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SURVEY OF CURRENT BUSINESS

Some Major Issues in Productivity Analysis

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By EDWARD F. DENISON

Some Major Issues in Productivity Analysis: An Examination of Estimates by Jorgenson and Griliches

The Office of Business Economics has been asked by several of the principal users of its data to supplement its established series on national output and its composition (GNP) by consistent measures of factor inputs, so as to facilitate the analysis of economic growth. The OBE is responsive to these requests and considers the preparation of measures of factor inputs an appropriate extension of its work on the national economic accounts. The estimates of business capital stocks and some other studies that have been published in the SURVEY OF CURRENT BUSINESS are important steps leading to the preparation of factor input measures.

The conceptual and statistical problems that are involved in the measurement of factor inputs are unusually difficult, however, and OBE believes that some discussion of these problems is called for before it engages itself to prepare the measures. To elicit such a discussion is a major purpose of publishing this article.

In this study, Edward F. Denison, one of the outstanding experts in the analysis of economic growth, provides a searching comparison of the concepts and statistical procedures that he considers appropriate for input measurement with those recently proposed by the eminent econometricians, Dale W. Jorgenson and Zvi Griliches. The Jorgenson-Griliches proposals differ sharply from those set forth by Denison, and also by many others who have done research in this field. For the convenience of the reader, the *Review of Economic Studies* article in which the Jorgenson-Griliches proposals appeared is reprinted—with some corrections by the authors—in this issue of the SURVEY.

These differences in concepts and procedures yield strikingly different conclusions. According to Denison, a substantial part of the postwar growth of national output has been due to an increase in productivity; according to Jorgenson-Griliches almost all of the increase has been due to an increase in factor inputs.

The issues raised by these opposing conclusions are not only important from the standpoint of basic research but are also likely to have far-reaching implications for the formulation of private and public policies directed at the promotion of economic growth. We believe that the publication of the Denison article and of a reply to it by Jorgenson and Griliches in a later issue of the SURVEY will be of substantial interest to all those concerned with economic growth.

IN a recent article, "The Explanation of Productivity Change," Professors Dale W. Jorgenson and Zvi Griliches found that increases in labor and capital input were responsible for almost all postwar growth in the United States [1]. They concluded that output per unit of input contributed little to the growth rate of output—only 0.10 percentage points, to be exact. This estimate contrasts with much larger amounts obtained in virtually all other studies. I arrived at 1.37 percentage points in *Why Growth Rates Differ: Postwar Experience in Nine Western Countries* (written with the assistance of Jean-Pierre Poullier) [2].

This review is a response to repeated requests to comment upon the article by Jorgenson and Griliches.[1] Do their estimates differ so much from mine because of differences in the time period analyzed, in the definition of output, or in the sector of the economy covered? Does the discrepancy reflect a mere difference in classifying growth sources into those regarded as increasing input and those regarded as raising output per unit of input? Or is it due to differences in statistical procedures? What are the differences in our procedures, what are their quantitative effects, and whose, in my opinion, are preferable? In this article, all of these questions are discussed.

To decompose the discrepancy in results, it is necessary to examine many aspects of the estimates. Section I of this review measures the effects of differences in time period, definition of output, and scope of the economy analyzed, and section II examines a minor difference in procedure. After allowance for these differences, most of the large discrepancy between our measures of output per unit of input remains. Our statistical measures of total output diverge because different price indexes are used for deflation; the effect is examined in section VI. Differences between our total input series for the sector of the economy analyzed by Jorgenson and Griliches are much larger. The input series differ because of (a) differences in the weights we use to combine individual inputs and (b) differences in the way we measure each individual input. In sections III and IV, I consider the change that would be introduced in my series, given my individual input measures, if the Jorgenson-Griliches weights were used. In sections V, VII, and VIII, I measure the effects upon their series, given their weights, of using their measure for each input in place of mine. The two preceding sentences must be qualified

NOTE.—Dr. Denison is Senior Fellow, The Brookings Institution, Washington, D.C. The views expressed in this article are those of the author and do not purport to represent the views of the other staff members, officers, or trustees of The Brookings Institution.

1. Its preparation was the occasion of rather extended communication among us, in the course of which Professors Jorgenson and Griliches clarified certain of their procedures, provided some unpublished data needed for comparison of our estimates, and offered suggestions on presentation. This assistance helped me to isolate the differences between our procedures and focus my discussion on these differences. It is acknowledged with gratitude.

I also benefited greatly from discussions of a draft of this review with George Jaszi, and of certain sections with Murray F. Foss, Guy V. G. Stevens, and Allan H. Young.

by noting, as I shall at the appropriate points, that lack of data necessitated some departures from this plan. In section IX, I provide a table that summarizes the results of the preceding sections and thus reconciles our output per unit of input series.

An equally important purpose of this article is to examine the merits of alternative procedures. In most sections I therefore discuss differences in procedure that happen not to be important sources of discrepancy in our series during the particular time period discussed as well as those that are, and in sections IX and X offer some general observations.

The section of most general interest may well be section VII, in which I examine the Jorgenson-Griliches capital utilization adjustment. I try there to nudge the theory of growth analysis forward a little. In addition, their capital utilization adjustment is the largest single reason that our output per unit series diverge.

I. Time Period, Definition of Output, and Scope of Economy Covered

THE Jorgenson-Griliches summary result, that output per unit of input contributed only 0.10 percentage points to a 3.59 percent a year increase in output, refers to the 1945–65 period. Use of 1945 as a starting point minimizes their figure. From 1948 to 1965 Jorgenson and Griliches obtain a growth rate of output per unit of input of 0.74.[2] Almost all of this increase came before 1950 and after 1961; the growth rate of their output per unit of input series was 0.01 from 1950 to 1961 and 2.01 from 1961 to 1965 [calculated from 1, table VIII]. Cyclical movements contribute to the difference between these periods, but even so the contrast is remarkable.

My summary estimate, that the increase in output per unit of input contributed 1.37 points to the growth rate, refers to the period from 1950 to 1962. For this timespan, Jorgenson and Griliches obtain 0.30, as against 0.10 for 1945–65. Thus, the difference in time period is responsible for 0.20 points of the difference between our summary estimates. Our estimates for 1950–62 and two subperiods are contrasted in the first two rows of the following table. The third row [from 2, table 21–1] shows my estimates after adjustment to eliminate, as best I could, the effects of differences among terminal years in the intensity of demand (i.e., short-term changes in intensity of utilization of employed resources).

	1950–62	1950–55	1955–62
Unadjusted:			
Jorgenson-Griliches	0.30	0.42	0.22
Denison	1.37	1.93	.97
Adjusted:			
Denison	1.41	1.54	1.31

The Jorgenson-Griliches series refers to real gross national product per unit of input in the private domestic economy; mine, to real national income (also called net national product valued at factor cost) per unit of input in the economy as a whole.

The reason I chose to analyze the growth of net rather than gross product is both fundamental and conventional.

"Insofar as a large output is a proper goal of society and objective of policy, it is net product that measures the degree of success in achieving this goal. Gross product is larger by the value of capital consumption. There is no more reason to wish to maximize capital consumption—the quantity of capital goods used up in production—than there is to maximize the quantity of any other intermediate product used up in production, such as, say, the metal used in making television sets. It is the television sets, not the metal or machine tools used up in production, that is the objective of the production process" [2, pp. 14–15].

Jorgenson and Griliches confine discussion of their choice of gross product to a single sentence. "Exclusion of depreciation on capital introduces an entirely arbitrary distinction between labour input and capital input, since the corresponding exclusion of depreciation of the stock of labour services is not carried out" [1, p. 256]. (They also cite an article by Domar, but it contains no reference to depreciation of labor.) Their statement is too brief to allow much discussion, particularly since Jorgenson and Griliches do not specify how they would depreciate labor. I am not aware of a definable labor counterpart to capital depreciation as a component of GNP that there is no advantage in increasing because it is not wanted—feeding, clothing, and housing children surely do not fall into this category—but if there be such, the appropriate remedy would be to change the measures of output and labor earnings.

I do not wish to pursue this subject further in this article, but must provide a statistical reconciliation of our estimates. This is facilitated by the fact that, sheerly by chance, conversion of my estimate of output per unit of input in the 1950–62 period to their concepts would scarcely change it because the difference in definition of output happens to be offset by the difference in the scope of the economy covered. The explanation is as follows:

(a) My output series refers to national income, or net national product (NNP) valued at factor cost, measured in 1958 prices. The Jorgenson-Griliches output series refers to gross national product valued at market prices, measured in 1958 prices. The choice between factor cost and market price weights to combine the components of product does not affect comparability of our results, but that between gross and net

2. National accountants would not draw inferences about postwar growth trends from an analysis beginning before 1948, at the earliest, because elimination of price controls distorted the real output measure in 1945–48, and because—in the case of 1945—of the great difference from later years in the composition of output. In addition, special aspects of postwar reconversion greatly affected the 1945–48 period.

product does. The *absolute* increase in the value of gross product at 1958 factor cost is equal to the increase in net product at 1958 factor cost plus the increase in depreciation valued in 1958 prices. Each year, the change in output per unit of input (and every other growth source except depreciable capital) contributes the same absolute amount to the increase in real GNP at factor cost as to real NNP at factor cost. (Depreciable capital contributes to the increase in real GNP an amount equal to its contribution to the increase in real NNP plus the absolute increase in depreciation at constant prices.) But the same absolute amount contributed by output per unit of input yields a smaller percentage increase in GNP at factor cost than in NNP because the value of GNP is bigger than that of NNP—in 1950 by 11.6 percent, according to my estimates. Hence, output per unit of input contributed less to the growth rate of GNP when measured in percentage points. For 1950–62, my estimates yield a contribution of output per unit of input to the growth rate of GNP of 1.24 percentage points as against 1.37 to the growth rate of NNP.[3]

(b) My output estimates refer to the economy as a whole; the Jorgenson-Griliches estimates, to the private domestic economy. Thus, the latter exclude the net inflow of property income from abroad and GNP originating in general government. However, my estimates imply *no* increase in output per unit of input in the sectors they exclude.[4] The *absolute* contribution of the increase in output per unit of input to the increase in output is therefore the same in the sector covered by the Jorgenson-Griliches estimates as in the whole economy. Because the level of private domestic GNP was smaller than that of total GNP, the contribution of output per unit of input to its growth rate is proportionately larger; it is 1.38.[5]

This is practically the same as my original figure of 1.37; adjustments (a) and (b) are almost exactly offsetting.[6] Thus, differences in definition and scope of output together account for none of the difference between our 1950–62 estimates of the contribution of output per unit of input.[7]

II. Divisia Indexes

JORGENSON and Griliches devote considerable attention in their article to their use of Divisia indexes (which are averages of growth rates, with frequent changes in weights) in their measurement of input and output. I shall not discuss the alleged theoretical superiority of Divisia indexes, but simply note that their substitution has no effect upon the comparisons. When Jorgenson and Griliches introduce them in moving from their table I to table II, the movement from 1950 to 1962 of their series for output, input, and factor productivity is almost unaffected. Indeed, introduction of Divisia indexes has no appreciable effect at other dates except at the very beginning of their period, when price and output patterns were distorted. Moreover, my own procedures for combining inputs are substantially equivalent to the use of Divisia indexes.

