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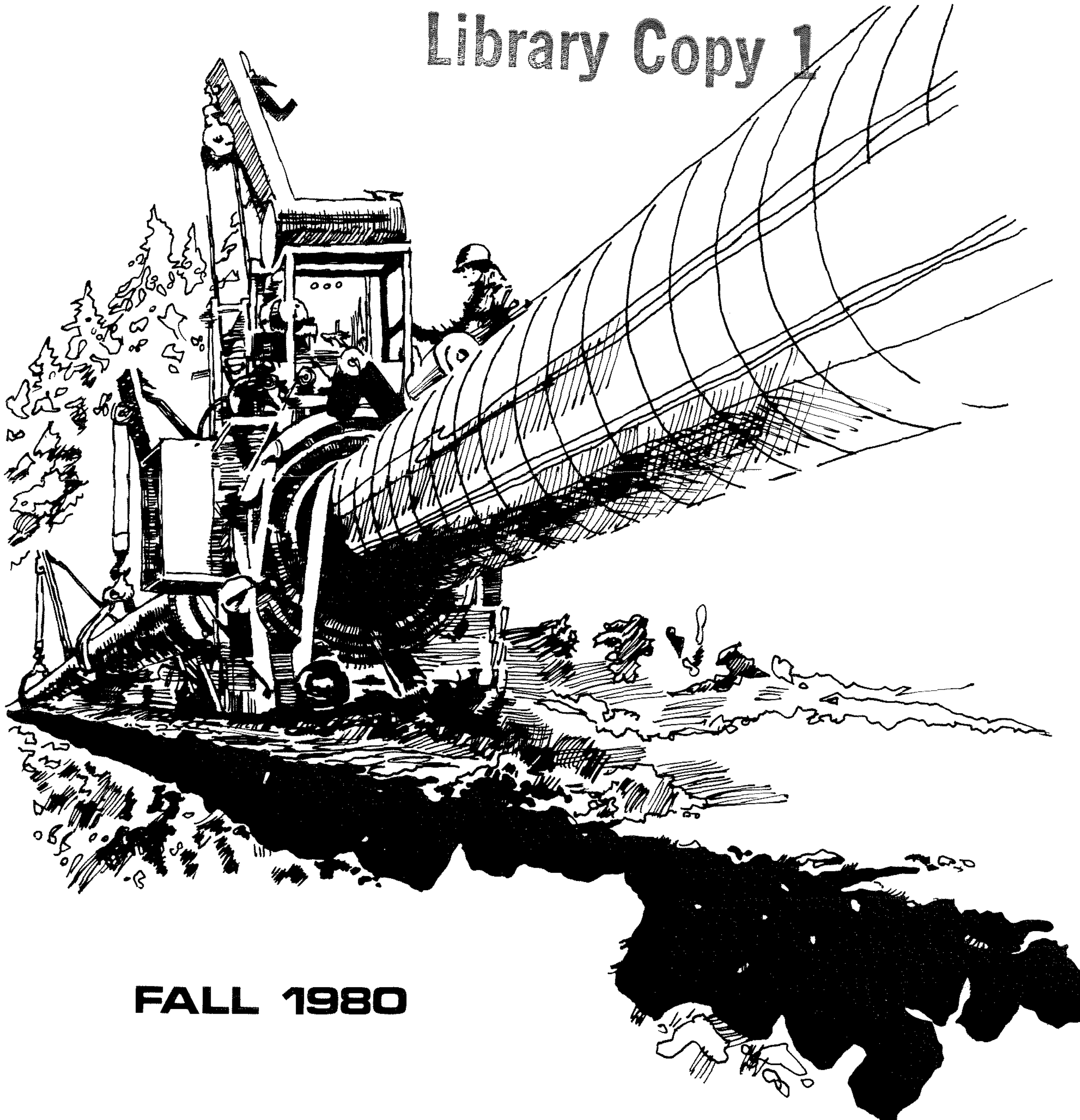

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RESOURCE ALLOCATION-INDUSTRY AND HOUSING

An Intersectoral Analysis of the Secular Productivity Slowdown

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Economists and policymakers have become increasingly concerned in recent years about the slowdown in U.S. productivity. Productivity has always exhibited a strong cyclical movement in line with changes in business conditions, but analysts today are less concerned with these quarter-to-quarter gyrations than with the *secular* (noncyclical) trend. For the private economy, the annual rate of increase in labor productivity (output per hour) averaged 3.2 percent for the 1948-65 period, but slowed to 2.3 percent in the 1965-73 period and then to only 1.2 percent in the 1973-78 period. The rate of increase in total factor productivity (output per weighted unit of capital and labor input) exhibited a similar slowdown—from an annual rate of 1.3 percent in the first period to 0.7 percent and 0.4 percent in the last two periods, respectively. Since 1978, the figures have been much worse, largely reflecting adverse cyclical factors in addition to this secular weakness.

Concern over the secular trend of productivity stems from its role as the key determinant of the nation's material standard of living. For example, at a 3.2-percent annual growth rate (the 1948-65 average), real income per hour would double in only 22 years, whereas at a 1.2-percent rate (the 1973-78 average), 58 years would be required. Moreover, the rate of labor-productivity increase is the major determinant of the difference between wage and price inflation. With a 3.2-percent rate of increase in labor productivity, annual wage inflation of 10.0 percent would translate roughly into price inflation of 6.8 percent. With a 1.2-percent productivity increase, however, the same rate of wage inflation would translate into price inflation of 8.8 percent. Labor-productivity growth therefore is clearly central to the political issues that arise when the gap narrows between wage and price inflation.

What factors underlie the secular deterioration in productivity growth? A decade ago, many studies attributed the deceleration in productivity growth to shifts in employment and output among sectors with different levels of labor efficiency.[1] In particular, the early-postwar shift of workers out of the low-productivity farm sector to higher-productivity sectors initially boosted aggregate U.S. productivity growth, but this positive effect waned as the farm share of total employment declined from 18 percent in 1948 to 5 percent in the 1970s.

The productivity slowdown would not be a major public-policy issue if this were all that was involved, because basic structural changes in the economy cannot be manipulated easily by government policy.[2] Even if they could be, generally it would not be in the public interest to do so, for such structural changes tend to reflect the public's basic preferences to spend their incomes and seek employment in ways that increase society's general welfare.

Some studies suggest that sectoral shifts are still of overriding importance,[3] but the evidence presented in this paper points strongly to the conclusion that such shifts have accounted for only a small portion of the slowdown in aggregate labor-productivity growth. This conclusion suggests the existence of other causal factors, such as a general slowdown in capital deepening—resulting perhaps from the

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combined effects of economic uncertainties, reduced output growth, inflation, tax laws, and regulations. In this case, then, an appropriate policy response would call for a re-examination of governmental policies and other factors that affect capital formation.

Many recent studies have approached the productivity problem in an aggregate context. This paper, in contrast, presents a disaggregated analysis of productivity in the private domestic U.S. economy, concentrating on the questions of intersectoral shifts and capital deepening.[4] We first present a twelve-sector disaggregation of labor productivity, and then a seven-sector analysis of capital deepening and total factor productivity.

Our technique advances the state of the art by providing close approximations for the relationship between aggregate and sectoral labor-productivity changes. We decompose aggregate labor-productivity increase into "rate" and "level" effects: the rate effect refers to the portion attributable to productivity growth within sectors, and the level effect refers to the portion attributable to shifts in employment and output across sectors. We then estimate the important role of capital deepening (i.e., increases in the capital-labor ratio) within seven major sectors, and examine in detail the bias inherent in using aggregate as opposed to sectoral data. Although we link a deceleration in capital deepening to the productivity slowdown, we do not investigate the underlying causes of retarded capital deepening.[5]

The results show that intersectoral labor and output shifts accounted for only a small amount of the slowdown in aggregate labor productivity. Between the 1948-65 and 1973-78 periods, intersectoral shifts contributed only 0.3 percentage points of the 2.0-percentage-point deceleration in aggregate labor-productivity growth. Moreover, sector-specific declines became evident in nine of twelve industrial sectors, indicating the widespread nature of the productivity slowdown.

Slower growth of the capital-labor ratios within sectors was found to be an important factor in the labor-productivity slowdown, accounting for almost half of the deceleration. On an industry level, this factor was particularly important in agriculture, mining, and the large "commercial and other" sector. The results of this study underscore the importance of disaggregation, since the aggregate approach tends to attribute too little of the labor-productivity slowdown to slower capital deepening.

Finally, we show that the productivity slowdown was not limited to labor productivity, but was evident also in total factor productivity (both labor and capital). The secular rate of increase in that more inclusive category declined from 1.3 percent per annum over the 1948-65 period to 0.7 percent and 0.4 percent over the 1965-73 and 1973-78 periods, respectively. The deceleration was broad-based, with acceleration evident in only two sectors— communication and commercial and other.

