 and 1973–78—a rather weak technique. The resulting values were weighted by the share of labor in total output in the three sectors.

ENERGY AND PRODUCTIVITY

We can make only a limited appraisal of the impact of higher energy prices on the growth of labor productivity in the private business and private nonfarm business sectors. Data on energy use are not available by sector, but rather by the following categories: industrial, commercial, transportation, and residential. These categories have not been mapped into the major economic sectors with sufficient accuracy to justify their inclusion in the productivity accounting framework. In addition, our framework uses a concept of output based on gross product originating, so that flows of intermediate products—including energy—are excluded, although value-added is included in the energy-producing sectors.

It is possible to appraise the effects of energy price increases based on the energy share in output in the major sectors, as Denison has done. However, his procedure implicitly assumes that the elasticity of substitution between energy and other factors is one, and strong evidence exists to the contrary, at least for the manufacturing sector. Berndt and Wood and Hudson and Jorgenson find complementarity between energy and capital in U.S. manufacturing;[38] Griffin and Gregory, using cross-section and time-series data for several countries, find substitution.[39] Our own recent investigation relied on a dynamic adjustment model of the manufacturing sector in an attempt to remove the short-term complementary use of capital and energy suggested by Griffin and Gregory as a major cause of the Berndt and Wood findings. We found stronger complementarity in the long-run than in the short-run version of the model.[40]

Using this model of the manufacturing sector, we undertook a simulation exercise for the 1973–78 period to assess the effects of increases in energy prices on the growth of labor productivity as these effects operate through changing the capital-labor ratio. Whatever actual effect energy prices have had on this ratio is included in the total estimated effect of capital formation on productivity. Here we suggest how much of that may be attributable to higher energy prices. The simulation assumes that energy prices rose at the same rate as the implicit price deflator for manufacturing rather than at the 22.3 percent rate that actually occurred. On this basis, the model suggests that the capital-labor ratio would have increased at an annual rate of about 2.3 percent instead of 1.7 percent. Thus labor productivity would have risen about 0.18 percentage point a year faster in manufacturing during 1973–78 if the relative price of energy had not changed. Hudson and Jorgenson also find a large reduction in investment for the 1972–76 period resulting from higher energy prices. Their study, which uses a more complete model of the economy, includes complementarity between energy and capital.[41]

38. Ernst R. Berndt and David O. Wood, "Technology, Prices, and the Derived Demand for Energy," *Review of Economics and Statistics*, vol. 57 (August 1975), pp. 259–68; Hudson and Jorgenson, "Energy Prices."

39. James M. Griffin and Paul R. Gregory, "An Intercountry Translog Model of Energy Substitution Responses," *American Economic Review*, vol. 66 (December 1976), pp. 845–57.

40. J. R. Norsworthy and Michael J. Harper, "Productivity Growth in Manufacturing in the 1980's: Labor, Capital, and Energy, in American Statistical Association, *Proceedings of the Business and Economic Statistics Section* (Washington, D.C.: ASA, forthcoming). The study was based on a four-factor model (capital, labor, energy, and intermediate materials) of manufacturing using energy data from Bureau of the Census, *Census of Manufactures*, for 1958, 1963, 1967, 1972, and 1977; and Bureau of the Census, *Annual Survey of Manufactures*, for intermediate years.

41. Hudson and Jorgenson, "Energy Prices," p. 1.33.

RESEARCH AND DEVELOPMENT

A number of investigators have argued that research and development expenditures have important effects on productivity growth. Kendrick is perhaps the strongest proponent of this view and his quantitative estimate of the effects of R&D is the largest.[42] Kendrick regresses the total-factor productivity (TFP) residual on a measure of the stock of accumulated knowledge. The quantitative estimates from this procedure depend upon how one quantifies knowledge and on how one defines TFP: if, as in Kendrick's case, it is defined as the ratio of output to the sum of share-weighted factor inputs, the effect will be relatively large; if, as in our analysis, factor-augmenting effects are removed from TFP, the effect will be smaller. In either case, the regression will attribute to R&D the effects of all unaccounted factors insofar as they have similar intertemporal patterns. On the other hand, to the extent that the effects of R&D can be seen in capital or labor or change the capital-labor ratio, some of the effect may be missed by attributing it to other factors in the analysis. It is not clear what approach, if any, can be relied upon to capture all the effects. Thus, although there seems to be a consensus that the decline in R&D expenditures is partially responsible for the slowdown in productivity growth, we found no satisfactory way to include the effect in our analysis.