III. The Input Weights: Total Labor vs. Total Capital and Land

TO calculate changes in total input, weights to combine the various types of input are required. Our weights, though different, share two characteristics that distinguish them from those of some other investigators. First, we each set the sum of our input weights equal to 100 percent (or 1). This has the effect of classifying gains from economies of scale as a contribution of output per unit of input to the growth of output.[8] Second, we each use the shares of labor, and of capital and land, in total earnings from production as weights to combine these broad types of input, and rely upon data from the national accounts to estimate these shares.[9]

Our actual weights differ as a result of differences in the scope and definition of our output measures and of differences in our estimating procedures. The latter contribute to the discrepancy between our results for growth of GNP per unit of input. During the postwar periods analyzed, capital-land input increased more than labor input so that the greater the weight attached to capital-land, the more a measure of

3. For consistency with OECD estimates, my GNP figures include a small amount for government capital consumption. This comes out again when I move to the private domestic economy in adjustment (b).

4. The entire increase in net property income from abroad is counted as a contribution of capital. Real GNP in general government is measured on the assumption that output per person employed does not change (this statement is only approximately accurate), and for this reason I used procedures that have the effect of measuring inputs in general government by employment [2, pp. 187–188]. Hence, no change in output per unit of input occurs in general government.

5. As indicated in section IV, my estimates imply that the contribution to the growth rate of *net* product at factor cost in the *private domestic* sector was 1.51.

6. This implies, of course, that the levels of total national income and private domestic GNP (both measured in 1958 prices at factor cost) happened to be almost the same at the start of the period (1950).

7. In measuring the effects of differences between us in concepts, scope, or procedures for this review, I often shortcut the calculations by using average weights or rates for the period examined even though we each subdivide the periods in our calculations. The results are accurate enough for the purpose at hand.

8. Throughout this review, I ignore as of no quantitative importance the fact that, in presenting the contributions of the sources to the growth rate, I allocated to output per unit of input 0.01 percentage points of an interaction term. Jorgenson and Griliches do not present contributions as such and hence omit this term, but with their estimates nothing would be allocated to productivity in any case. I also ignore rounding discrepancies that cause their growth rate of output to exceed the sum of the growth rates of input and output per unit of input at intermediate points in their analysis by small amounts varying up to 0.06 (as presented in their table IX).

9. My reasons for using income shares are stated in 2, chapter 4.

total input increases and the less output per unit of input increases.

Differences related to scope and definition

The weights used in my study refer to the shares of labor and capital-land in total national income. I measure labor earnings as the sum of (1) the compensation of employees and (2) a portion (about three-fifths) of proprietors' income; this portion is derived on the assumption that the labor share of national income originating in proprietorships and partnerships is the same as the labor share of national income originating in nonfinancial corporations [2, p. 37]. My estimate of the total earnings of capital and land is equal to the sum of the following items: the remainder (about two-fifths) of proprietors' net income; corporate profits (before tax) and inventory valuation adjustment; the rental income of persons; and net interest. The labor share plus the capital-land share equals national income. (Whatever is not earned by labor is counted as earnings of capital and land despite the fact that "pure" profit—whether a return to entrepreneurship or monopoly profit—is included.)[10] Depreciation is revalued at replacement cost in the computation of corporate and noncorporate earnings and rental income, and of total national income.[11] On the average in the 1950–62 period, labor earnings represented 78.6 percent and capital and land earnings 21.4 percent of total national income.[12] These percentages are shown in line 1 of the following table. The remainder of the table will help the reader follow the rest of this discussion.

The Jorgenson-Griliches analysis is confined to the private domestic sector. My results imply that labor earnings averaged 74.7 percent and capital and land earnings 25.3 percent of national

	Labor share	Property share
Denison labor estimates:		
1. Whole economy, national income	78.6	21.4
2. Private domestic economy, national income	74.7	25.3
3. Private domestic economy, GNP at factor cost	67.2	32.8
Jorgenson-Griliches labor estimates:		
4. Private domestic economy, GNP at factor cost	70.8	29.2
5. Private domestic economy, GNP at market prices	63.8	36.2

income in this sector. Jorgenson and Griliches analyze the growth of gross rather than net output; this obviously calls for a difference in procedure somewhere in the calculations. One acceptable possibility is to include depreciation with the earnings of capital and land in the derivation of weights, and this is what Jorgenson and Griliches do.[13] If depreciation is added to national income and to the capital-land share, and the percentages are recomputed, my estimates indicate that labor earnings averaged 67.2 percent of gross domestic product at factor cost in 1950–62 and that capital-land earnings together with depreciation averaged 32.8 percent. (These figures are unaffected by the method of measuring depreciation.) These shares, shown in line 3 of the table, differ from those in line 1 for conceptual reasons. Their use by Jorgenson and Griliches to analyze gross private product would have introduced little or no discrepancy between their estimate of output per unit of input and that which I derived in section I after allowance for differences in the definition and scope of our output measures.

Differences due to estimating procedures

The Jorgenson-Griliches weights differ from these for two reasons. First, although their estimate of labor earnings, like mine, equals compensation of employees plus a portion of proprietors' income, they obtain the latter by a different procedure. They assume that labor earnings of proprietors are equal to the number of proprietors (exclusive of unpaid family workers) times compensation per fulltime equivalent employee in the private domestic economy [1, p. 278]. This procedure allocates approximately all of proprietors' income to labor and none to capital and land. The labor share obtained by this procedure averages 70.8 percent, and the capital-land share 29.2 percent, of private domestic GNP at factor cost instead of 67.2 and 32.8, the percentages at which I arrive. My allocation of proprietors' income seems to me the more reasonable, but admittedly both procedures have substantial precedent. In the nature of the case, there is no way to check the results directly. Their use of a larger estimate of labor earnings would, in itself, lead Jorgenson and Griliches to a *higher* estimate of the contribution of output per unit of input to growth than I obtain. However, it is much more than offset by what I regard as an error in their derivation of capital-land earnings.

Jorgenson and Griliches state in their statistical appendix [1, p. 278] that "total income from property is gross private domestic product in current prices less private domestic labour income." Gross private domestic product was valued at market prices in their calculation. This means that Jorgenson and Griliches count indirect business tax liability minus "subsidies less current surplus of government enterprises" and plus business transfer payments and the "statistical discrepancy" in the national accounts as earnings of capital and land. Jorgenson and Griliches inform me that this inclusion was intentional, not an oversight. Inclusion of these items in the earnings of capital and land raises their capital-land share from 29.2 percent to 36.2 percent, or by almost one-fourth, and lowers their labor share from 70.8 to 63.8.[14] (These shares, shown in row 5 of the preceding text table, were computed from annual

10. Since Jorgenson and Griliches do the same, this does not cause our estimates to diverge.

11. The estimates are based on use of Bulletin F lives and straight-line depreciation. They were prepared before the results of the latest OBE capital stock study for nonresidential structures and equipment became available.

12. I do not actually use weights for the period as a whole in calculations, nor do Jorgenson and Griliches. I use weights for three subperiods, and they change weights annually. The averages provide a convenient summary.

13. This procedure is not necessarily exactly equivalent to that which I used in section I above to adjust my estimates to a gross product basis, but any difference in the end result for output per unit of input is probably trivial.

14. It also has the effect of including indirect taxes, and the other reconciliation items mentioned, in profits *after tax* in the numerator of the "implicit rate of return after taxes" that Jorgenson and Griliches show in table VI, column 4, of their article. Their article gives no hint of this peculiar definition of an after tax rate of return. I doubt that many readers of their article can be aware of it.

figures given me by Jorgenson and Griliches.)

The principal item at issue, quantitatively, is indirect business tax liability. Jorgenson and Griliches do not explain why they include indirect business taxes in their weights or why, if they are to be included, there is more reason to add them to capital-land earnings than to labor earnings. Possible reasons for their procedures are hard to visualize, and I can only speculate as to what they may have had in mind.

The fact that Jorgenson and Griliches are analyzing the growth of gross product valued at market prices (which, viewed from the "income side," includes indirect taxes), rather than gross product valued at factor cost, surely necessitates no difference in weights. Share weights are used as estimates of the relative response (elasticity) of output to changes in labor input and to capital-land input; for example, use of weights of 30 percent for capital and land and 70 percent for labor to analyze gross product growth would imply that a given percentage increase in every type of capital-land input raises gross product by three-sevenths as large a percentage as does the same percentage increase in every type of labor input. There is no systematic reason for the percentage response of gross product valued at market prices to differ from the percentage response of gross product at factor cost.[15]

Possibly Jorgenson and Griliches mean to challenge the classification of indirect taxes as indirect. The income division that is appropriate for use as weights is the distribution of earnings that would prevail in the absence of taxes, *taking as given* the existing quantities of each input in the sector and period analyzed. To approximate this distribution, analysis is required of what is often called "shortrun" tax incidence (to distinguish it from analysis of incidence when any impact of taxes on the quantities of factors is taken into account). My use of the classification of taxes followed in the national accounts thus implies the following assumptions. First, that personal income and inheritance taxes (and various licenses, minor taxes, and nontax recipts of governments that are classified as personal) do not alter the distribution of earnings before taxes; hence, they need not be deducted from before-tax shares to achieve the desired distribution. Second, that the "shortrun" incidence of payroll taxes is on labor earnings; hence, labor earnings should be measured inclusive of payroll taxes. Third, that the "shortrun" incidence of corporate profit tax accruals is on corporate profits; hence, corporate profits should be measured inclusive of corporate profits taxes. Fourth, that the incidence of taxes classified as indirect is on no particular type of income and their presence does not alter relative shares measured exclusive of such taxes. Taxes classified as indirect, and the average percentage of total "indirect business tax and nontax accruals" represented by each type in 1950–62, are: sales and excise taxes and customs duties, 55 percent; property taxes, 33 percent; business motor vehicle licenses, 2 percent; other business taxes, 7 percent; business nontaxes, 3 percent.