In Section I, we analyze the rate and level effects of labor productivity in a disaggregated framework. In Section II, we analyze total factor productivity, the role of the capital-labor ratio, and measures of aggregation bias. Finally, we present the conclusions and policy implications of the paper.

I. Sectoral Decomposition of Labor Productivity Change

Published labor productivity data are calculated with the use of direct aggregation: outputs are added across sectors, labor inputs are also summed, and total output is then divided by total labor input to arrive at a calculated aggregate level of labor productivity.[6] In a multisector model that employs directly aggregated data, aggregate labor productivity is affected over time by productivity change within each sector and by the shift of output and employment among sectors with different levels of productivity. The following formulation, which is derived in the note on page 24, decomposes aggregate productivity change into rate, level and interaction effects.[7]

$$\frac{\Delta P}{P} = \Sigma q_i \frac{\Delta P_i}{P_i} + \Sigma q_i \frac{\Delta l_i}{l_i} + \Sigma q_i \frac{\Delta P_i}{P_i} \frac{\Delta l_i}{l_i} \quad (1)$$

where

P = aggregate output per hour (labor productivity)

P_i = output per hour in the i-th sector

q_i = real output share of the i-th sector

l_i = share of hours employed in the i-th sector

$\frac{\Delta P}{P}$ = percentage change in productivity over the discrete time period.

The rate effect is the part of aggregate productivity growth that comes about as a result of changes in productivity *within* sectors. In the context of labor productivity, it is the amount of change that would have occurred over time had each sector's share of total employment remained constant. In contrast, the level effect is the part of aggregate productivity change that results solely from shifts of labor (and output) *among* sectors—i.e., the amount that would have occurred had productivity levels remained constant within sectors, while labor (and output) shifted among sectors of dif-

Table 1
Labor and Real Product Shares by Industry for Selected Years, 1948–78 (Percent)

	Labor Shares[1]				Real Product Shares[2]			
	1948	1965	1973	1978	1948	1965	1973	1978
Private Domestic Nonresidential Economy	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Agriculture[3]	**18.3**	**8.5**	**5.8**	**5.4**	7.0	4.4	3.6	3.4
Mining	1.7	1.1	0.9	1.2	3.0	2.2	1.9	1.8
Construction	5.6	6.3	6.8	6.9	6.6	7.7	5.9	5.3
Nondurable Goods Mfg.	12.6	12.4	11.6	10.8	12.4	12.2	12.4	12.2
Durable Goods Mfg.	14.8	17.3	17.0	16.4	18.0	19.4	18.9	18.1
Transportation	5.7	4.4	4.2	4.1	6.8	5.1	5.1	4.8
Communication	1.2	1.3	1.6	1.5	1.4	2.3	3.2	4.2
Utilities	0.9	1.0	1.0	1.0	1.5	2.6	3.0	2.9
Wholesale Trade	**4.8**	**5.7**	**6.2**	**6.8**	6.6	7.6	8.9	8.9
Retail Trade	**16.9**	**18.0**	**18.2**	**18.2**	12.9	12.4	12.4	12.3
Finance and Insurance	**3.3**	**4.9**	**5.7**	**6.3**	9.7	10.5	10.4	11.1
Services	**13.9**	**18.8**	**20.8**	**21.2**	14.2	13.6	14.3	15.0

[1]Labor data are based on actual hours worked by persons engaged in production, which encompasses full- and part-time workers as well as active proprietors. The data come from the National Income and Product Accounts (NIPA), Table 6.11—except for agriculture (including forestry and fisheries), where data are obtained from household surveys undertaken by the Bureau of the Census for the Bureau of Labor Statistics. (Unpaid household workers engaged in production are included in the agricultural data, but excluded from data of other sectors.)
[2]Output data are actual 1972-dollar gross product (NIPA, Table 6.2). Output in the finance and insurance industry excludes imputed output from owner-occupied farm and nonfarm dwellings (NIPA, Table 8.3, lines 63 and 75).
[3]Includes forestry and fisheries.

Sources: U.S. Department of Commerce and Bureau of Labor Statistics.

fering productivity levels. Finally, over a discrete time period, a (usually very small) interaction effect results from the compounding of simultaneous changes of productivity levels within sectors and labor shares among sectors. (In continuous time, the interaction term drops out.) For each effect, percentage changes within sectors are weighted by real output shares to arrive at sectoral contributions to the aggregate. An individual sector's contributions to the aggregate rate, level, and interaction effects are simply its contributions within the respective summations.[8]

The rate effect has more than empirical relevance. It represents an aggregate productivity index free of "aggregation bias" caused by shifts among sectors of differing productivity levels. For some time, economists have used the Divisia productivity index (named after the French mathematician) largely because of its freedom from such bias. In Appendix A, the rate effect under direct aggregation and the Divisia index are shown to be close approximations.

Empirical Results

Table 1 shows labor and real product shares within the private domestic nonresidential economy.[9] The most notable labor shifts in the postwar period have been the net decline in the agricultural sector and the net increase in the service-related sectors—comprising wholesale and retail trade, finance and insurance, and services (highlighted in the table). Changes in labor shares in other sectors have been comparatively modest. Meanwhile, shifts in real-output shares generally have been smaller but in the same direction as shifts in labor shares.

Table 2 shows the secular annual rates of increase in labor productivity for the total and for twelve industrial sectors over subperiods within the 1948-78 span.[10] The slowdown in both the 1965-73 and 1973-78 periods was widespread throughout the economy. Only three sectors—communication, finance and insurance, and services—experienced an acceleration in the rate of productivity advance in the most recent period, and only in communication and services was the most recent rate above that in the 1948-65 period.[11] All other sectors showed a marked deceleration—and mining, construction and wholesale trade experienced an actual decline in labor productivity. The decline in mining has often been attributed to new safety regulations and practices (the value of which is not included in measured output), and to the intensive use of marginal facilities in response to higher energy prices. The declines in construction and wholesale trade remain a puzzle to productivity analysts.[12]

There appears to be no direct correlation between the magnitude of measurement error and magnitude of productivity slowdown. For example, productivity change may be subject to considerable measurement error in con-

Table 2
Secular Productivity Change Between Peak Years by Industry[1] (Annual Rates of Increase)

	1948–65	1965–73	1973–78
Private Domestic Nonresidential Economy	3.2	2.3	1.2
Agriculture	5.1	4.6	1.6
Mining	4.3	1.9	−4.8
Construction	3.4	−2.1	−1.1
Nondurable Goods Manufacturing	3.3	3.3	2.3
Durable Goods Manufacturing	2.8	2.2	1.1
Transportation	3.1	2.9	0.8
Communication	5.4	4.6	7.1
Utilities	6.3	3.5	0.7
Wholesale Trade	3.0	3.4	−0.6
Retail Trade	2.7	2.1	1.1
Finance and Insurance	1.3	0.1	0.8
Services	1.2	1.7	1.8

[1]Compound annual growth rates calculated between the first and last year of each subperiod.

Sources: See Table 1.

struction, trade, finance and insurance, and services. However, the first two sectors have shown large decelerations in productivity growth, whereas the other two have not (footnotes 11 and 12).

Table 3 shows the growth rate of aggregate productivity decomposed into rate, level, and interaction effects. From this evidence, the productivity slowdown can be attributed largely to a slowdown in the rates of productivity growth *within* sectors rather than to shifts in employment *across* sectors. The rate of aggregate productivity growth declined 0.98 percentage points between the 1948-65 and 1965-73 periods (from 3.24 percent to 2.26 percent). Of this decline, 0.77 percentage point was accounted for by the change in the rate effect, and only 0.20 percentage point by the change in the level effect.

Between the 1965-73 and 1973-78 periods the story was similar, with the change in the rate effect accounting for 0.91 percentage point of the 1.02-percentage-point decline in the rate of aggregate productivity growth. In short, over the three subperiods, the rate effect—i.e., slowdown in productivity advance within sectors—accounted for 1.68 percentage points of the 2.00-percentage-point decline in aggregate productivity advance.[13]

Table 3
Decomposition of Labor Productivity Change Into Rate, Level, and Interaction Effects
(Annual Rates of Increase)

	1948–65	1965–73	1973–78
Private Domestic Nonresidential Economy	3.24	2.26	1.24
Percentage Point Change	—	−0.98	−1.02
Rate Effect	2.82	2.05	1.14
Percentage Point Change	—	−0.77	−0.91
Level Effect	0.43	0.23	0.15
Percentage Point Change	—	−0.20	−0.08
Interaction	−0.01	−0.02	−0.05

Sources: See Table 1. Calculated using equation (1), iterated annually.

It is important to consider both the respective sizes of the two effects within periods and their changes from period to period. For example, the level effect—the shifting of labor among sectors of differing productivity levels—added 0.43 percentage point to the aggregate-productivity growth rate during the 1948-65 period. But this positive boost receded to 0.23 and 0.15 percentage points per year in the two later periods, respectively. Despite its contribution to the productivity slowdown, the level effect nevertheless was still positive.