Accounting for the Slowdown

As the preceding discussion indicates, some hypotheses about the causes of the productivity slowdown defy quantification. In table 10 we present the estimated effects of those factors that could be incorporated into this analysis for the private business, private nonfarm business, and manufacturing sectors. All three sectors show significant declines in labor productivity for both slowdown periods; the total effect of those slowdowns is smallest in manufacturing and greatest in private business, where the farm-to-nonfarm shifts of labor and capital contributed sub-

42. John W. Kendrick, *The Formation and Stocks of Total Capital,* General Series, 100 (National Bureau of Economic Research, 1976). Kendrick represents the stock of accumulated knowledge by the capitalized value of research and development expenditures.

Table 10. Rates of Growth of Labor Productivity and of Capital and Labor Effects on Productivity, by Sector, Selected Periods, 1948–78

Annual average, in percent

Item	*Private business*			*Private nonfarm business*			*Manufacturing*		
	1948–65	*1965–73*	*1973–78*	*1948–65*	*1965–73*	*1973–78*	*1948–65*	*1965–73*	*1973–78*
Labor productivity growth	3.32	2.32	1.20	2.77	2.02	1.09	3.13	2.47	1.70
Capital effect									
Capital-labor ratio	0.76	0.75	0.21	0.68	0.84	0.20	0.54	0.72	0.44
Asset composition	0.06	0.10	0.05	0.05	0.08	0.04	0.03	0.05	0.03
Intersectoral shifts	0.12	0.17	0.03	0.00	0.00	0.00	n.a.	n.a.	n.a.
Pollution abatement capital	0.00[a]	−0.03[a]	−0.09	−0.01[a]	−0.04[a]	−0.09	−0.03[a]	−0.09[a]	−0.19
Total	0.94	0.99	0.20	0.72	0.88	0.15	0.54	0.68	0.28
Labor effect									
Labor force composition	0.12	0.06	0.10	0.12	0.01	0.04	0.14	0.05	0.08
Interindustry shifts	0.15	0.20	−0.07	−0.02	0.12	−0.08	−0.02	−0.02	0.05
Ratio of hours worked to hours paid	−0.05	−0.14	−0.09	−0.04	−0.14	−0.08	−0.04	−0.07	0.02
Total	0.22	0.12	−0.06	0.06	−0.01	−0.12	0.08	−0.04	0.15
Effect of other factors	2.16	1.21	1.06	1.99	1.15	1.06	2.51	1.83	1.27

Sources: Computed by authors as explained in the text, using data from the Bureau of Economic Analysis and the Bureau of Labor Statistics.
a. As indicated in the text, estimates for these periods are based on partial data.
n.a. Not available.

stantially to growth before 1965. In private business and private nonfarm business, total-factor productivity growth, the "other factors" category in the table, declines very little between 1965–73 and 1973–78.

The changes in the growth rates from table 10 are presented in table 11 as a way of detailing the contributions to the productivity slowdown from the various factors analyzed. One conclusion is immediate—two slowdowns occurred with two different patterns of contributing causes: the 1965–73 slowdown is largely unexplained by factors quantified in this analysis; the 1973–78 slowdown is largely accounted for by the relative weakness in capital formation.