No one supposes this classification of taxes to be precise. For example, I have myself suggested that at least the portion of the corporate income tax that is levied on regulated utilities probably is passed on in higher prices, causing my capital-land share to be overstated relative to labor. But, with some allowance for offsets, I have regarded the national accounts classification as acceptable.

If Jorgenson and Griliches count indirect taxes as earnings of capital and land because of incidence considerations, this implies that they accept the first three assumptions listed above and reject the fourth in favor of an assumption that the shortrun incidence of indirect taxes rests on capital and land.

For one tax classified as indirect, that on real property, this assumption may be preferable.[16] Indeed, in the context of considering the effect of taxes on the allocation of resources among sectors of the economy, I have myself suggested that one should not consider the impact of the corporate income tax, which bears only on the corporate sector, without simultaneously considering the property tax, which bears most heavily on the principal noncorporate sectors of the private economy: housing and farming [3, pp. 186–187]. It is plausible to argue that neither tax is shifted in the short run. But I see no possible reason to suppose that the short-term incidence of the other components of indirect tax and nontax liability rests on capital and land. These represent the bulk of the category, so I regard addition of indirect taxes to capital-land earnings as mainly an error.[17]

Although counting the difference between factor-cost and market prices as property income raises the Jorgenson-Griliches capital-land share of private domestic GNP by 7.0 percentage points in 1950–62, their actual weight averages only 3.4 percentage points higher than the weight implied by my estimates (with depreciation added) because of their smaller allocation of proprietors' income to property income.

My own estimate of output per unit of input is only moderately sensitive to differences in weights of this magnitude. If I were to substitute their weights for mine, my estimate of the contribution of output per unit of input would be lowered by about 0.08 percentage points.[18] I shall use this number to measure the difference in our results that is due to differences in our division of the weights between labor and capital-land as a whole. However, it should be noted that the Jorgenson-Griliches estimates are much more sensitive than mine to differences in weights because they estimate the

15. The movement over time of gross product at 1958 market prices differs from that of gross product at 1958 factor cost only if the composition of output shifts toward or away from products that were taxed (or subsidized) at above- or below-average rates in 1958. Any difference in movement is not related to share weights in the economy as a whole. (In 2, pp. 15-16, I suggest that if, in the output measure whose growth is analyzed, the components of output are weighted by market prices, such shifts should themselves be treated as a statistical "source" of growth.)

16. Even if this is so, it is an open question whether addition of property taxes to capital-land earnings would, on balance, improve the weights in view of the probable overstatement of the capital-land weight in both our estimates that results from counting "pure profit" and all of the corporate income tax in this share.

17. Inclusion of other, smaller reconciliation items between GNP at market prices and GNP at factor cost in property income seems tenable for only one minor subcomponent: corporate contributions to non-profit organizations.

differential between the increase in capital-land input and labor input to have been far larger than I do. Substitution of my weights for theirs would raise their estimate of output per unit of input much more than 0.08. In the reconciliation I attempt, this extra amount will be reflected in the difference I identify with differences in our measures of changes in inputs.

IV. Allocation of the Total Capital-Land Weight Among Components

THE procedures that Jorgenson and Griliches and I adopt to estimate the contribution of capital and land to growth are similar at the most general level.

The total weight of capital and land is first divided among types of capital and land in proportion to the estimated earnings of each type. In my estimates five types are distinguished. One of these, international assets, does not appear in the portion of the economy analyzed by Jorgenson and Griliches. The others are: residential structures and residential land, nonresidential structures and equipment, nonresidential land, and inventories. Jorgenson and Griliches use a different classification. They distinguish among residential structures, nonresidential structures, equipment, residential and nonresidential land, and inventories.

Once the weights are assigned, each component of capital-land is treated as a separate input. An index measuring the quantity of each input must be developed. The weight is then multiplied by the growth rate of the index to arrive at the contribution of each component to growth.[19] (In my case contributions of international assets and, as explained in section V, residential property are calculated by a different procedure that does not require an input index.) The total capital-land contribution is the sum of the contributions of the components. In this section, I consider the weights. Later sections will examine the input indexes.

Because I analyze net product and my total capital-land weight includes only net (after-depreciation) earnings, my total capital-land weight is allocated among types of assets in proportion to their estimated net earnings. Jorgenson and Griliches allocate earnings in two parts. The portion of their capital-land weight corresponding to net (after-depreciation) earnings is allocated by estimates of net earnings, as in my procedure. To net earnings of each type of *depreciable* asset, they add depreciation (replacement in their terminology) in order to obtain gross earnings. This corresponds to their measurement of gross product and inclusion of depreciation in their total capital-land weight. This difference in our weighting procedure is legitimate because we are analyzing the growth of different output measures.

The preceding description of the Jorgenson-Griliches methodology pertains to their final estimates, which incorporate the adjustments introduced in moving from their table V to table VI. The weighting structure they initially use—in their tables I through V—is a mixture in that the total capital-land weight includes depreciation but is allocated among components by net earnings alone.

Use of asset values to allocate net earnings

The total weight of capital and land (excluding depreciation in the Jorgenson-Griliches estimates) is, as I have indicated, divided among components in proportion to their net earnings. But first the earnings of each component must be estimated, and this requires some assumptions.

The earnings of an enterprise can be measured, but most enterprises use more than one type of capital and land and there is no way to observe directly the earnings of each type. The analyst has no alternative but to assume that the individual enterprise earns the same rate of return on each.[20] Given this assumption, the total net earnings of capital and land in each enterprise can be distributed among different types of assets in proportion to their value to obtain the earnings of each type.

Jorgenson and Griliches introduce a second assumption: that the rate of return is the same in all enterprises. The two assumptions together permit them to allocate the net earnings of capital-land among types of assets by current asset values in the private economy as a whole. Except for a modification for capital gains and taxes, which I shall discuss shortly, this is their procedure.

The second assumption is not required by the nature of the economy.

18. Substitution of their higher estimates of the labor content of proprietors' income for mine, and addition of all the reconciliation items between GNP at factor cost and GNP at market prices to my estimates of capital-land earnings, would lower my labor share of total national income in 1950–62 from 78.6 to 74.1. By my procedures, the difference of 4.5 percentage points would be allocated among nonresidential structures and equipment, nonresidential land, and inventories in proportion to their present weight. (The weight of other capital-land components is independently derived.) Such a shift in weights would lower my estimate of the contribution of labor input by 0.06 percentage points, raise the contribution of capital by 0.14, and hence lower my estimate of the contribution of output per unit of input to the growth rate of national income in the whole economy in 1950–62 by 0.08. The effect on the growth rate of GNP at factor cost per unit of input in the private domestic sector would be the same, for reasons explained in section I.

19. The actual arithmetic of the Jorgenson-Griliches calculation differs from this description, but it is arithmetically equivalent. Suppose, in a year 1, that in current prices total income and output are $100 and earnings of inventories are $5 (equal to 5 percent of the total weight). Suppose that inventory input is measured by its value in 1958 prices, and this value is $100 in year 1 and $110 (10 percent more) in year 2. The more usual procedure would multiply the 10 percent increase in inventory input by its 5 percent weight, and conclude that the increase in inventories had raised output by 0.5 percent. The Jorgenson-Griliches procedure is to divide the $5 of inventory earnings in year 1 by the $100 of constant-price value in year 1 to obtain a "service price" of 5 cents per unit ($1 of value in 1958 prices) of inventories. The 100 units of inventory input in year 1 and the 110 units in year 2 are then multiplied by 5 cents, yielding $5 in year 1 and $5.50 in year 2. The difference of 50 cents is the contribution of the increase in inventories, and is again equal to 0.5 percent of the year-1 value of output.

20. Jorgenson and Griliches and I each assume statistically, subject to some later qualifications about capital gains and taxes, that, if the rate of return is the same for all types of assets, the ratio of net earnings to net value at current prices is also the same. This is not a wholly satisfactory assumption [2, p. 143, and 3, pp. 28, 112–113, 289–294], but it introduces no discrepancy between our results because we both use it.

If data were available, one could allocate earnings separately for each enterprise and add up the results. If it turned out, for example, that enterprises having a high proportion of their assets in inventories had a higher rate of return, on the average, than enterprises having a high proportion of their assets in fixed capital, this procedure would (I believe appropriately) yield a higher weight for inventories and a lower weight for fixed capital than would a summary allocation of total capital-land earnings in the economy as a whole by the value of different types of assets in the economy as a whole. With the statistics available, this procedure cannot be implemented for individual enterprises. But I have found it possible to introduce what I regard as major improvements in the weighting structure by dealing with groups of enterprises.

(1) The earnings of capital and land used in the provision of housing services—called the "services of dwellings" industry in international compilations—were isolated [2, p. 40].[21] They are almost the same as total earnings in this industry since labor earnings are trivial. Since residential capital and residential land are the only types of capital and land used by this industry, and since (by definition) these assets are not used by any other industry, the earnings of residential capital and land can be unambiguously identified. Actual earnings of residential property are smaller than the estimate that would be obtained if total earnings in the economy as a whole were allocated by asset values, and hence my procedure leaves more weight for the remaining assets.[22]

(2) The net flow of property income from abroad, corresponding to the earnings of international assets, was also isolated; however, once my estimates are adjusted to correspond to the scope of the economy they cover, this procedure does not affect the comparison with Jorgenson and Griliches because income from abroad is outside their sector.

(3) The remaining earnings of capital and land—those arising in the domestic nonhousing sector—were divided between farm and nonfarm components. *Within* each sector, the total was distributed among nonresidential structures and equipment, nonresidential land, and inventories, in proportion to their net value. The estimates for the farm and nonfarm sectors were then added to obtain total earnings for each of these three types of assets. Farming has a lower ratio of earnings to assets than the nonfarm nonresidential sector, and a higher proportion of its assets are in land and a lower proportion in structures and equipment. Hence, the separate attention I give to agriculture results in a lower weight for land and a higher weight for nonresidential structures and equipment than would be obtained if the farm-nonfarm division were not made.