Table 4 shows the contributions of each sector to the total rate effect.[14] The 1948-65 period was dominated by the large positive contribu-

Table 4
Decomposition of Rate Effect by Industry (Percentage Contributions to Annual Rates of Change)

	1948–65	1965–73	1973–78
Private Domestic Nonresidential Economy	2.82	2.05	1.14
Agriculture	**.31**	**.21**	**.06**
Mining	**.11**	**0.4**	**−.09**
Construction	**.25**	**−.14**	**−.06**
Nondurable Goods Manufacturing	**.40**	**.41**	**.28**
Durable Goods Manufacturing	**.50**	**.40**	**.18**
Transportation	.17	.14	.04
Communication	.10	.13	.26
Utilities	.13	.10	.02
Wholesale Trade	**.22**	**.27**	**−.04**
Retail Trade	**.34**	**.26**	**.13**
Finance and Insurance	.14	.01	.09
Services	**.16**	**.23**	**.28**

Sources: Table 3 and the individual rate effects in equation (1), iterated annually.

tions of agriculture, construction, manufacturing, and trade. The sizable contribution of the agricultural sector came mostly from its rapid 5.1-percent annual productivity increase (Table 2), as its real output share in 1948 was only 7.0 percent (Table 1). But agriculture's contribution to the rate effect was almost nil in the most recent period, with a decline in its productivity growth rate to 1.6 percent and a decline in its real output share to only half of its 1948 level. In mining and construction, the rate effects declined sharply, turning negative with declines in the levels of labor productivity. In the two manufacturing and two trade sectors, the rate effects were large in the early period, but declined significantly by the most recent period (turning negative for wholesale trade). The diminution in these rate effects can be attributed almost entirely to slower rates of labor productivity advance within sectors (Table 2), because of the rough constancy of real output shares (Table 1).

The rate contribution accelerated in the 1973-78 span only in communication, services, and finance and insurance—and in the latter sector, it still fell below its 1948-65 annual contribution. The rate of labor-productivity increase accelerated sharply in communication (largely the telephone industry) while the sector's share of real product also rose.

To summarize, the slowdown in aggregate labor-productivity growth was almost wholly attributable to productivity slowdowns within the twelve industrial sectors. The level effect, in contrast, accounted for only 0.3 percentage point of the 2.0-percentage-point deceleration in aggregate labor-productivity growth between the 1948-65 and 1973-78 periods. The slowdown was spread widely across nine of the twelve sectors, as demonstrated first by the slowdown within sectors (Table 2), and also by the individual contributions to the rate effect (Table 4), which take into account both the intrasectoral slowdowns and their relative weights in the aggregate index.

II. Capital Deepening and Total Factor Productivity

In this section, we measure total factor productivity—the rate of change of output per unit of combined input of labor and capital. Through the specification and estimation of aggregate and disaggregated production functions, we estimate the slowdown in total factor productivity for the aggregate economy and for seven major sectors, and compare the resultant trends to those of labor productivity. We also estimate the role played by capital deepening (rise in the capital-labor ratio) in labor productivity growth, through a comparison of aggregate and disaggregated methods of analysis.

Capital deepening affects labor productivity differently from total factor productivity. It can affect labor-productivity growth in at least two ways. First, given a positive marginal product of each factor of production, an increase in the amount of capital used by the same number of workers will result in a larger amount of output produced per worker. Second, given the embodiment of technological improvements in new plant and equipment, capital growth should provide a further boost to labor productivity. If both effects are important, capital formation will have a magnified impact on labor-productivity growth over time.

Table 5 shows a slowdown in growth in the aggregate and sectoral capital-labor ratios[15] over time, with the exceptions of manufacturing and utilities. More importantly, slower growth in the capital-labor ratios was not simply the result of slower growth in the capital stock. Aggregate capital and labor growth both accelerated in the second period, and labor growth remained relatively high even in the third period. On an aggregate basis, therefore, the slower growth of the capital-labor ratio largely reflected faster labor growth, particularly in the 1965-73 period when capital growth also accelerated. The results for the 1973-78 period were mixed, however, as capital growth decelerated from its 1965-73 rate in all but one sector.

These patterns suggest no evidence of declining investment (except in mining) until the most recent period. However, the rate of new investment failed to keep pace with accelerated labor growth in the 1965-73 period, and has since dropped off precipitously. Norsworthy, Harper, and Kunze suggest that the behavior of capital-labor growth is consistent with an observed acceleration in the price of labor relative to capital between the 1948-65 and 1965-73 periods and a subsequent deceleration between the 1965-73 and 1973-78 periods.[16] Others have attributed this development to the rapid growth of inexperienced workers over time. As the growth rate of inexperienced workers tapers off in the 1980s, capital-labor growth may accelerate once again, although the recent decline in capital formation suggests that such optimism may be unwarranted.

Production Functions

To measure growth of total factor productivity, we must specify a production function linking labor, capital, and output. The output data used here (as in most aggregate productivity studies) are net of intermediate inputs to production, so the production function should properly include only the primary inputs—labor, land (including natural resources), and capital.[17] Actually, we include only labor and capital, because of the weakness of data for land by industry. For simplicity, we use a standard Cobb-Douglas production function with constant returns to scale. However, this type of function requires strict separability[18] and constrains the elasticity of substitution between labor and capital to be constant and equal to one. The function also includes a time trend as a proxy for whatever technical change that is not included in new capital investment:

$$Q = Ae^{rt}K^{\alpha}L^{\beta} \qquad (2)$$

where Q = output,
A = constant term,
r = rate change of disembodied technology or total factor productivity,[19]
t = time trend,

Table 5
Rates of Growth of Capital and Labor by Sector, 1948–78
(Percent)

	1948–65			1965–73			1973–78		
	K/L	K	L	K/L	K	L	K/L	K	L
Private Domestic Nonresidential Economy	2.8	3.3	0.4	2.5	4.0	1.4	1.8	3.1	1.2
Agriculture[1]	7.3	2.8	−4.2	7.3	3.0	−4.0	3.1	2.3	−0.8
Mining	5.4	2.9	−2.3	1.3	1.4	0.0	−4.3	2.2	6.8
Manufacturing	1.9	2.8	0.9	2.3	3.3	1.0	2.4	2.6	0.2
Transportation	1.3	0.2	−1.0	0.4	1.2	0.7	−0.5	0.3	0.8
Communication	6.4	7.6	1.1	5.1	8.8	3.5	5.0	6.0	1.0
Utilities	5.1	6.0	0.9	4.3	6.4	2.0	5.0	5.9	0.9
Commercial and Other[2]	3.2	4.8	1.6	1.9	4.2	2.3	0.4	2.2	1.8

[1]Data for agriculture differ slightly from those in Section I, because forestry and fisheries are excluded from agriculture in this table (and in Section II) to conform to the capital-stock data.
[2]Construction, wholesale and retail trade, finance and insurance, and services.

Sources: Gross capital-stock data are from U.S. Department of Commerce for agriculture (excluding forestry and fisheries) and manufacturing, and from Data Resources, Inc., for other sectors. (These data are calculated by DRI using Department of Commerce service-life assumptions.) See Table 1 for sources of labor data.

K = capital,
L = labor,
α = elasticity of output with respect to capital,
β = elasticity of output with respect to labor.

The constant-returns constraint requires $\alpha + \beta = 1$. Using this constraint and dividing both sides by L, we obtain an expression that relates labor productivity (Q/L) to the capital-labor ratio:

$$P = Ak^{\alpha}e^{rt} \quad k = K/L, P = Q/L \tag{3}$$

In this formulation, α represents the elasticity of labor productivity with respect to the capital-labor ratio (i.e., the percentage change in labor productivity with respect to a one-percent change in the capital-labor ratio). If the rate of growth of total factor productivity is zero (i.e., there is no disembodied technical change and $r = 0$), the rate of growth of labor productivity is simply α times the rate of growth of k, the rate of increase in the capital intensity of production. This can be seen by totally differentiating (3) logarithmically with respect to time.

$$\frac{dP}{P} = rdt + \alpha(dk/k) \tag{4}$$

which can be approximated by

$$\%\Delta P = r + \alpha(\%\Delta k) \tag{5}$$

where r represents the percentage change in total factor productivity (disembodied technical change).

To assess the role of capital formation in the slowdown, it is necessary to determine α. Although this can be done in more than one way,[20] our approach estimates the aggregate and sectoral production functions econometrically, using historical data. The contribution of the capital-labor ratio to labor-productivity growth, with the aggregate method, then is $\alpha\left(\frac{dk}{k}\right)$, where α is estimated from equation (5). Similarly, equation (5) also can be estimated for each of the seven industries, and the contribution of the sectoral capital-labor ratio to sectoral productivity growth is calculated as $\alpha_i\left(\frac{dk_i}{k_i}\right)$.