In the private business sector, the broadest aggregate, the total effects from capital formation augmented productivity growth in the first slowdown period; the effect of changes in capital composition more than compensated for the slight impacts of expenditures for pollution abatement and the capital-labor ratio. The latter effect was due entirely to slower growth in the capital-labor ratio in the farm sector, where the growth of the capital-labor ratio slowed largely because the rapid migration of labor from the farm sector had ended. Labor effects in the first slowdown period in the private business sector were small, although they contributed somewhat to the slowdown. Favorable interindustry shift effects were more than offset by a decline in the ratio of hours worked to hours paid and changes in the composition of the labor force. The dominant effect in the first slowdown period comes from other factors, which account for more than 90 percent of the total decline in the growth of labor productivity.

Different factors account for the productivity slowdown in the second period. Capital effects account for 0.79 percentage point out of a total decline of 1.12 percentage points. In this period the decline in growth of the capital-labor ratio contributes the largest effect, but changes in the asset and interindustry composition also add to the slowdown, and capital spending for pollution abatement makes a small negative contribution as well. Labor effects contribute somewhat more to the 1973–78 slowdown than in the earlier period, but the pattern is quite different. Changes in the composition of the labor force resulting largely from increased education have a positive effect on productivity growth, as does the ratio of hours worked to hours paid (though, again, the data underlying this latter estimate are weak). Interindustry shifts of the labor force have a strong negative influence. Other factors play a much smaller role than in

Table 11. Contributions to the Slowdown in the Growth of Labor Productivity, by Sector, 1965–78[a]

Annual average, in percentage points

Item	*Private business*			*Private nonfarm business*			*Manufacturing*		
	1965–73 slowdown	*1973–78 slowdown*	*Total*	*1965–73 slowdown*	*1973–78 slowdown*	*Total*	*1965–73 slowdown*	*1973–78 slowdown*	*Total*
Change in labor productivity growth	−1.00	−1.12	−2.12	−0.75	−0.93	−1.68	−0.66	−0.77	−1.43
Contribution from capital effect									
Capital-labor ratio	−0.01	−0.54	−0.55	0.16	−0.64	−0.48	0.18	−0.28	−0.10
Asset composition	0.04	−0.05	−0.01	0.03	−0.04	−0.01	0.02	−0.02	0.00
Intersectoral shifts	0.05	−0.14	−0.09	0.00	0.00	0.00	n.a.	n.a.	n.a.
Pollution abatement capital	−0.03	−0.06	−0.09	−0.03	−0.05	−0.08	−0.06	−0.10	−0.16
Total	0.05	−0.79	−0.74	0.16	−0.73	−0.57	0.14	−0.40	−0.26
Contribution from labor effect									
Labor force composition	−0.06	0.04	−0.02	−0.11	0.03	−0.08	−0.09	0.03	−0.06
Interindustry shifts	0.05	−0.27	−0.22	0.14	−0.20	−0.06	0.00	0.07	0.07
Ratio of hours worked to hours paid	−0.09	0.05	−0.04	−0.10	0.06	−0.04	−0.03	0.09	0.06
Total	−0.10	−0.18	−0.28	−0.07	−0.11	−0.18	−0.12	0.19	0.07
Contribution from effect of other factors	−0.95	−0.15	−1.10	−0.84	−0.09	−0.93	−0.68	−0.56	−1.24

Source: Derived from the results of table 10.

a. The 1965–73 slowdown is measured relative to the 1948–65 base period; the 1973–78 slowdown, relative to the 1965–73 slowdown.

n.a. Not available.

the 1965–73 slowdown; only about 13 percent of the 1973–78 slowdown in the private business sector is not accounted for by the measured capital and labor effects.

In the private nonfarm business sector the pattern in the first slowdown period is generally similar to that for the private business sector, although capital effects are even more favorable to productivity growth because the capital-labor ratio grows more rapidly in 1965–73 than in 1948–65. The pattern of labor effects is quite similar to that in private business, although the net impact is slightly smaller. And other factors are again the dominant slowdown factor. Indeed, after adjusting for capital and labor effects, the contribution to the slowdown of other factors is somewhat larger than the slowdown in labor productivity itself.