My average weights for the 1950–62 period are shown as percentages of total national income and of total nonlabor income in the first two columns of the following table. The next two columns give similar data for the private domestic sector.

The last column gives a percentage breakdown of the total capital-land weight that corresponds *conceptually* to the percentage distribution of the net (after-depreciation) portion of the Jorgenson-Griliches final weights, except for an adjustment for capital gains and taxes that they introduce. (It also corresponds conceptually to their division of the total gross capital-land weight, including depreciation, used in the construction of their table I.)[23]

Their distributions differ from this statistically, however, because they allocated total net capital-land earnings among components by values in the private domestic economy as a whole, without giving separate attention to the "services of dwellings" and agricultural industries.[24] For this reason, they presumably assigned a much higher proportion than I of the total net capital-land weight to residential structures and to residential and nonresidential land, and a lower proportion to nonresidential structures and equipment and (to a lesser extent) inventories.[25] On balance, the weighting structure for net earnings *within* their capital-land aggregate probably yielded a smaller increase in combined capital-land input, and hence tended to produce a *larger* increase in output per unit of input, than my weights would have done. This is chiefly because land, to which they assign more weight, did not increase.

	Whole economy		Private domestic economy	
	Percent of national income	Percent of capital-land earnings*	Percent of national income*	Percent of capital-land earnings*
International assets	0.6	3		
Residential structures and land	3.5	16	4.3	17
Nonresidential structures and equipment	11.2	52	13.6	54
Nonresidential land	2.9	14	3.5	14
Inventories	3.2	15	3.9	15
Total capital and land	21.4	100	25.3	100

*Approximate.

21. In most Western European countries, the "services of dwellings" is considered a separate industry, for which the necessary data are published. In the United States, this activity is divided between the "real estate" and "farms" industries and not published separately, but it can be approximated from the details of the national accounts worksheets.

22. My precedures avoid the need to further divide the earnings of residential property between structures and sites. If such a breakdown were desired in order to preserve the Jorgenson-Griliches classification of assets, it could be obtained by allocating earnings *within* the housing sector by asset values.

23. Note, however, that Jorgenson and Griliches classify residential land with other land rather than with dwellings. They also subdivide nonresidential structures and equipment.

24. And possibly also because of differences in data used.

25. In their table I, they presumably also assigned a lower proportion of their total weight than I to structures and equipment and a higher proportion to land and inventories because, to arrive at the current value of structures and equipment, they use the double declining balance formula which yields lower values for such assets than the straight-line formula I adopted. In their final gross earnings weights, this difference is more than offset since depreciation is added back to the capital component to which it pertains.

Capital gains

Anticipated capital gains or losses and taxes on income may bias earnings weights derived in the ways I have described if their presence causes the percentage distribution of asset values to diverge from that of earnings within a sector of the economy where the distributions have been assumed to be the same [3, p. 28]. I believe any such bias in my estimates to be trivial, but must devote extended discussion to the topic because Jorgenson and Griliches assign it a central place in their analysis.

I shall consider capital gains first. Jorgenson and Griliches believe the presence of capital gains or losses affects the validity of the assumption that earnings are distributed like asset values. They state: "Asset prices for different investment goods are not proportional to service prices because of differences in . . . rates of capital gain or loss among capital goods" [1, p. 267]. Their idea is that current asset values are proportional to the sum of earnings and capital gains so that allocation of earnings by asset values assigns too much to assets producing large capital gains and too little to assets producing small capital gains or capital losses. They do not discuss the timespan over which capital gains and losses must be cumulated to secure this proportionality, but I presume it is the discounted value of the anticipated stream of earnings and capital gains that would be supposed pertinent.

The relevance of this idea to the actual data we both use must now be explored. It is necessary, I believe, to distinguish sharply between land and reproducible capital. The current value of land is estimated market value; Jorgenson and Griliches and I rely upon Raymond Goldsmith for data. Land prices may and often do reflect not only current earnings related to current marginal products but also the expectation that marginal products will be higher in the future because of increasing land scarcity (relative to other factors). Land is also an inflation hedge and may reflect the expectation of a rise in the general price level as well. Hence, the ratio of current earnings to value may be lower for land than for capital, and allocation of earnings by value may overweight land and underweight capital.

The case of land has no counterpart within the reproducible capital aggregate. The values Jorgenson and Griliches and I use for capital components are their current replacement costs, estimated by use of price indexes for new equipment, structures, and goods held in inventory. These values are firmly anchored to the present price level and present production costs of capital goods and are not affected by capital gains. (Actually, I doubt that it would matter if the values were true market values, since there is no general reason for these to depart from reproduction costs.) Therefore I see no reason to suppose the allocation of weights among structures, equipment, and inventories is biased by capital gains.

As indicated, land may be overweighted and all the capital components correspondingly underweighted because of capital gains. But if this is true of my weights, the bias must be slight. My weight for dwellings and dwelling sites (including vacant lots, which yield no current income) is completely unaffected because it is based directly on earnings, excluding capital gains, and my procedure does not require a division of this weight between dwellings and their sites. Division of total earnings between farm and nonfarm industries greatly reduces any possible overweighting of private *nonresidential* land. In addition, I used conservative estimates of the value of land (Goldsmith's earlier, rather than later and higher, estimates). Finally, the weight I assigned nonresidential land is so small that it could be reduced even radically with no great effect. If it were cut 40 percent, for example, and this weight reassigned to nonresidential structures, equipment, and inventories, my estimate of the contribution of output per unit of input would fall by only 0.04 percentage points in 1950–62.

If capital gains bias weights obtained from a distribution by asset values, the Jorgenson-Griliches weights, prior to their attempted correction, are subject to larger error than mine because they do not isolate earnings in the "services of dwellings" and agricultural industries in which land is very important.

Jorgenson and Griliches attempt to eliminate the bias that they presume would otherwise enter their weights by introducing a formula that is based on the assumption that, each year, values of types of capital and land are proportional to the sum of the earnings and capital gains derived from them in that year.

The formula can best be understood with the aid of an arithmetic example. Assume for some year the arbitrarily selected data for the private domestic economy shown in the following table. (The table will be used again, and includes some numbers not needed as yet.) For simplicity, I let the data refer to the base year for deflation so that asset values are the same in current and constant prices. The first column gives data based on "true" depreciation (replacement) as estimated by Jorgenson and Griliches; the second, on capital consumption as shown in the national income estimates. Only two types of capital—equipment and inventories—are present, and each has a value of $50,000. (Residential and nonresidential structures are handled like equipment in the formula, and land, like inventories.) During the year, there is a capital gain (realized and unrealized) of $1,500 on the stock of equipment and $500 on inventories. The problem is to divide the total

	Jorgenson-Griliches basis	National accounts basis
Income and product account:		
Sales (equal GNP at market prices)	$60,000	$60,000
Labor earnings	45,000	45,000
Gross capital earnings [a]	15,000	15,000
Depreciation on equipment	7,000	5,000
Interest and profit [a]	8,000	10,000
Interest	1,000	1,000
Profit before tax [a]	7,000	9,000
Corporate income tax [b]	3,333	3,333
Profit less corporate income tax [a]	3,667	5,667
Addenda:		
Value of capital	100,000	----------
Equipment	50,000	----------
Inventories	50,000	----------
Capital gains	2,000	----------
Equipment	1,500	----------
Inventories	500	----------

[a] Includes indirect business taxes and other reconciliation items between factor cost and market price valuation for consistency with the Jorgenson-Griliches classification.
[b] Includes tax on capital gains.

Jorgenson-Griliches gross capital earnings weight of $15,000 (or 25 percent of the total input weight of $60,000) between equipment and inventories when the Jorgenson-Griliches estimate of "true" depreciation is accepted.

The usual procedure would assign to equipment the $7,000 of depreciation on equipment, and divide the $8,000 of net earnings between equipment and inventories in proportion to their values—in the example, $4,000 each.[26] The total weight of equipment is then $11,000 and of inventories $4,000.

In the absence of a corporation income tax, Jorgenson and Griliches would compute the weight (they call it the "service price") for the $50,000 value of each of the two assets by the following formula [1, p. 256]:

$$p_k=q_k\left[r+\delta_k-\frac{\dot{q}_k}{q_k}\right]$$

where p_k is the price of the k^{th} capital service, q_k is the price of the k^{th} investment good, r is the rate of return, net of "true" depreciation but inclusive of capital gains, on all capital, δ_k is the "instantaneous rate of replacement of the k^{th} investment good" (i.e., the ratio of depreciation to net value), and $\frac{\dot{q}_k}{q_k}$ is the ratio of the capital gain on the k^{th} investment good to the value of that good.

If there were no capital gains in my example ($\dot{q}_k$ would then be zero for both equipment and inventories), this formula would yield the same weights as the simple procedure: $11,000 for equipment and $4,000 for inventories. The price of $50,000 of equipment would be calculated as

$$\$50{,}000\left[\frac{8{,}000}{100{,}000}+\frac{7{,}000}{50{,}000}-\frac{0}{50{,}000}\right]$$

or $11,000.

The price of $50,000 of inventories would be calculated as

$$\$50{,}000\left[\frac{8{,}000}{100{,}000}+\frac{0}{50{,}000}-\frac{0}{50{,}000}\right]$$

or $4,000.

The example actually assumes capital gains of $2,000, of which $1,500 is on equipment holdings and $500 on inventory holdings. When these are introduced, the weights (service prices) shift toward inventories, which have a lower rate of capital gain. The estimated price (earnings) of $50,000 of equipment becomes

$$\$50{,}000\left[\frac{8{,}000+2{,}000}{100{,}000}+\frac{7{,}000}{50{,}000}-\frac{1{,}500}{50{,}000}\right]$$

or $10,500.

The price of $50,000 of inventories becomes

$$\$50{,}000\left[\frac{8{,}000+2{,}000}{100{,}000}+\frac{0}{50{,}000}-\frac{500}{50{,}000}\right]$$

or $4,500.

The assumption of the calculation is that asset values each year are proportional to the sum of net (after-depreciation) earnings and capital gains in that year.[27] Jorgenson and Griliches base their weights (service prices) for each year on such a calculation (or rather a more complicated one to which I shall come shortly) for that year.