Before equation (5) can be estimated, terms must be added to account for the effect of the business cycle on labor productivity, and to allow for secular shifts in the growth rate of total factor productivity. To remove business-cycle-related movements, annual changes in the manufacturing capacity-utilization rate were used as a surrogate for business-cycle conditions affecting the aggregate and sectors.[21]

We allowed the value of r to vary over the subperiods of the 1948-78 period, to reflect the probability of a growth slowdown for total factor productivity as well as for labor productivity. Thus we added dummy variables to account for shifts in r among the 1948-65, 1965-73, and 1973-78 periods.[22]

Adding the cyclical and dummy variables to equation (5) produces the following equation for estimating the aggregate and the seven sectors:

$$\%\Delta P = r + \delta_1 d_1 + \delta_2 d_2 + \alpha\%\Delta k + \gamma\%\Delta UCAP + \mu \tag{6}$$

where time subscripts have been suppressed for simplicity. The estimated coefficients have the following interpretations:

r = average annual rate of increase in total factor productivity (disembodied technical change), 1948-65;
δ_1 = shift in the average rate of change of total factor productivity between the 1948-65 and 1965-73 periods;
δ_2 = shift in the average rate of change of total factor productivity between the 1948-65 and 1973-78 periods;
α = elasticity of labor productivity with respect to the capital-labor ratio (and of output with respect to capital);

γ = elasticity of labor productivity with respect to the capacity-utilization rate in manufacturing.

Table 6 shows the estimation results for equation (6) with ordinary least squares, with Cochrane-Orcutt data transformations. Given that the equations are expressed in percentage-change form, the R-squared values are remarkably high, although the standard errors of the regressions reveal considerable variation in the estimated rates of labor-productivity change within sectors.[23]

The coefficients r, $r+\delta_1$, and $r+\delta_2$ give the estimated annual rates of increase of total factor productivity over the three subperiods. As shown in Table 7, they indicate a similar movement in total factor productivity as in labor productivity, in the aggregate and in most sectors. However, there were a few exceptions, especially the "commercial and other" sector, which showed a deceleration in labor-productivity growth but an acceleration in total factor productivity. Apart from data errors, we can interpret the divergence in trends to mean that improvements in efficiency helped improve the productivity of costly capital inputs in this sector. This seems logical, because inexperienced and inexpensive labor inputs tended to increase the fastest in areas such as retail trade and services.

Because aggregate labor-productivity growth is a function of within-sector productivity growth, as well as of input and output shifts among sectors, we can derive an alternative estimate of the effect of capital-intensity growth on aggregate labor-productivity change by combining estimates for individual indus-

Table 6
Regressions of Production Functions for the Private Domestic Nonresidential Economy and Major Sectors, 1948–78

	r	δ_1	δ_2	α	γ	$\bar{R}^2$	S.E.E.	D.W.	ρ
Private Domestic Nonresidential Economy[1]	1.3*	−0.6*	−0.9*	.67**	.37*	.61	1.1	2.05	−.25
	(2.52)	(−1.55)	(−1.77)	(4.21)	(5.48)				(−1.39)
Agriculture[2]	1.2	−0.6	−1.2	.64**	−.32*	.71	2.6	1.92	−.53*
	(1.25)	(−.81)	(−1.14)	(5.60)	(−3.87)				(−3.36)
Mining	2.8*	−1.2	−6.0*	.34**	.16	.68	2.4	1.44	.10
	(2.91)	(−.94)	(−3.16)	(2.45)	(1.68)				(.56)
Manufacturing	1.6*	−0.1	−0.6	.53**	.61*	.23	2.1	1.98	−.25
	(2.19)	(−.12)	(−.64)	(1.99)	(2.79)				(−1.38)
Transportation	2.8*	0.0	−1.7	.19	.36*	.41	2.2	1.87	−.24
	(5.35)	(.04)	(−1.64)	(.85)	(3.00)				(−1.34)
Communication	1.6*	0.0	2.6*	.59**	.14*	.62	1.5	2.25	−.42*
	(2.75)	(−.05)	(4.46)	(7.43)	(2.66)				(−2.47)
Utilities	2.6*	−2.4*	−4.8*	.68**	.09	.44	2.6	1.92	−.43*
	(1.82)	(−2.78)	(−4.94)	(2.54)	(1.12)				(−2.54)
Commercial and Other	0.4	0.1	0.5	.55**	.21*	.36	1.4	2.04	−.03
	(.53)	(.08)	(.59)	(2.84)	(3.81)				(−.15)

Entries in parentheses are t-statistics. * Indicates that the coefficient is significantly different from zero with 90-percent confidence, with the use of a two-tailed test. ** Indicates the same with the use of a one-tailed test.
[1]Capital data were calculated as the sums of component sectors. With the use of the BEA aggregate for gross capital stock in the private domestic nonresidential economy, the estimates were comparable: $r=0.9$; $\delta_1=-0.7$, $\delta_2=-0.7$, $\alpha=.73$, $\gamma=.37$.
[2]Excludes forestry and fisheries.

Source: see text.

tries. To derive the proper weights, we begin by dividing aggregate productivity change into rate and level effects, as shown by the continuous version of equation (1),

$$\frac{dP}{P} = \underbrace{\Sigma q_i \frac{dP_i}{P_i}}_{\text{(Rate)}} + \underbrace{\Sigma q_i \frac{dl_i}{l_i}}_{\text{(Level)}} \qquad (7)$$

Substituting equation (4) for the individual sectors, we obtain

$$\frac{dP}{P} = \Sigma q_i \left[r_i dt + \alpha_i \frac{dk_i}{k_i} + \frac{dl_i}{l_i} \right] \qquad (8)$$

where $\alpha_i \frac{dk_i}{k_i}$ represents the i-th sector's contribution of growth in capital intensity to its own sector's productivity growth. Therefore, the weights for calculating the sectoral contributions of capital-intensity growth $\left(\alpha_i \frac{dk_i}{k_i}\right)$ to aggregate labor-productivity growth are the output shares, q_i.

We aggregated the industry contributions of capital-intensity growth, using output shares to obtain an estimate of the importance of growth in the disaggregated capital-labor ratios to the slowdown in aggregate productivity growth. Table 8 compares this result with that obtained

Table 8
Contribution of Growth in the Capital-Labor Ratio to Labor Productivity Growth, 1948–78
(Average Annual Rates of Increase)

	1948–65	1965–73	1973–78
Aggregate Productivity	3.24	2.26	1.24
Change from Prior Period	—	−0.98	−1.02
Contribution of K/L			
Aggregate Method[1]	1.88	1.66	1.23
Change from Prior Period	—	−0.22	−0.43
Disaggregated Method[2]	1.70	1.34	0.76
Change from Prior Period	—	−0.36	−0.58

[1] $\alpha dk/k$.
[2] $\Sigma q_i \alpha_i dk_i/k_i$, where the q_i's are the average shares within the subperiods.

Sources: Tables 1, 3, 5, 6, and text.

Table 7
Labor Productivity and Total Factor Productivity, 1948–78
(Annual Growth Rates, in Percent)

	Labor Productivity			Total Factor Productivity		
	1948–65	1965–73	1973–78	1948–65	1965–73	1973–78
Private Domestic Nonresidential Economy	3.2	2.3	1.2	1.3	0.7*	0.4*
Agriculture[1]	5.3	5.1	1.9	1.1	0.5	−0.1
Mining	4.3	1.9	−4.8	2.8	1.6	−3.2*
Manufacturing	3.0	2.6	1.6	1.6	1.5	1.0
Transportation	3.1	2.9	0.8	2.9	2.9	1.2
Communication	5.4	4.6	7.1	1.6	1.6	4.2*
Utilities	6.3	3.5	0.7	2.6	0.2*	−2.2*
Commercial and Other	2.3	1.4	0.9	0.4	0.5	0.9

*Indicates a statistically significant shift in total factor productivity at the 90-percent confidence level, as compared with the rate in the 1948–65 period (see Table 6).
[1]Excludes forestry and fisheries.

Sources: Tables 5 and 6.

from the aggregate estimated equation. Both methods indicate a large role for capital deepening in the growth of labor productivity. However, the aggregate method attributes greater importance to the capital-labor ratio in explaining labor-productivity growth (especially in 1973-78), and less importance in explaining its *slowdown*. Specifically, the aggregate method attributes 0.65 percentage point (one third) of the 2.00-percentage-point slowdown in labor-productivity growth to slower growth of the capital-labor ratio, while the disaggregated method attributes 0.94 percentage point (almost half) to slower growth of the capital-labor ratio.