In the second period, capital effects contribute nearly 80 percent of the observed slowdown in labor productivity. As in the private business sector, the dominant impact comes from slower growth in the capital-labor ratio. Capital spending for pollution abatement and changes in the asset mix each have a small effect. Labor effects contribute somewhat, with a downward push on productivity from interindustry shifts more than offsetting small contributions in the other direction from the composition of the labor force and changes in hours worked. As in the private business sector, the measured capital and labor effects account for most of the 1973–78 slowdown in productivity growth in the private nonfarm business sector.

The productivity slowdown pattern in the manufacturing sector is similar to that for private nonfarm business in 1965–73: capital effects contribute to faster productivity growth, and total labor effects reduce it. During this period, the acceleration of the capital-labor ratio increased productivity growth by about 0.2 percentage point a year, but was partially offset by expenditures for pollution abatement capital and a slight asset effect. Labor effects made a small contribution to the slowdown, largely through changes in the composition of the labor force. Other factors not accounted for in the analysis dominate the productivity decline in manufacturing in the first slowdown period.

In the 1973–78 period, some differences emerge between the manufacturing sector and the private nonfarm business sector. The productivity slowdown is somewhat smaller in manufacturing. Capital effects, dominated by slower growth in the capital-labor ratio, are more strongly influenced by expenditures for pollution abatement capital. The effect,

Table 12. Capital and Labor Effects on the Growth of Labor Productivity, Private Nonfarm Nonmanufacturing Sector, Selected Periods, 1948–78

Annual average

Item and period	*Total labor productivity*	*Capital effect*	*Labor effect*	*Effect of other factors*
Rate of growth (percent)				
1948–65	2.57	0.78	0.11	1.68
1965–73	1.78	0.95	−0.10	0.93
1973–78	0.80	0.11	−0.22	0.91
Contribution to slowdown (percentage points)				
1965–73 slowdown	−0.79	0.17	−0.21	−0.75
1973–78 slowdown	−0.98	−0.84	−0.12	−0.02
Total	−1.77	−0.67	−0.33	−0.77

Source: Data are inferred from tables 10 and 11 as described in the text.

however, is still small in manufacturing, where a major impact of environmental regulations would be expected to be felt. Capital effects, however, explain only about half of the 1973–78 slowdown in manufacturing, a much smaller proportion than in private nonfarm business. The labor effects augmented productivity growth. Thus, in the second period, other factors play a larger role in the slowdown of the manufacturing sector than in the other sectors.

The slowdown patterns for the nonfarm nonmanufacturing sector that are implied by the nonfarm and manufacturing results in tables 10 and 11 are summarized in table 12. The capital effects were determined by weighting the capital effects in each sector by the relative size of their capital stock. A similar procedure was used for labor productivity and labor effects based on the nonfarm nonmanufacturing share in the hours of private nonfarm business labor.[43]

In this sector, productivity again slows noticeably in both periods. In the first period, total capital effects work against the slowdown, while

43. Direct computation would have been preferable. However, the difference in patterns between the nonfarm business and manufacturing sectors did not emerge until it was too late to compute these effects directly. Although the total effects for capital, labor, and other factors reported in table 12 would change very little when directly computed, detailed effects of changes in factor composition and interindustry shifts would be revealed.

total labor effects contribute to it and are noticeably larger than those for all nonfarm business. As in the private nonfarm business sector, other factors are the primary source of the decline in productivity growth. Almost all the second slowdown is explained by capital and labor effects that parallel those in total private nonfarm business, so that other factors play a minor role.

For any of the major sectors analyzed here, to view the productivity slowdown as a single phenomenon beginning in the mid-1960s would distort the temporal pattern of contributions to it, and would likely lead to poor policy prescription. From the evidence of the recent period, the unexplained decline in multifactor productivity growth is largely behind us, while the problem of capital formation is current. It also appears that the changing composition of the labor force has contributed somewhat less to the slowdown in either period than some other estimates have suggested and, correspondingly, may offer somewhat less hope for reversal in the future.