I find it impossible to believe that the procedure adopted by Jorgenson and Griliches actually improves the weights. It might be appropriate to apply the Jorgenson-Griliches assumption that values are proportional to the sum of net earnings and capital gains—but only with the use of average capital gains over long periods of time to adjust earlier years—if (1) asset values used in the calculations were independently obtained sales values and (2) substantially different rates of capital gain on different types of capital were forecast by firms and (3) their forecasts were accurate. But the second condition is unlikely and the third so restrictive that I doubt the procedure would be an improvement even if the first condition were met. Actually, the first condition is not met; as already noted, the capital stock values used are not market values but current reproduction costs that are not affected (except very indirectly and irrelevantly) by prospective capital gains. Consequently, the bias that Jorgenson and Griliches seek to eliminate is not present in the original data.[28] Their capital gains adjustment thus introduces a bias in the opposite direction—that is, it overweights capital assets on which capital gains are small.

Even if all three conditions were met, the relevance of an annual calculation would elude me. Since capital gains are highly erratic from year to year, the weights must also change erratically from year to year. It could hardly be argued that market prices of capital goods and land fluctuate annually so as to maintain proportionality between capital values and the sum of earnings and capital gains each year, nor could firms adjust the composition of their real assets annually even if they could foresee the pattern of each year's capital gains and losses. The supposed error in the use of asset values to derive weights for a year could have no relationship at all to the size of capital gains in that year.

Tax on corporate profits

I turn now from capital gains to taxes on income. Jorgenson and Griliches consider only the tax on corporate profits. It is sometimes argued that the presence of this tax leads to allocation of resources in such a way as to cause the after-tax rate of return in the corporate sector to be the same as, and hence the before-tax rate of return higher than, that in the noncorporate sector.

Because earnings from all types of capital and land used by corporations are taxed alike, it is easy to avoid any bias from this source in the distribution of capital-land earnings (which include this tax) among types of assets if asset values are available separately for corporations. One need only allocate earnings of capital and land in the taxed corporate sector in proportion to asset values in corporations, to allocate earnings in the untaxed noncorporate sector in proportion to noncorporate asset values, and then to add the two

26. I follow here the Jorgenson-Griliches procedure of counting indirect taxes, etc., as part of the net earnings component.

27. The calculation implies net earnings of $3,500 and capital gain of $1,500 for equipment, and net earnings of $4,500 and capital gain of $500 for inventories.

28. Except perhaps for the division of the weight between land, on the one hand, and the four capital components as a group, on the other.

distributions to secure the final earnings estimates for use as weights. This procedure avoids any bias from the tax whether the tax diverts resources from the corporate to the noncorporate sector or does not.

My estimates do treat separately two sectors that are overwhelmingly noncorporate: housing and agriculture. However, the combined earnings of corporate and noncorporate firms within the nonfarm nonhousing sector were allocated by their combined asset values. This introduces an error into my weights for nonresidential structures and equipment, inventories, and nonresidential land if both (1) the rate of return after tax (rather than before tax) was the same for corporate and noncorporate firms, and (2) the percentage distribution of assets among the three types was different in corporate and noncorporate firms. The first condition would mean that before-tax earnings per dollar of value of each type of capital and land are higher in corporations than in noncorporate firms. If this is so, and if the second condition is also met, failure to allocate capital-land earnings of corporate and noncorporate firms (within the nonfarm nonhousing sector) separately would yield too large an estimate for earnings of types of assets used most by noncorporate firms and too small an estimate for types used most by corporations. However, the distribution of assets in noncorporate nonfarm firms could scarcely differ enough from that in nonfarm corporations to introduce an error of appreciable size.

Because Jorgenson and Griliches make a single allocation for the whole private domestic economy, without isolating housing and agriculture, the potential bias in their estimates is much larger and extends to residential as well as nonresidential capital and land. The direct way for them to remove the potential bias would be to make separate allocations of earnings in corporate and noncorporate sectors. An indirect way, having no advantage because it requires the same information, would be to increase the weight attached to corporate assets by (1) raising the value of corporate holdings of each type of asset by the ratio of after-tax earnings to before-tax earnings in corporations; (2) adding the resulting adjusted value of corporate holdings to the unadjusted value of noncorporate holdings of each type of asset; and (3) allocating combined corporate and noncorporate before-tax capital-land earnings among types of capital and land in proportion to the adjusted asset values so obtained. I surmise that Jorgenson and Griliches may have had this in mind when they introduced their formula for the determination of service prices in the presence of a direct tax on income.

This formula, which is used in their actual calculations in place of the simpler formula already discussed, is quite complex because it tries to deal simultaneously with capital gains and the corporate income tax, including the effects of differential taxation of capital gains. I believe the formula is intended to allocate earnings among types of capital and land on the assumption that asset values each year are proportional to the sum of net (after depreciation) earnings and capital gains in that year when earnings and capital gains from each type of asset are each measured after deduction of the corporate income tax applicable to them.

The formula, which I shall now describe, does not actually do this. In fact, it does nothing at all to remove the bias, just discussed, that allocative effects of the corporate income tax may be presumed to introduce. The reason is that Jorgenson and Griliches apply the *same* ratio of before-tax earnings to after-tax earnings (the average ratio for the whole private economy) to both corporate and noncorporate assets instead of using the corporate ratio for corporate assets and a ratio of one for noncorporate assets.

Introduction of new terms does not improve the results obtained by the simpler no-tax formula already described but instead compounds the errors. In particular, it accentuates the erroneous shift of the weights from capital-land components on which capital gain is high to those on which capital gain is small. In addition, it shifts weight from depreciable assets to land and inventories if (as is the case) "true" depreciation as measured by Jorgenson and Griliches exceeds capital consumption allowances as measured in the national accounts (which they use as a proxy for depreciation allowable for tax purposes). I presume their purpose in doing this is to allow for supposed effects of taxing depreciable assets on amounts that represent recovery of capital rather than true earnings, but defects in their formula and measurements make the amounts shifted haphazard.

The formula [1, p. 267, formula 11] is:

$$p_k=q_k\left[\frac{1-uv}{1-u}r+\frac{1-uw}{1-u}\delta_k-\frac{1-ux}{1-u}\frac{\dot{q}_k}{q_k}\right].$$

The definitions of the terms [as given in 1, pp. 256, 267, and 277–279 and in correspondence from the authors] and their values for equipment and for inventories in my example above are as follows:

p_k is the price of the k^{th} capital service. In using the example, I let it refer for convenience to the price of the service of $50,000 worth of equipment, and of $50,000 worth of inventories.

q_k is the price of the k^{th} investment good. In the example, it is $50,000 for equipment and $50,000 for inventories.

u is the ratio of corporate profits tax liability to profits before taxes in the private domestic sector of the economy.

Corporate profits tax liability is taken from the national accounts. It includes tax liability incurred because of inventory profits and other capital gains.

"Profits before taxes" in the private domestic sector are measured as property income (Jorgenson-Griliches definition) less capital consumption allowances and private domestic net interest, both taken from the national accounts. Profits before taxes are therefore equal to the sum of "corporate profits and inventory valuation adjustment" in the domestic sector, the proportion of "proprietors' income" not allocated to labor, the "rental income of persons," "indirect business tax and nontax liability," "business transfer payments," and "statistical discrepancy," minus "subsidies less current surplus of government enterprises." [29]

If the reason that Jorgenson and Griliches count indirect taxes as capital-land earnings is a belief that their shortrun incidence is on this share, one would also expect indirect taxes to be counted as taxes on these earnings. This is not done; indirect taxes are not counted as taxes on income but as part of income after tax.

This variable is the same for each type of asset, regardless of its distribution between the corporate and noncorporate sectors. In the example,

$$u=\frac{3,333}{9,000}=.3704.$$

r is the ratio of (a) total income from property less profits tax liability less the current value of replacement plus the current value of capital gain to (b) the current value of capital stock. It is the same for all types of capital and land. In the example,

$$r=\frac{15,000-3,333-7,000+2,000}{100,000}=.06667.$$

v is the ratio of private domestic net interest to the after-tax rate of return, r, multiplied by the current value of the capital stock. It is the same for all types of capital and land. In the example,

$$v=\frac{1,000}{.06667\times 100,000}=.15.$$

w is the proportion of "true" replacement (depreciation) that is allowable for tax purposes. Jorgenson and Griliches obtain this proportion as the ratio of capital consumption allowances, as measured in the national accounts, to their estimates of depreciation (replacement). They use the same ratio for all types of depreciable assets (residential structures, nonresidential structures, and equipment). For equipment in the example,

$$w=\frac{5,000}{7,000}=.7143.$$

No value is needed for inventories (or land).

δ_k is the rate of replacement (depreciation) of the k^{th} investment good. For equipment in the example,

$$\delta_k=\frac{7,000}{50,000}=.14.$$

No value is needed for inventories.

x is defined as the proportion of capital gains included in income for tax purposes. However, Jorgenson and Griliches inform me that, in their calculations, x actually was assumed to be zero for all types of assets.[30]

$\frac{\dot{q}_k}{q_k}$ is the rate of capital gain on the k^{th} investment good. I defer a description of the derivation of $\dot{q}_k$. In the example, the ratio is

$$\frac{1,500}{50,000}=.03 \text{ for equipment,}$$

and

$$\frac{500}{50,000}=.01 \text{ for inventories.}$$

When the values derived from the example are inserted, weights of $10,794 for equipment and $4,206 for inventories are obtained. For equipment p_k equals:

$$\$50,000\left[\frac{1-(.3704\times.15)}{1-.3704}\times.06667+\frac{1-(.3704\times.7143)}{1-.3704}\times.14-\frac{1-(.3704\times 0)}{1-.3704}\times.03\right]=\$10,794.$$

For inventories, p_k equals:

$$\$50,000\left[\frac{1-(.3704\times.15)}{1-.3704}\times.06667+.00-\frac{1-(.3704\times 0)}{1-.3704}\times.01\right]=\$4,206.$$

Effects of the formula

It is informative to recapitulate results from the example, and insert the results of one additional calculation. When no account was taken of capital gains or taxes, weights of $11,000 for equipment and $4,000 for inventories were obtained. Use of the no-tax formula to allow for capital gains shifted the weights to $10,500 and $4,500. If tax depreciation had been the same as true depreciation in the example, substitution of the formula with taxes present would have further shifted the weights to $10,046 and $4,954, this change reflecting the Jorgenson-Griliches assumption that capital gains are tax free.[31] With allowance, in addition, for taxation of part of "true" depreciation on equipment, the weight of equipment is raised to $10,794 and that of inventories reduced to $4,206. The particular numbers reflect only the figures assumed in the example, of course, but the direction of the changes at each

29. As originally printed, the Jorgenson-Griliches article stated that "the variable u, the rate of direct taxation, is the ratio of profits tax liability to profits before taxes for the corporate sector. These data are from the U.S. national accounts" [1, p. 277]. This definition, though logical if u were to be used only for corporate assets, would make the equation as it stands wholly inconsistent.