An explanation of this discrepancy involves an analysis of the estimated α's from equation (6). If the Cobb-Douglas specification of the production function is appropriate, the estimated aggregate α should be roughly .2 to .4, depending on whether one compares it to the profit share or to the nonlabor share of gross private domestic product.[24] However, as Table 6 shows, the estimated α from the aggregate equation is .67. Clark (1978) obtained a similar result of .70 for his aggregate equation using gross capital stock (.48 using net capital stock).[25]

Clark (1978 and 1979) attributed the discrepancy between his estimate of α and capital's income share to the embodiment of technical progress in new capital goods. (Under this condition, new capital investment would produce output greater than that predicted by the percentage change in capital times its income share.) The estimated α from a simple production function such as (5) might well be greater than capital's share if technical progress is introduced largely through its embodiment in new capital goods. However, it would affect the α's of both the aggregate and sectoral equations, and thus would not explain why the aggregate α is above the sectoral estimates.

Aggregation Bias

Comparison of the aggregate α with those of the individual sectors (Table 9) indicates that aggregation bias might be partly responsible for the high value of the aggregate α. All but one of the α_i's from the individual equations are lower than the aggregate, ranging from .19 to .68, with an unweighted average of .50.

Another way to compare the industry α_i's with the estimated α from the aggregate equation is to calculate a weighted average, with the weights based on the following identity:[26]

$$\alpha = \Sigma \alpha_i q_i \left(\frac{dK_i/K_i}{dK/K} \right) \tag{9}$$

The aggregate α in any time period depends on the percentage increases in the capital stock in each sector relative to the total, as well as on the α_i's and q_i's. Although the aggregate α represents the percentage change in output that occurs as a result of a one-percent increase in aggregate capital stock, the size of this output increase will depend in part on the sources of growth in capital stock.[27]

Table 9
Output-Capital Elasticities vs. Nonlabor Income Shares, 1948–78

Industry	α	Standard Error	Nonlabor Income Share
Private Domestic Nonresidential Economy	.67	.16	.43
Agriculture	.64*	.11	.85**
Mining	.34*	.14	.63
Manufacturing	.53	.27	.31
Transportation	.19	.22	.31
Communication	.59	.08	.50
Utilities	.68	.27	.65
Commercial and Other	.55	.19	.45

*Significantly different from the nonlabor income share at the 90-percent confidence level, with the use of a two-tailed test.
**Because of the high proportion of self-employment in farming, this share includes a significant amount of income that should probably be classified as return to labor.

Sources: Table 6, and National Income and Product Accounts, Table 6.1.

Equation (9) provided values of α of .65, .59, and .45 for 1948-65, 1965-73 and 1973-78, respectively. The deceleration primarily reflected a slowing trend in the relative increases in the capital stock of the large "commercial and other" sector over the three periods. These calculations for the aggregate α were all lower than the value of .67 that was estimated using the aggregate equation. Therefore, the aggregate α is biased in its level, since one would expect its estimated value to lie within the bounds of the three calculated values. Also, it is biased in its insensitivity to compositional shifts in output and capital over time, since the sectoral α_i's imply an aggregate α that declines in each subperiod.

As noted earlier, the contribution of capital-intensity growth to productivity growth with the aggregate method is $\alpha(dk/k)$. In addition to the biases in aggregate α, there is also a (potentially offsetting) bias in dk/k. This bias occurs because the aggregate method does not distinguish between two different effects—changes in the aggregate capital-labor ratio, k, that are due to growth of capital intensity within sectors, and changes that are due to shifts in employment shares among sectors with different levels of capital intensity. These compositional shifts are important because of the persistent tendency for sectors with relatively low capital-labor ratios (except agriculture) to expand their shares of employment over time. Therefore, the rate of growth of the aggregate capital-labor ratio understates the combined within-sector rates of growth and the combined effects of their decelerations over the three subperiods.

The empirical importance of this effect can be seen from Table 10, which decomposes the aggregate growth of the capital-labor ratio into rate and level effects using equation (B-2) in Appendix B. The rate effect accounts for the within-sector growth of capital intensity, while the level effect measures the net contribution of shifts among sectors with different capital-labor ratios. The level effect is negative in all three periods, and declines in absolute value over time. Hence the growth rate of the aggregate capital-labor ratio (the total effect in Table 10) understates the amount of growth of within-sector capital intensity (the rate effect) during the three time periods, and also understates the extent of its decline.

The biases in aggregate α and in dk/k are in part offsetting, but because of their combined effect, the aggregate method underestimates the importance of capital-intensity growth in the *slowdown* of aggregate labor-productivity growth. With the disaggregated method, slower capital-intensity growth accounts for 0.94 percentage point (almost one-half) of the 2.00-percentage-point decline in labor-productivity growth between the 1948-65 and 1973-78 periods, as opposed to 0.65 percentage point (one-third) of the decline with the aggregate method. A detailed analysis of the aggregation bias from a theoretical point of view is presented in Appendix B.

Table 10
Breakdown of Aggregate Capital-Labor Growth Into Rate and Level Effects

	1948–65	1965–73	1973–78
Total	2.80	2.47	1.83
Change from Prior Period	—	−0.33	−0.64
Rate Effect	3.26	2.86	2.17
Change from Prior Period	—	−0.40	−0.69
Level plus Interaction Effect	−0.46	−0.39	−0.34

Source: Equation B-2 in Appendix B, using subperiod averages for share variables.

III. Summary and Conclusions

The growth rate of aggregate labor productivity slowed from 3.2 percent per year in the 1948-65 period, to 2.3 percent and 1.2 percent in the 1965-73 and 1973-78 periods, respectively. In this study we have analyzed the linkages among the sectors and the aggregate. The results indicate that the sharp productivity slowdown was widely dispersed across most sectors of the economy. Moreover, almost half of the slowdown was related to capital investment's failure to keep up with the rapid growth of the labor force.

Similar results were evident from our analysis of the broader measure, total factor productivity. This measure showed a deceleration from a 1.3-percent annual growth rate in the 1948-65 period to rates of 0.7 percent over 1965-73 and 0.4 percent over 1973-78. This deceleration also occurred widely across most sectors.

Intersectoral shifts in employment and output—the "level" effect—explained only a minor part of the aggregate productivity slowdown. The effect of shifts across sectors with differing productivity levels was relatively small in the early period (0.43 percent per year over 1948-65), and was even smaller in recent years (0.15 percent per year over 1973-78). The diminution of the level effect thus accounted for only 0.3 percentage point of the 2.0-percentage-point deceleration in aggregate labor-productivity growth.

The small level effect evident in the U.S. private economy over the past generation contrasts starkly with the large sectoral-shift effects normally evident in rapidly industrializing countries, where workers move rapidly from low-productivity agricultural employment to high-productivity industrial jobs. The productivity boost from sectoral shifts of this type, once important in U.S. economic history, apparently is no longer so.

Reduced growth of capital deepening explains almost half of the labor-productivity slowdown on a disaggregated basis, but only one-third of the slowdown on an aggregate basis. The aggregate method understates the importance of the slowdown in capital deepening, because of aggregation bias. Our theoretical and empirical results strongly support the use of disaggregated data—which is important because most other productivity studies have relied on aggregated data. Shifts in employment shares among sectors can cause difficulty, both in the estimation of the production function and in its application to questions such as those examined here. While it would be impossible to avoid these difficulties altogether, it is still worthwhile to disaggregate the data as far as possible.

The effect of the slowdown in capital-intensity growth on labor productivity growth was paralleled by a coincident decline in total factor productivity growth. The two trends signify not only a decelerating substitution of capital for labor, but also a deterioration in the rate of increase in the combined efficiency of the two inputs. That trend, in fact, has pervaded most sectors of the economy. The aggregate observations were confirmed—if not strengthened—by the disaggregated analysis.

The underlying causes and possible remedies of these worrisome trends have become the subject of much controversy. A number of contributing factors have been cited for the productivity slowdown, such as rapid increases in the number of inexperienced workers, business-cycle uncertainties, higher energy prices, inflation, governmental regulations, environmental priorities, and tax laws. Although all factors seem to have had some impact, no single one stands out as the prime cause of the slowdown in capital deepening or productivity growth. But our analysis suggests that, whatever the underlying causes, the effects of the slowdown have been pervasive throughout the economy.

Appendix A
The Rate Effect and Divisia Aggregation

One can interpret the rate effect under direct aggregation as a close counterpart to labor-productivity change as measured by Divisia aggregation. Economists believe Divisia aggregation to be particularly appropriate for measuring productivity change,[28] because this approach is consistent with generalized production functions such as the translog function, and because the aggregate index is based on a weighted average of within-sector rates of change, thereby effectively netting out level effects. For the multisector Divisia index of aggregate productivity, outputs and inputs are not summed directly across sectors as they are under direct aggregation. Instead, growth rates of real outputs (inputs) are calculated for each of the sectors, and the aggregate index of real output (input) growth is then computed as a *weighted average* of the growth rates of real outputs (inputs) in each of the sectors, where the weights are *nominal* output (nominal input) shares. The Divisia productivity index is thus the difference between the instantaneous rates of growth of output and inputs.