Factors Affecting Capital Formation

Because slower capital formation appears to have been a major cause of the slowdown in labor productivity in the 1973–78 period, it is important to understand why. Table 13 attempts to shed light on this question.[44]

The acceleration of the capital-labor ratio in 1965–73 may be explained by price-induced substitution of capital for labor. The price of labor grew about 2 percentage points a year faster than the price of capital services in 1948–65, more than 4 points faster in 1965–73, and 1 point faster in 1973–78. These differences measure the relative price change of labor as compared to capital: the price incentive to substitute capital for labor was thus about twice as strong in 1965–73 as it was in the earliest period, and about four times as great as in 1973–78. A factor holding down the relative price of capital services in 1965–73 was the investment tax credit for equipment that went into effect in the mid-1960s.

44. Data for the private nonfarm business sector are shown because the slowdown in capital formation in agriculture began before 1973–78, and the relative rise of wages in the agriculture sector further obscures the relative price movements that prevailed in private nonfarm business.

Table 13. Rates of Growth of Input Prices, Private Nonfarm Business Sector, Selected Periods, 1948–78

Annual average, in percent

Period	*Price of capital services*	*Labor compensation per hour*	*Price of energy input*[a]
1948–65	2.84	4.60	−0.73
1965–73	2.20	6.58	4.73
1973–78	7.95	8.98	22.29

Source: J. R. Norsworthy and Michael J. Harper, "The Role of Capital Formation in the Recent Productivity Growth Slowdown," Working Paper 87, (Bureau of Labor Statistics, January 1979).

a. The energy price series is for 1954–65, 1965–73, and 1973–77. It is based on the ratio of total cost of purchased fuels in manufacturing to a translog index of electricity, coal, coke, fuel oil, and natural gas quantities from Bureau of the Census, *Census of Manufactures*. The wholesale price index was used to interpolate some price components between Census benchmarks.

The relative price explanation for the acceleration in the capital-labor ratio in the 1965–73 period also explains the deceleration in 1973–78, when the relative price change was so small. The rapid rise in energy prices that took place in late 1973 and early 1974 may be another important factor contributing to the slowdown in this last period. If capital and energy are complements, the rise in energy prices would have retarded capital formation.[45]

The weak productivity growth of recent years has corresponded with a rapid and continued rise in employment from the trough of the 1973–75 recession through early 1979. This phenomenon, which has been widely observed and described as puzzling, is consistent with the much closer movements in the prices of capital and labor and the complementarity between capital and energy. Under these conditions, increases in output would be achieved with relatively greater expansion of labor input and less expansion of capital (and hence energy) than under the price conditions that prevailed since 1948 in general, and in the 1965–73 period in particular. This tentative explanation is consistent with findings by Hudson and Jorgenson for the 1973–76 period.[46]

45. There are, of course, other dimensions to the problem, and therefore to a satisfactory explanation for it. For example, an accelerator model of capital accumulation is examined in Peter K. Clark, "Investment in the 1970s: Theory, Performance, and Prediction," *BPEA, 1:1979*, pp. 73–113. The slowdown in output growth of more than 1 percentage point a year between 1965–73 and 1973–78 would also explain part of the slowdown in capital formation in the latter period.

46. Hudson and Jorgenson, "Energy Prices."

Conclusions

The main conclusions of our investigation of the slowdown in the growth of labor productivity can be summarized briefly.

There are two distinct phases to the slowdown in the growth of labor productivity: 1965–73 and 1973–78. Differences are apparent both in the pattern of productivity growth among industries and in the factors contributing to the decline.

The 1965–73 slowdown is largely unexplained by the factors we have considered. Capital formation was not a cause; changes in the composition of the labor force played a relatively minor role. Although R&D expenditures slowed during this period and may well have contributed to the productivity slowdown, we devised no satisfactory means to take this factor into account. Intersectoral shifts of capital and labor did not contribute.

The 1973–78 slowdown is dominated by the effects of reduced capital formation. Some effect is also attributable to interindustry shifts in labor and capital. The sharp rise in energy prices may show up in a framework such as ours through its impact on capital formation and may help explain the relative weakness in capital formation in recent years.