30. In their article this is not really clear. They write only that "the proportion of capital gains included in income is zero by the conventions of the U.S. national accounts" [1, p. 267]. This must be interpreted to mean that "the variable x, the proportion of capital gains included in income for tax purposes (but not the value of capital gains as they appear elsewhere in the formula) is zero." The two statements are unrelated, and while the first is true, the second is not. Some capital gains (the inventory valuation adjustment in particular) are fully, and others partly, taxed. Jorgenson and Griliches include these taxes in the numerator of u, which has the effect of charging them to earnings instead of to capital gains. With x equal to zero, $-ux$ in the numerator of the last term of the formula could be omitted without changing the results.

31. This calculation uses only the column in the example headed "Jorgenson-Griliches." The values of the variables are the same as those just given except that u is .4761 instead of .3704, and w (for equipment) is 1 instead of .7143.

step helps to explain just what the formula does to the weights. I have already pointed out the main consequences.

The Jorgenson-Griliches formula may have theoretical interest.[32] But as they have applied it, it is hardly to be taken seriously as a tool for statistical analysis. The alterations in weights, away from assets with large capital gains, that would be introduced by their simple "tax-absent" formula are untenable. If they were tenable, the additional changes introduced by their "tax-present" formula would not be. The only bias potentially introduced by the corporate income tax (except by differential taxation of earnings and capital gains) is not affected. The overall corporate tax rate, u, as measured, is meaningless. It also is obviously wrong to assume that this tax bears as heavily upon dwellings and land as upon other assets. How indirect taxes can be counted as part of before-tax capital-land earnings but not as a tax on these earnings defies my understanding. Capital gains are not actually taxed at zero, as is assumed; they are taxed at a wide range of effective rates, ranging up to full taxation of the nonfarm inventory valuation adjustment. The fraction of depreciation (replacement) as measured by Jorgenson and Griliches that is taxable is not the same for all types of depreciable assets, as is assumed; the ratio of reproduction cost to original cost varies greatly between long-lived structures and short-lived equipment, and the proportions of these assets on which fast depreciation is allowed also varies greatly in the later years of their period.[33] Furthermore, much of the depreciation in the national accounts (particularly that on most dwellings) has no tax relevance at all (and farm depreciation is already on a replacement-cost basis). But these objections are, of course, largely superfluous if I am correct in asserting that the capital gains adjustment is itself a mistake.

Estimates of capital gains

The estimates of capital gains used by Jorgenson and Griliches that underlie the whole analysis are themselves subject to considerable criticism. The capital gain on any type of asset in a year is properly the difference between (a) the change in the value of holdings of the asset from the beginning to the end of the year, and (b) the value of the change in the quantity of the asset, measured in current prices. This figure can be approximated within an acceptable error by multiplying the value of the asset at the beginning of the year by the percentage change during the year in a price index for the stock of the asset.

Jorgenson and Griliches inform me that they used the former of these methods to secure capital gains on land, utilizing data from Raymond W. Goldsmith. For the capital items, however, they use neither of these measures. They write: "The capital gain for each asset is the product of the rate of growth of the corresponding *investment* deflator and the value of the asset in constant prices of 1958" [1, p. 279, italics added]. This differs from proper procedure in two respects. First, they measure changes in prices from the average of one year to the average of the next, instead of from the beginning to the end of the year. This is important for their annual series, but probably washes out over a period of years. Second, and more important, they use the implicit deflator for investment instead of the implicit deflator for the capital stock. This procedure yields an accurate approximation of the capital gain only if the two deflators are the same. They are the same if, but only if, the composition of the stock of an asset is the same as the composition of investment in it during each of the years compared—gross investment in the case of depreciable assets, net investment in the case of inventories. Only in this case are the weights appropriate for a capital stock price index the same as those that underlie the investment price index.

In the national accounts framework, this condition is met only for residential structures, which are treated as a single commodity both in deflation of investment and in building up a capital stock series. It is not met for nonresidential structures or for producers' durables, for each of which deflation is performed in considerable detail.[34] It is wildly not met for inventories; the composition of inventory change is usually very different from that of the stock of inventories. Moreover, the composition of inventory change varies greatly from year to year. As a consequence of this (together with the fact that, on a 1958 base, the levels of price indexes for different inventory components diverge greatly as one moves away from 1958), the implicit deflator for the change in inventories properly moves very erratically, especially in years far removed from 1958, even though the deflator for the stock of inventories moves smoothly. Jorgenson and Griliches note and dislike these wild movements. But instead of correcting their method to use the deflator for the stock of inventories instead of inventory change, they arbitrarily alter the deflator for inventory change by substituting the consumption deflator.

Depreciation

When an investment yielding a positive gross return is made, gross output is increased, depreciation is increased, and net output is increased by the difference between the two, which is the net product of the investment. If one were interested in analyzing the growth of both gross and net product, he could proceed in any of three ways. (1) He could analyze the growth of net product using net earnings weights (as I did in *Why Growth Rates Differ*), and add constant-price depreciation to output and to the contribution of capital in order to analyze gross product (as I did in section I of this paper). When I apply this method to the private domestic sector covered by Jorgenson and Griliches, my estimates yield the following results:

	Growth rate of output	Contribution of inputs	Contribution of output per unit of input
Net product	3.23	1.72	1.51
Gross product	3.35	1.97	1.38

32. However, if the formula is viewed as a theoretical construct rather than a description of their procedures, u, v, w, and x should all carry the subscript k since they differ for each asset type.

33. Tax depreciation differs from the Jorgenson-Griliches estimate of true depreciation chiefly because original cost is not the same as reproduction cost and because double declining balance depreciation is not allowed or, if allowed, is not used by taxpayers because they do not think it to be to their advantage.

34. The fact that Jorgenson and Griliches treat each of these as a single commodity, with a single service life, in constructing capital stock series does not suffice to remove the objection.

(2) He could analyze the growth of gross product using gross earnings weights (as Jorgenson and Griliches do), and subtract constant-price depreciation from output and from the contribution of capital in order to analyze net product. (3) He could analyze the growth of net product using net earnings weights and the growth of gross product using gross earnings weights. The three procedures are exactly equivalent only in special circumstances, but their results are not likely, in practice, to diverge very much. To explore the considerations involved in the choice would take me far afield, and I content myself with the assertion that, to measure net product, it is better to use net product weights than to follow the second alternative.

Jorgenson and Griliches [1, p. 257] criticize John W. Kendrick for not using service prices as his weights. They are wrong. Kendrick analyzed growth of net product and appropriately used net earnings weights. To include depreciation in the weights in an analysis of the growth of net product, as Jorgenson and Griliches insist he should do, would be a plain error that would lead to overstatement of the contribution of capital to growth.[35] That the other aspect of their service prices—their capital gains and tax adjustment—would have improved his estimates is just not credible on the basis of my preceding discussion.

Effect of differences in weights

When Jorgenson and Griliches adjust their initial estimates to use what they call "prices of capital services" in their calculations, they raise their 1950–62 growth rate of total input, and lower that of output per unit of input, by 0.35 percentage points [computed from 1, tables V and VI]. This number combines the effects of two changes from their initial estimates. First, Jorgenson and Griliches remove an error present in their initial weights. Whereas they initially allocate the depreciation component of their gross capital-land earnings weight like net earnings, they now allocate it correctly by depreciation. Second, they introduce the adjustment for capital gains and corporate income tax that I have described. The portion of the 0.35 percentage points that results from the reallocation of depreciation does not represent a discrepancy between their estimates and mine of the contribution of output per unit of input to GNP growth in the private domestic sector. I cannot isolate this portion but it is clearly substantial and, like the combined adjustment, positive. The portion that results from the adjustment for capital gains and taxes does cause a discrepancy, but I cannot isolate the amount nor even be sure whether it is positive or negative.[36] Neither can I calculate the discrepancy between our results (not necessarily included in the 0.35) that is introduced by my according separate treatment to housing and agriculture. Hence, I cannot measure the difference in our output per unit of input series that resulted from the difference in our allocation of the total capital-land weight among components, and this introduces a gap into the reconciliation table I provide in section IX.[37]

Consideration of the bearing of the Jorgenson-Griliches discussion of service prices upon my own estimates suggests only one qualification of my procedures. This is the possibility, already examined, that I may slightly bias my results by overweighting nonresidential land.

V. The Measurement of Capital-Land Inputs (Excluding the "Utilization" Adjustment)

I turn now to input series for the various types of capital and land. This section compares my estimates with those of Jorgenson and Griliches after their adjustment for what they call "errors" in investment goods prices, but not for changes in "utilization." Their "utilization" adjustment will be discussed separately in section VII.

Nonresidential land

Jorgenson and Griliches and I each estimate the input of nonresidential land to have been constant over the period.[38] Its contribution to growth is therefore zero in both series.[39]

Inventories

To measure inventory input, I use the OBE series for the value of farm and nonfarm inventories in 1958 prices; this is the series that is consistent with the annual changes published in the national accounts. The growth rate of this series times the inventory share of national income equals the contribution of inventories to growth.

Jorgenson and Griliches initially use a conceptually similar, but statistically different, series obtained by starting with a base-year value and cumulating annual changes published in the national accounts. They then introduce a certainly erroneous change in the price deflator; they substitute for the inventory deflator the deflator for personal consumption expenditures. This error is apparently a byproduct of their faulty procedure for measuring capital

35. Unless the second alternative listed above were to be adopted, which Jorgenson and Griliches do not suggest.

There have been some studies of gross product that have included depreciation in the weight of capital and land as a whole but have allocated it among components by value of the stock. The Jorgenson-Griliches criticism of this procedure (which corresponds to theirs in construction of their table 1) is correct.

36. The percentage division of the Jorgenson-Griliches gross capital-land earnings weight between net earnings and depreciation also affects the results. It may or may not differ appreciably from mine. Their depreciation is presumably larger because they use the double declining balance instead of the straight-line formula. But their net earnings are also larger because they include indirect taxes.