In algebraic form, the multisector Divisia productivity index may be stated[29]

$$\frac{dP}{P} = \Sigma y_i \frac{dQ_i}{Q_i} - \Sigma w_i \frac{dL_i}{L_i}, \qquad \text{(A-1)}$$

where y_i = nominal output share of the i-th sector

Q_i = real output of the i-th sector

w_i = nominal wage share of the i-th sector

L_i = labor hours employed in the i-th sector

The Divisia index is a continuous index, although it is normally approximated with a discrete counterpart because of the unavailability of continuous output and input data.[30] With annual data, the above formula can be approximated for annual growth rates:

$$1 + \frac{\Delta P}{P} \approx \frac{1 + \Sigma y_i \frac{\Delta Q_i}{Q_i}}{1 + \Sigma w_i \frac{\Delta L_i}{L_i}} \qquad \text{(A-2)}$$

where the annual subscripts have been suppressed for simplicity.

There are two conceptual differences between the direct and Divisia productivity indices. First, the Divisia index essentially measures only the rate effect, and hence is free of the "bias" imparted by a level effect. In the aggregate Divisia index, within-sector growth rates are weighted by shares that sum to one, so that the growth rate of the aggregate index reflects only the weighted average of the growth rates within the individual sectors. Second, the Divisia index weights the growth rates of sectoral components by their *nominal* output and factor shares. These nominal shares are the products of real shares and relative prices, the latter of which proxy for the marginal values (outputs) and marginal products (inputs). Thus, the Divisia index is effectively a value-weighted "rate" index.

The similarity between the Divisia index and the direct-aggregation-rate effect can be demonstrated easily. From equation (1) in the text, the continuous form of the rate effect in direct aggregation is

$$\Sigma q_i \frac{dP_i}{P_i},$$

which can be rewritten as

$$\sum q_i \frac{dQ_i}{Q_i} - \sum q_i \frac{dL_i}{L_i}. \qquad \text{(A-3)}$$

By comparison, the Divisia index in equation (A-1) can be rewritten as

$$\sum p_i q_i \frac{dQ_i}{Q_i} - \sum v_i\, l_i \frac{dL_i}{L_i}, \qquad \text{(A-4)}$$

where p_i = the relative price of output in the i-th sector

v_i = the relative wage of labor in the i-th sector.

Equations (A-3) and (A-4) demonstrate that the rate effect under direct aggregation and the Divisia productivity index are identical, except that the rate effect uses real output shares as weights (even for inputs), whereas the Divisia index uses nominal output and input shares as weights for outputs and inputs, respectively.

Table A-1 demonstrates that the rate effect and the Divisia index result in strikingly similar measures of aggregate-productivity change. Thus, both the rate effect and the Divisia index provide a good measure of productivity change net of "aggregation bias," and the choice between the two rests largely on whether or not one prefers to weight data by prices as proxies for marginal products.

Table (A-1)
Two Measures of Labor Productivity Growth
(Annual rate, in percent)

	1948–65	1965–73	1973–78
Rate Effect	2.82	2.05	1.14
Percentage Point Change	—	−0.77	−0.91
Divisia Index	2.80	2.07	1.18
Percentage Point Change	—	−0.73	−0.89

Sources: Table 3 in the text for the rate effect. Equation (A-2) is iterated annually for the Divisia index.

Appendix B
Aggregation Bias

Aggregation bias may occur when sectors with varying characteristics are treated as if they were homogeneous. If there were no aggregation bias—that is, if all components of the aggregate were alike—the two methods used in this paper to calculate the contribution of the capital-labor ratio to productivity growth would produce the same results. However, the empirical results indicate that this is not the case. To examine the theoretical difference between the two methods, we first need to separate changes in the capital-labor ratio into rate and level effects, deriving results analogous to equation (3) for labor-productivity change. Since

$$k = \Sigma l_i k_i \,, \qquad \text{(B-1)}$$

then

$$\frac{dk}{k} = \Sigma l_i \frac{dk_i}{k} + \Sigma \frac{k_i}{k} dl_i$$

$$= \Sigma \frac{\frac{L_i}{L}}{\frac{K}{L}} \frac{K_i}{L_i} \frac{dk_i}{k_i} + \Sigma \frac{k_i}{k} dl_i \qquad \text{(B-2)}$$

$$= \Sigma \frac{K_i}{K} \frac{dk_i}{k_i} + \Sigma \frac{k_i}{k} dl_i$$

From equation (4), the contribution of the capital-labor ratio to labor-productivity change as measured by the aggregate method is $\alpha\frac{dk}{k}$, or:

$$\alpha\left[\Sigma\frac{K_i}{K}\frac{dk_i}{k_i} + \Sigma\frac{k_i}{k} dl_i\right] \qquad \text{(B-3)}$$

The contribution as measured by the disaggregated method, as previously described in equation (8), is $\Sigma q_i \alpha_i \frac{dk_i}{k_i}$. Clearly, the two calculations would produce identical results if

$$\Sigma\frac{k_i}{k} dl_i = 0 \text{ and } \frac{\alpha K_i}{K} = \alpha_i q_i, \text{ or } \frac{\alpha}{\alpha_i} = \frac{Q_i/Q}{K_i/K}.$$

These conditions would be fulfilled if the sectors were homogeneous, since then $k_i = k$ for all i, and thus the term $\Sigma\frac{k_i}{k} dl_i$ is zero by definition. Also, since the output-capital ratios would be the same across sectors, $Q_i/K_i = Q/K$. The aggregate α could then be derived from equation (9), setting $\alpha_i = \alpha_j$ for all i and j.

$$\alpha = \alpha_i \Sigma \frac{Q_i/K_i}{Q/K} \frac{dK_i}{dK} = \alpha_i \Sigma \frac{dK_i}{dK} = \alpha_i \frac{1}{dK} \Sigma dK_i \quad \text{(B-4)}$$

and since $\Sigma dK_i = dK$, $\alpha = \alpha_i$.

In this situation, therefore, there is no ambiguity involved in the definition of the aggregate α, which is independent of the data. Since there is no aggregation bias, use of a disaggregated method provides no further information.

Given the Cobb-Douglas production function and a perfectly competitive economy, the two methods would also produce the same results so long as there were no employment shifts among sectors. The Cobb-Douglas function implies $\frac{\delta Q_i}{\delta K_i} = \alpha_i \frac{Q_i}{K_i}$ for all i, and perfect competition implies $\frac{\delta Q_i}{\delta K_i} = \frac{\delta Q_j}{\delta K_j}$. Therefore, $\alpha_i \frac{Q_i}{K_i} = \alpha_j \frac{Q_j}{K_j}$, and from equation (B-4),

$$\alpha = \Sigma \alpha_i \frac{Q_i}{K_i} \frac{K}{Q} \frac{dK_i}{dK} = \frac{\delta Q_i}{\delta K_i} \frac{K}{Q} \Sigma \frac{dK_i}{dK} = \frac{\delta Q_i}{\delta K_i} \frac{K}{Q} \quad \text{(B-5)}$$

Hence, the condition $\alpha \frac{Q}{K} = \alpha_i \frac{Q_i}{K_i}$ would hold under constant employment shares even if the sectors were not perfectly homogeneous. However, the existence of sectoral shifts in employment shares will result in a difference between the aggregate and disaggregated methods, so long as sectors are not homogeneous. Specifically, the difference will be $\alpha \Sigma \frac{k_i}{k} dl_i$, or the level effect in capital-labor ratio growth multiplied by α.

The existence of this level effect also introduces bias into the ordinary-least-squares estimation of the aggregate α. Since sectors with higher capital-labor ratios typically have higher labor-productivity levels, the shift effect, $\Sigma \frac{k_i}{k} dl_i$, in the growth equation for the capital-labor ratio (B-2) is correlated with the level effect in equation (7), which (from footnote 8) can be written equivalently as

$$\frac{dP}{P} = \underset{\text{(Rate)}}{\Sigma q_i \frac{dP_i}{P_i}} + \underset{\text{(Level)}}{\Sigma \frac{P_i}{P} dl_i}. \quad \text{(B-6)}$$

Hence the independent variable in the aggregate-productivity equation (4), dk/k, is correlated with the error term. This can be seen by first adding an error term to equation (4) for the aggregate and sectors, assuming for simplicity that $r = 0$ (no disembodied technical change):

$$\frac{dP}{P} = \alpha \frac{dk}{k} + u \quad \text{(B-7)}$$

and

$$\frac{dP_i}{P_i} = \alpha_i \frac{dk_i}{k_i} + u_i \quad \text{(B-8)}$$

Then, substituting (B-8) into (B-6), and (B-2) into (B-7), we have:

$$\frac{dP}{P} = \Sigma q_i \alpha_i \frac{dk_i}{k_i} + \Sigma q_i u_i + \Sigma \frac{P_i}{P} dl_i = \alpha \Sigma \frac{K_i}{K} \frac{dk_i}{k_i} + \alpha \Sigma \frac{k_i}{k} dl_i + u. \quad \text{(B-9)}$$

Rearranging terms, (B-9) becomes

$$u = \Sigma q_i u_i + \Sigma \left(q_i \alpha_i - \alpha \frac{K_i}{K} \right) \frac{dk_i}{k_i} + \Sigma \left(\frac{P_i}{P} - \alpha \frac{k_i}{k} \right) dl_i. \quad \text{(B-10)}$$

As before, if the sectors are homogeneous, $\alpha_i q_i = \alpha K_i/K$, $P_i = P$, and $k_i = k$. Then, the second two terms in (B-10) reduce to zero, and the error term, u, is composed only of the weighted random components u_i. If the sectors are not homogeneous, however, the error term will consist solely of random components only if there is no aggregation bias. As before, this condition will be met if the Cobb-Douglas and perfect-competition assumptions hold, so that $\alpha Q/K = \alpha_i Q_i/K_i$, and if there are no changes in employment shares. If the Cobb-Douglas and perfect-competition assumptions hold, but there are shifts in employment shares, (B-10) reduces to:

$$u = \Sigma q_i u_i + \Sigma\left(\frac{P_i}{P} - \alpha\frac{k_i}{k}\right)dl_i. \quad \text{(B-11)}$$

Recalling that $P = Q/L$, $k = K/L$, and making use of the relation $\alpha_i q_i = \alpha K_i/K$, we can write equation (B-11) as

$$u = \Sigma q_i u_i + \Sigma q_i(1-\alpha_i)\frac{dl_i}{l_i}. \quad \text{(B-12)}$$

The estimate of α will be biased if the non-random part of the error term, $\Sigma q_i(1-\alpha_i)\frac{dl_i}{l_i}$ is correlated with $\frac{dk}{k}$. The level or bias effect in $\frac{dk}{k}$, i.e., the second term in equation (B-2), is

$$\Sigma\frac{k_i}{k}\,dl_i, \text{ or } \Sigma\frac{K_i}{K}\frac{dl_i}{l_i}$$

Substituting $\frac{K_i}{K} = \frac{\alpha_i}{\alpha}q_i$, this term becomes $\frac{1}{\alpha}\Sigma\alpha_i q_i\frac{dl_i}{l_i}$. Since the nonrandom part of u is $\Sigma q_i\,(1-\alpha_i)\,\frac{dl_i}{l_i}$, the degree to which α is biased depends on how close $(1-\alpha_i)$ is to α_i. We know that the α_i must lie between 0 and 1; the closer they are to 0.5, the closer will be the correspondence between the independent variable and the error term in equation (4).

As we have seen, the industry output-capital elasticities in fact cover a fairly wide range, .2 to .7 (Table 9). However, the unweighted average is .50, while the average weighted by output shares is .45. Therefore, there is some indication that the independent variable, dk/k, in the aggregate equation (4) (or equation (6)) is positively correlated with the error term. This correlation should produce an upward bias in the estimation of α in the aggregate equation. This seems to be the case, because of the discrepancy between the estimates of α and α_i in Table 6.

RATE AND LEVEL EFFECTS

Several studies have decomposed aggregate productivity change into rate and level effects, but the formulae used were complicated and difficult to interpret. Nordhaus (1972) derived a multi-sector framework that somewhat resembled the one in this paper. Independently, Grossman and Fuchs derived a two-sector model that was simplified and extended by Beebe. Subsequently, Clark and Blakemore formulated and solved the multisector problem much more concisely, and their analysis was used by Haltmaier. The derivation below extends that of Clark and Blakemore, and results in a decomposition that is easily interpreted and applied.

Using the following definitions,

Q_i = real output in the i-th sector ($i = 1, \ldots, N$)

$Q = \Sigma Q_i$ = aggregate real output

$q_i = Q_i/Q$ = i-th sector's share of real output

L_i = labor hours employed in the i-th sector

$L = \Sigma L_i$ = aggregate hours employed

$l_i = L_i/L$ = i-th sector's share of hours employed

$P_i = Q_i/L_i$ = real output per hour in the i-th sector

$P = Q/L$ = aggregate output per hour

and beginning with the identity,

$$P \equiv Q/L = \frac{\Sigma Q_i}{L} = \frac{\Sigma P_i L_i}{L} = \Sigma P_i l_i \ ,$$

then for a discrete time period,

$$\Delta P = \Sigma l_i \Delta P_i + \Sigma P_i \Delta l_i + \Sigma \Delta P_i \Delta l_i \ ,$$

where the three terms represent the rate, level, and interaction (second order) terms, respectively. For a percentage change over the finite interval,

$$\frac{\Delta P}{P} = \frac{1}{P}\Sigma l_i \Delta P_i + \frac{1}{P}\Sigma P_i \Delta l_i + \frac{1}{P}\Delta P_i \Delta l_i \ .$$

Using the following identities,

$$P \equiv Q/L;\ l_i \equiv L_i/L;\ P_i \equiv Q_i/L_i$$

and

$$\frac{P_i}{P} \equiv \frac{Q_i/L_i}{Q/L}\ , \text{ or } \frac{1}{P} = \frac{Q_i/Q}{L_i/L}\frac{1}{P_i}\ ,$$

and substituting into the above equation,

$$\frac{\Delta P}{P} = \Sigma\frac{L_i}{Q}\Delta P_i + \Sigma\frac{Q_i/L_i}{Q/L}\Delta l_i + \Sigma\frac{Q_i/Q}{L_i/L}\frac{1}{P_i}\Delta P_i \Delta l_i$$

$$= \Sigma\frac{L_i}{Q}\frac{P_i}{P_i}\Delta P_i + \Sigma\frac{Q_i}{Q}\frac{1}{l_i}\Delta l_i + \Sigma\frac{\Delta P_i}{P_i}\frac{Q_i}{Q}\frac{\Delta l_i}{l_i}$$

$$= \Sigma\frac{Q_i}{Q}\frac{\Delta P_i}{P_i} + \Sigma\frac{Q_i}{Q}\frac{\Delta l_i}{l_i} + \Sigma\frac{Q_i}{Q}\frac{\Delta P_i}{P_i}\frac{\Delta l_i}{l_i}$$

$$= \Sigma q_i\frac{\Delta P_i}{P_i} + \Sigma q_i\frac{\Delta l_i}{l_i} + \Sigma q_i\frac{\Delta P_i}{P_i}\frac{\Delta l_i}{l_i},$$

which are the rate, level, and interaction effects used in the text.

1. Denison (1973) and Nordhaus (1972). Because these studies were done prior to the 1973 business-cycle peak and the economy had not recovered fully from the effects of the 1970 recession, it was difficult to measure the secular productivity slowdown.

2. Such shifts may be tied in part to the relative supplies of inexperienced and experienced workers. See Perry and Wachter and Perloff.

3. For example, see Thurow, pp. 86–87.

4. For other recent papers that employ various degrees of disaggregation, see Norsworthy, Harper, and Kunze, Haltmaier, Gollop and Jorgenson, Gollop, Kendrick and Grossman, and Bennett.

5. For an extensive analysis, see Norsworthy, Harper, and Kunze. For comprehensive summaries see Kendrick, Denison, and Tatom. Other recent papers of importance are by Berndt, Crandall, Nordhaus (1980), and Kopcke.

6. Direct aggregation is not the only method of aggregation; nor is it necessarily the best, particularly in the case of productivity. However, it is used officially and is commonly understood—all official published productivity data are based on direct aggregation. For these reasons, the formulae derived in this paper are based on direct aggregation, although we compare our results to those obtained using Divisia aggregation.

7. Equation (1) can be calculated over a full period or calculated iteratively within the period. For example, in analyzing the rate, level, and interaction effects over, say, a 10-year period, one could perform a single calculation for the entire period using the q_i at the beginning of the 10-year span and the full 10-year percentage changes in each of the other variables to arrive at the calculated components. The rate, level, and interaction components would sum to the total, with each component and the total expressed as a 10-year percentage change. In converting to annualized compound rates of change, however, the components no longer would sum to the total because of nonlinearities involved in compounding. (See Levine for a generalization of this problem.)

An alternative is to iterate equation (1) annually (or over any other short period), calculating a rate of change for the total and each component for each year in the 10-year period and allowing the q_i to change for each year. This method, which is used throughout the paper, has three advantages: the annualized growth rates of components always sum to that of the total; the q_i are representative of the average values of each subperiod rather than simply the initial values; and the method of calculation is comparable to that of the annual Divisia index against which the rate effect is compared in Appendix A.