37. The combined effect of this and certain other differences is estimated in section IX to be 0.33 percentage points.

38. Their estimates combine residential with nonresidential land. Perhaps they would assume some slight decrease in nonresidential land and an increase in residential land if they were to make the distinction.

39. Because of differences in the *weight* assigned to this nongrowing factor, already discussed, this does *not* mean that land does not affect our results.

gains, which I have already discussed.

Growth rates of the stock of inventories from 1950 to 1962 are 3.00 for my series [2, p. 190], 4.06 for their initial series, and 4.14 for their series after the price substitution (both computed from 1950 and 1962 values in 1958 prices provided by Jorgenson and Griliches). The initial Jorgenson-Griliches inventory series increases by about the same *absolute* number of 1958 dollars as mine. Its much larger *percentage* change and growth rate reflect a much lower figure for the base-year value of the stock; their series for total inventories runs at a bit lower level than the OBE series for nonfarm inventories alone. The data they use for level and change are evidently inconsistent.

The difference of 1.14 points between their final inventory growth rate and mine accounts for 0.04 percentage points of the difference between our estimates of output per unit of input growth, based on my share weights; the amount based on their share weights would probably be about the same. Of the divergence, 0.03 is due to the low level of their inventory series; this is raised to 0.04 by their price adjustment.

Nonresidential structures and equipment: Denison series

One's choice of a capital stock series to measure input of nonresidential structures and equipment necessarily depends on his judgment as to whether or not the ability of a capital good to contribute to production declines during its actual service life because it performs less well, requires more maintenance, or is installed in a less optimal use than it was initially as a result of demand shifts and the like; and, if it does decline, by how much and in what time pattern. Gross stock (the value of the stock without deduction for accumulated depreciation) provides an appropriate measure if there is no decline. Use of a net stock series is always inappropriate on theoretical grounds; net value drops as the length of the remaining service life declines, and this has no relevance to ability to contribute to production currently. In *Why Growth Rates Differ*, I assumed that the ability of capital goods to contribute to production typically does decline during their service lives but not very much. I suggested [2, pp. 140–141] that if one weighted the growth rate of gross stock about 3, and that of net stock based on straight-line depreciation about 1, he would obtain a series that might reasonably approximate the decline in the ability of capital goods to contribute to production as they grow older. To give some weight to net stock in this way is merely a convenient method of introducing a declining pattern.

In my actual estimates, I gave *equal* weight to gross stock, based on Bulletin F lives, and to net stock, based on Bulletin F lives and straight-line depreciation. (For the 1950–62 period, but not the subperiods, estimates of the contribution of capital to growth with the capital stock data I had were actually the same whether gross stock or net stock was used, so that the weights actually did not matter for the whole period.) I did so partly because I feared the gross stock series then available to me was unduly sensitive to possible errors in estimated service lives as a result of its construction with but little detail and without a distribution of retirements, and I wished to reduce this sensitivity; and partly because of the needs of international comparisons [2, pp. 140–141].

My estimates were made before the latest OBE capital stock study was completed. Before I continue this section, the change that use of the new OBE data would introduce into my estimates needs examination. Had the OBE study been completed, I would have used OBE capital stock series based on Bulletin F lives, on use of the Winfrey distribution for retirements, and on use of the OBE "price deflation II."

Growth rates of the stock of nonresidential structures and equipment from 1950 to 1962 computed from five measures, and my estimates of the contribution of structures and equipment to the growth rate based on each, are as follows: [40]

Nonresidential structures and equipment capital stock series	Growth rate (percent)	Contribution to growth rate of national income (percentage points)
Average of gross and net stock series, equal weights:		
1. Used in *Why Growth Rates Differ*	3.74	0.43
2. OBE revised—Deflation I	3.24	.37
3. OBE revised—Deflation II	3.51	.40
Average of gross stock (weighted 3) and net stock (weighted 1):		
4. OBE revised—Deflation II	3.40	.39

Row 1 shows the estimates I actually used. Row 2 shows that the incorporation of revised OBE data, based on Bulletin F lives, straight line depreciation, and the Winfrey distribution, but retaining the same deflators (OBE Deflation I) as the estimates I actually used, would lower my estimate of the contribution of capital to growth by 0.06 percentage points. The change is due mainly to the use of much more detail in the calculation of stocks. Row 3 shows that substitution of OBE's series based on their Deflation II for nonresidential structures would yield a contribution of capital 0.03 percentage points higher than does use of their Deflation I series. (I shall comment on the difference shortly.) After this substitution, the contribution of nonresidential structures and equipment based on revised data remains 0.03 points lower than the estimate I actually used.

Given estimates incorporating the Winfrey distribution and the use of considerable commodity detail, and in the absence of international comparisons, I would weight gross stock about three and net stock (based on straight line depreciation) one, instead of assigning equal weights. This would yield a contribution of 0.39 points (row 4) and would lower the estimates I actually used for the contribution of capital by 0.04. My estimate for the contribution of output per unit of input is thus 0.04 points too low by reference to the estimate I would now secure by use of the data presently available.

40. The revised OBE data were provided by letter on December 19, 1967. My average 1950–62 weight for nonresidential structures and equipment is 11.2 percent of total input.

Nonresidential structures and equipment: Jorgenson-Griliches series

Jorgenson and Griliches treat nonresidential structures and producers' durables as separate inputs in their estimates. For each, they use the double declining balance formula to obtain a capital stock series. No detail is used for either calculation.

Capital stock series obtained by the double declining balance formula have always heretofore been described as "net stock" series. Estimates of the value of net stock obtained by this formula assume that net value declines rapidly—much more rapidly than the straight line formula assumes. Justification of so rapid a decline in net value has relied on the argument that obsolescence is rapid; this justification seems to require that obsolescence not only shortens service lives (this is reflected in all capital stock series) but also *greatly* accelerates the loss of value during the shortened service life.

Although their method is the same, Jorgenson and Griliches sometimes appear to regard the series they obtain by the double declining balance formula not as a net stock series but as a gross stock series. Thus, in describing the derivation of a capital series, they state [1, p. 255]: "The quantity of new investment goods reduced by the quantity of old investment goods *replaced* must be added to accumulated stocks." And, again: "We assume that the proportion of an investment *replaced* in a given interval of time declines exponentially over time." [Both italics mine.] And they usually (though not on page 277) refer to the value eliminated from the stock each year as "replacement" rather than as depreciation. *If* they mean "replacement" to be construed as equal to discards, they are indeed trying to construct a gross stock series. But if this *is* their intent, their method is certainly odd. I do not know what evidence they would muster to support the assumption (which is also applied, even more improbably, to dwellings) that discards decline exponentially (i.e., are greatest in the first year after purchase or installation and thereafter decline each year). But even if it were true that discards decline exponentially, their exponents (because they use *double* declining balance) apparently are about twice too big to retain the (Bulletin F) average service lives that they initially accept and from which they begin the calculation [1, p. 277]; that is, they greatly cut their own average service lives. Starting with a 15.1-year average service life for equipment, for example, they estimate half the stock has vanished after 5 years, and seven-eighths after 15 years.

Whatever the intent, changing the name does not change the data, and I shall regard the series constructed by Jorgenson and Griliches as measuring what such series have always been regarded as measuring—the net stock based on the double declining balance formula—and what they call "replacement" as an estimate of depreciation. A series based on this formula makes the ability of an individual capital good to contribute to current production drop much faster than seems to me at all plausible. Whatever can be said to justify its use in measuring net value has no relevance to measurement of changes in ability to contribute to current production.

I have puzzled over the Jorgenson-Griliches discussion of why they use their formula [1, p. 255] but have been unable to discern its relevance to the choice of a capital stock series to measure changes in capital input.[41]

It may be necessary to note here that the choice of a particular formula to measure capital depreciation (or "replacement") in the process of computing income share weights, including the net capital values used to allocate total net capital-land earnings among components, in no way dictates that the same formula should be used to construct the capital stock series that is used to indicate changes in capital input over time. Different series not only can be used for the two purposes but, conceptually, must be. For weighting, value must decline as remaining service life diminishes whereas a measure of current services must not do so. Thus, it is entirely consistent to use net stock values to determine weights, and whatever series seems most suitable (including, in particular, gross stock) to measure changes in capital input (or services) over time. Jorgenson and Griliches themselves accept this view when they adjust their capital services for changes in utilization (section VII below) without changing their depreciation.

I wish to stress that the choice of depreciation or replacement formula appropriate for measurement of changes in capital input has nothing to do with "vintages," that is, with the way one wishes to treat quality differences in capital goods that do not reflect a difference in costs and that result in "unmeasured" quality change (or "embodied" technical progress) as time goes on. Use of a fast depreciation formula is not a method of making an allowance for unmeasured quality change. This can be readily seen from the fact that, with any continuous rate of quality improvement in capital goods, net capital stock based on double declining balance depreciation can rise either more or less than gross stock or net stock based on straight line depreciation. From 1950 to 1962, for example, data from the OBE capital stock study show identical percentage changes for net stock when straight line depreciation is used and when the double declining balance method is used.[42]

Jorgenson and Griliches employ series they themselves derive by use of the double declining balance formula. They assign a single service life to all nonresidential structures and to all producers' durables, whereas OBE assigns different lives to each of a large number of components. The growth rate of their value of nonresidential structures and equipment (from the beginning of 1950 to the beginning of 1962) is 0.17 higher than that of the corresponding OBE series. Even so,

41. The Jorgenson-Griliches discussion seems to visualize steady growth of replacement investment, and their rationalization seems to require, in addition, steady growth of new investment. But if gross capital investment grew at a steady rate (and service lives were not changed over time), it would make little or no difference whether an index of gross stock (in the usual sense of the term) or of net stock computed by any of the usual formulas were used to measure capital input. It is only because investment has been irregular—particularly because of depression and war—that the problem of selection has any importance.

42. This is the case whether "constant cost I" or "constant cost II" estimates are compared. Changes are computed from the average of the beginning and end of 1950 to the similar figure for 1962.

in the period examined, their series is not radically different from other measures. The 1950–62 growth rates of the capital stock series they initially obtained (prior to their price substitution) and used in constructing their table I, are 4.11 for equipment, 3.42 for nonresidential structures, and 3.72 for nonresidential structures and equipment combined (computed from data for the value of the stock in 1958 prices provided by Jorgenson and Griliches).