8. An individual sector's contributions to the overall rate, level, and interaction effects are respectively,

$$q_i \frac{\Delta P_i}{P_i}, \quad q_i \frac{\Delta l_i}{l_i}, \text{ and } q_i \frac{\Delta P_i}{P_i} \frac{\Delta l_i}{l_i}$$

Since q_i/l_i may be expressed alternatively as P_i/P (the sector's relative level of productivity) the level effect may also be written as

$$\Sigma \frac{P_i}{P} \Delta l_i \quad \text{and} \quad \frac{P_i}{P} \Delta l_i$$

In this form, the level effect is the change in the sectors' labor shares weighted by their relative productivity levels.

9. The private domestic nonresidential economy excludes output of government and government enterprise, "rest of the world," and the imputed rental value of farm and nonfarm dwellings. Residential construction is included in the total.

10. Labor productivity exhibits a strong cyclical component, because the stock of capital is largely fixed in the short run and labor may be combined with capital at differing intensities. Moreover, because there may be significant costs associated with labor turnover, fluctuations in labor productivity tend to lag the business cycle (see Gordon and Sims). For the data in this section, the cycle in productivity is removed by calculating trends between selected "peak" years for productivity: 1948, 1965, 1973, and 1978. (see Norsworthy, Harper, and Kunze, pp. 389–90.) For the regressions in Section II, a cyclical variable is entered directly into the equations to account for the cyclical component of productivity. Moreover, the entire analysis was performed on cyclically adjusted output and labor data that were constructed using an econometric scheme derived from work by Clark (1978) and Nordhaus (1972). The results based on cyclically adjusted data were very close to the ones reported here. The two methods gave similar growth rates because the end points of the periods are peak productivity years.

11. The relatively steady behavior of the productivity series for finance and insurance and for services may result from unreliable output data. See Footnote 12.

12. The decline in the construction industry is sometimes attributed to erroneous real-output data, although it is difficult to explain why data problems would cause a sudden shift in the behavior of the series. In the construction, finance and insurance, and service industries, output is measured in terms of inputs in several constituent industries where there is no standardized product. There also is inadequate correction for quality change in the price indices within these industries. These problems suggest that the output and productivity data for these sectors may be of insufficient quality for productivity analysis, although they do not suggest that the shifts in trends are necessarily linked to data problems. See Norsworthy, Harper, and Kunze, p. 393, and Rees.

13. Pre-1972 data were utilized in some studies that attributed the deceleration in the late-1960's and early-1970's to the level effect. Because of the difficulty in removing the cyclical effect of the 1970 recession from the data, the years beyond 1968 could be relied on only tenuously. At that time, the diminished level effect due to the declining shift out of agriculture appeared to explain a large part of the small deceleration then apparent in aggregate productivity growth. The recent contention of Thurow, pp. 86–88, reiterating the present importance of the level effect, simply is not supportable using disaggregation at the level used in this (or his) study.

14. To get the rate effect, one does not simply multiply the real product share in Table 1 times the annual rate of increase in Table 2, although these figures are appropriate for analyzing that effect. For its calculation, see Footnote 7.

Sectoral level effects are not shown in Table 4 because the individual level effect is negative if Δl_i is negative, i.e., if the sector's labor share declined over the period. So long as a sector's labor share increased, the level effect is positive even if the sector displays relatively low productivity. Thus, the level effects measure only a portion of the full effect on aggregate productivity when labor shifts from one sector to another. To see this, consider what would happen if a worker were to shift from the agricultural to the manufacturing sector. Both output and employment would fall in agriculture, but would rise in manufacturing. The full effect of such a shift depends on the productivity levels in *both* sectors, and thus cannot be picked up by a level effect associated with a single sector. Generalizing from this example suggests that one should focus on the aggregate level effect (Table 3) rather than on the individual level effects of the sectors.

Separate analysis by the authors shows that the most important labor shifts impinging on the level effect have been the declining share of labor in agriculture (a sector with a low *relative level* of productivity); an increasing labor share in services (low relative productivity level) and finance and insurance (high relative productivity level); and a shift in mining (high relative productivity level) from a declining to a rising labor share. Although the labor shares of the manufacturing sectors have declined on balance, the productivity levels of these sectors are very close to the aggregate average.

15. As noted in Table 5, capital data are for gross capital stocks. The sources are the Department of Commerce for agriculture and manufacturing, and Data Resources, Inc., for the other sectors. (Data for the total are sums of the sectoral data.) The analysis was performed also using sectoral data by Kendrick and Grossman. The results were comparable except for a few sectors, most notably mining, where the estimated α's made little sense. Jane Haltmaier is exploring other data sources, but we are not yet prepared to make strong statements about the quality of our data. We have also run our equations using Commerce data for aggregate gross and net capital stocks, and we report these results in the paper.

16. Norsworthy, Harper and Kunze found that the capital-labor ratio accelerated in the 1965–73 period for the private nonfarm business sector. According to their analysis (pp. 419–20), the investment tax credit appears to have reduced the rise in the cost of capital during the 1965–73 period, while the sudden rise in energy prices in 1973–74 (and the apparent complementarity of energy and capital in production) may have retarded capital formation in the 1973–78 period.

17. Much debate has centered around the inclusion of energy input or its price in a value-added production function. Most energy use should be excluded, although the price of energy might provide a reasonable surrogate for other factors, such as changes in the optimal capital-labor ratio. See Kopcke.

18. Strict separability requires that exclusion of some inputs, such as goods in intermediate stages of production, not affect the optimal mix of the included inputs, labor and capital.

19. Disembodied technical change and changes in total factor productivity are used interchangably to mean a shift in the production function. See Jorgenson and Griliches, p. 250, and Norsworthy, Harper, and Kunze, p. 395.

20. Under the assumptions that production conforms to the Cobb-Douglas formulation and that the economy is perfectly competitive, the elasticity of output with respect to each factor will be equal to that factor's share of total income. Thus, α can be estimated as capital's historical income share. This is the approach used by Denison.

21. Because capacity utilization in manufacturing is probably not a good surrogate for business conditions in many sectors, we experimented with other ways of removing the cycle in labor productivity. Data for normal hours and output were constructed using a technique based on work by Clark (1978) and by Nordhaus (1972). Although this method produced similar results, it is much more complex and has led to much controversy. We also used the method described in the paper, with percentage changes in 1972-dollar GNP (less the mean percentage change) in place of the capacity-utilization rate. Although real GNP is preferable because of its broader-based coverage, it imparts a bias because its percentage changes are endogenous to the *secular* trend in productivity. Therefore, we found it preferable to use the manufacturing capacity-utilization rate as a proxy for the economy-wide business cycle.

22. The dummies are zero except for the following years: $d_1 = 1$ for the annual changes 1965–66 through 1972–73, and $d_2 = 1$ for 1973–74 through 1977–78.

23. The means of the dependent variables are the average rates of labor-productivity change over the 1948–78 period, which can be approximated from Table 7.

24. Since only two factors of production (labor and capital) have been included in the estimated equations, it is difficult to say which figure should be used. The figures correspond to the shares of income (output) classified as (1) profit-type return only, and (2) profit-type return plus net interest, indirect business taxes, and capital consumption allowances. The latter share has been quite stable over the 30-year period, ranging from .39 to .47. The income (output) measure is gross domestic product, less government. Data are from Table 6.1 of the National Income and Product Accounts.

25. Net capital stock is not available on a disaggregated basis. In estimating our aggregate equation using the BEA series for net capital stock, we obtained an estimate of .55. Thus our empirical results are quite close to those of Clark.

26. Equation (9) is derived as follows:

$$\alpha = \frac{dQ}{dK}\frac{K}{Q} = \Sigma\frac{dQ_i}{dK_i}\frac{dK_i}{dK}\frac{K}{Q} = \Sigma\frac{dQ_i}{dK_i}\frac{K_i}{Q_i}\frac{dK_i}{dK}\,q_i\,\frac{K}{K_i}$$

$$= \Sigma\alpha_i q_i\left(\frac{dK_i}{K_i}\Big/\frac{dK}{K}\right)$$

27. Since the aggregate α depends on the sectoral mix of capital-stock growth, the concept of an aggregate α as a simple elasticity becomes ambiguous once one pursues the microeconomic approach. This problem, which is not new in economics, lies at the heart of the aggregate vs. sectoral relationships addressed in this paper.

28. Siegel, Jorgenson and Griliches, Solow, Norsworthy, Harper and Kunze, Gollop and Jorgenson, Gollop, Star and Hall, and Richter. The Jorgenson and Griliches paper, pp. 250–254 and 260–261, gives perhaps the clearest and most precise derivation of the multisector Divisia productivity index.

29. Jorgenson and Griliches, p. 252. There is also an equivalent dual counterpart expressed in terms of prices, since Divisia aggregation presumes that prices equal marginal values.

30. See Jorgenson and Griliches, p. 260–261, and Star and Hall.

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