However, in moving from their table II to table IV, Jorgenson and Griliches greatly accelerate the rise in the growth of the equipment stock by deflating past gross investment in producers' durables by the price deflator for consumers' durables instead of that for producers' durables. This substitution raises the 1950–62 growth rate of their equipment stock alone by 1.49 points, to 5.60, and the growth rate of nonresidential structures and equipment combined by 0.62 points, to 4.34 (computed from capital stock data provided by Jorgenson and Griliches).

To justify the substitution, Jorgenson and Griliches state that, for items that appear in both the BLS consumers' price index and the BLS wholesale price index, the retail and wholesale series diverge by roughly the same amount as the composite indexes. They further state that the consumers' price index is better because more money is spent on it.

It is desirable to deflate common components of consumers' expenditures for durable goods and producers' purchases of durable goods by the same deflator, the best available—at least when they are sold by the same outlets on similar terms. But automobiles are the only important common component (as well as the only component of the consumer and wholesale price indexes that is mentioned by Jorgenson and Griliches).[43] And OBE already uses the same (consumers') price series to deflate consumer and business purchases of automobiles. The sharp divergence between the implicit deflators for all consumers' durables and all producers' durables is ascribable to commodities *not* common to the two series. Production processes for the two sets of goods are very different. Consumers' durables, which had the smallest price rise of any sizable product group, are dominated by mass-produced, standardized products. Their exceptional price behavior was due to radio and television receivers, "kitchen and other household appliances," and automobile "tires, tubes, accessories, and parts." Producers' durables, in contrast, are dominated by items produced in small volume, including a large element of individualized, built-to-order items most akin to custom services. I do not see how any inference about changes in prices of producers' durables can be drawn from prices of consumers' durables, or that the latter provide a more relevant comparison with the former than any other prices.

The OBE deflator for producers' durables is, to be sure, subject to substantial error in either direction because the data entering it are incomplete and their reliability low—mainly because so many components are *not* standardized. But there is no a priori presumption that the series is biased upward by reference to the usual price index criteria. I regard this substitution as unwarranted.

It must be stressed that this price substitution cannot be rationalized as an attempt to allow for quality change not involving a difference in costs at a common date ("unmeasured" quality change). Neither the CPI nor the WPI makes any such allowance (nor do any of the GNP deflators).[44]

In contrast to producers' durables, there is a presumption that the deflator for the nonresidential structures portion of GNP is biased upward by reference to usual price index criteria. This is because most components are based on prices of construction materials and labor, rather than on output prices, and hence do not allow for changes in output per man-hour in on-site construction work. This bias has long been recognized, but its size has been hard to appraise.

For use in its capital stock study, OBE developed an alternative nonresidential construction price series that attempts to eliminate this bias, and used it as an alternative to the GNP nonresidential construction price deflator to derive its Deflation II capital stock estimates that I have already mentioned. These estimates differ from OBE's Deflation I estimates only because of the use of a different construction deflator. Jorgenson and Griliches make the same substitution in moving from their table II to table IV. This raises the 1950–62 growth rate of their nonresidential structures series by 0.50 percentage points, from 3.42 to 3.92, and the growth rate of nonresidential structures and equipment combined by 0.28 points, from 3.72 to 4.00 (computed from data provided by Jorgenson and Griliches).[45] The effect on the combined series is almost identical to that (0.27 points) introduced when the similar substitution was made between lines 2 and 3 of the text table above, and the effect upon the growth rate of *total* input when my weights are used is also the same, 0.03 percentage points.[46]

The 4.00 growth rate of the stock of nonresidential structures and equipment obtained by Jorgenson and Griliches when their construction price substitution but not their equipment price substitution is introduced may be compared with the 3.40 growth rate I obtain by use of the revised OBE data with use of Deflation II (text table above). The 0.60 difference reflects both a difference in choice of capital stock series and OBE's greater use of commodity detail. Based on my weights, it accounts for 0.07 percentage points of the difference between us in output per unit of input.

Residential structures and land

My methodology does not require an input series for residential structures

43. Some types of office furniture might be regarded as having a household counterpart, and there are items of trivial importance.

44. In my view, there is no way to do so. But this is a controversial matter that need not be discussed here.

45. With *both* the equipment and construction price substitutions, the 1950–62 growth rate of the Jorgenson-Griliches series for nonresidential structures and equipment is 4.65.

46. Robert J. Gordon has also attempted to construct a series for deflation of nonresidential construction from which the bias has been eliminated. Data he has generously provided me show that substitution of his series for the OBE nonresidential construction deflator would raise the growth rate of a series for the stock of nonresidential structures and equipment (specifically, the gross stock based on Bulletin F lives) by 0.40 percentage points. A change of this size would raise the growth rate of a total input series, based on my weights, by 0.04 percentage points as against the 0.03 indicated by the OBE Deflation II series.

and land. Instead, I isolate the amounts of national income, measured in constant prices, that originated in the "services of dwellings" industry in the same way as the current dollar figures were obtained in deriving share weights. The same procedure can be followed for GNP at factor cost. I find [2, pp. 123–126, 413] that the increase in the stock of dwellings and residential land contributed 0.25 percentage points to the growth rate of national income and 0.32 points to the growth rate of GNP at factor cost from 1950 to 1962.[47] This method of direct measurement, which I first used in [2], is, in my opinion, an important advance in growth analysis. It provides a measure for the contribution of this very large part of the capital-land stock to the growth of output as actually measured that is entirely accurate, except for some slight statistical difficulty in the United States in disentangling the details of the national product estimates. An incidental advantage, it may be noted, is that the figure for the contribution to GNP makes no use of, and consequently cannot be affected by, errors in the price index for residential construction.

Jorgenson and Griliches measure the contribution of residential structures as the growth rate of the dwellings stock times the weight assigned to dwellings—the procedure I used in an earlier study [3]. However, instead of using a gross stock series to measure changes in the services of dwellings, as I did then, they use net stock calculated by the double declining balance formula. It seems to me impossible to suppose that this pattern remotely resembles that of the flow of services of dwellings during their service life. The 1950–62 growth rate of the dwellings stock computed by this formula, as they initially estimate it for use in their table I, is 4.53 (computed from data provided by Jorgenson and Griliches).

The deflator for residential construction may be presumed to have an upward bias for the same reason as the deflator for nonresidential construction. Jorgenson and Griliches attempt to allow for this by deflating residential construction expenditures by the OBE Deflation II series for nonresidential construction in place of the residential construction deflator. This raises the 1950–62 growth rate of their dwellings stock by 0.39 points, from 4.53 to 4.92.[48]

Residential land is combined with other land in the Jorgenson-Griliches procedure. As already indicated, their combined growth rate (and contribution to growth) is zero.

If I had used the Jorgenson-Griliches growth rate for the net stock of dwellings, and multiplied it by *my* share weights, I would have obtained a much lower figure than I did for the contribution of dwellings to growth of total national income: probably around 0.13 percentage points instead of 0.25.[49] My output per unit of input series would then have been raised by about 0.12 points. I am not, unfortunately, able to quantify the effect upon *their* estimates of the difference between us in the measurement of the contribution of housing.

Summary comment

The Jorgenson-Griliches estimates of the contribution of capital and land to GNP growth differ from mine because of (1) differences in weights; (2) differences in the initial method of measuring capital and land inputs, including the difference in method of estimating the contribution of dwellings; (3) their substitutions of price indexes; and (4) a utilization adjustment they introduce. I have already examined the weights (1); discussion of the utilization adjustment (4) is deferred to section VII.

The total effect of all their price substitutions (3) was to raise their 1950–62 growth rate of total input, and lower that of output per unit of input, by 0.23 percentage points [computed from 1, tables II and IV]. This calculation is based on use of their weights. Of this amount, in the neighborhood of 0.07 points derives from adjustment of construction. The remaining 0.16 points are due to substitutions of price series for producers' durables and inventories (almost entirely the former), which I regard as illegitimate. (It is partly offset by an output adjustment described in section VI below.)

The effect of (2), differences in measures of input (*other* than price substitutions for producers' durables and inventories), I can calculate only with the use of my weights—that is, the numbers refer to the change in my series that use of their input indexes would introduce. Of the difference between us in total input and output per unit of input, the difference in our measure of inventory input (excluding their price substitution) accounts for about 0.03 percentage points, and land indexes for none. Their nonresidential structures and equipment series rises enough more than the revised OBE series I would use to account for 0.07 points; both are based on the OBE II construction deflator. The difference in residential structures accounts for *minus* 0.12 points. The difference in capital stock measures (or their equivalent, in the case of dwellings) thus accounts for *minus* 0.02 points of the difference in our output per unit of input measures, based on my weights and apart from the effects of their price substitutions for producers' durables and inventories.

My incorporation of revised OBE data for nonresidential structures and equipment would *add* 0.04 points to the difference between us.

47. The increase in gross product at factor cost, valued in 1958 prices, was put at $15.7 billion.

48. From 1950 to 1962, the Deflation II series rises less than the residential construction deflator, so the substitution implies that the bias in the deflator is *downward* in this period. This accounts for the negative adjustment in the growth rate of output that the following section shows is introduced by this price substitution. Over the longer time span reflected in the capital stock series, the adjustment is in the right direction.

49. This calculation supposes that about one-fourth of the weight I assign to dwellings pertains to sites, as distinguished from structures.

VI. Effect of Price Index Alterations on Output

JORGENSON and Griliches substitute investment price indexes in deflating the investment components of GNP as well as in measuring capital stock. The 1950–62 growth rate of their private domestic GNP is raised by 0.09 percentage points [calculated from 1, tables II and IV] and this partially offsets the deduction from output per unit of input they introduced by substituting prices in capital stock measurement.

To isolate the separate effects of their price substitutions on output, I duplicated their calculations. The breakdown of their adjustment is: producers' durable equipment 0.10; nonresidential structures 0.03; residential structures, −0.03; and inventories, 0.00. (The total, 0.10, presumably differs from their 0.09 because of rounding.) Thus, their entire output adjustment stems, on balance, from the use of consumers' durables prices to deflate producers' durables; none of it results from the legitimate attempt to adjust construction prices.

VII. The Utilization Adjustment for Capital and Land

MORE than half of the difference between our output per unit of input growth rates in 1950–62 results from an adjustment that Jorgenson and Griliches introduce for changes in utilization of capital and land. Their general idea is that the hours per year that capital is used have increased secularly, and that a given percentage increase in capital hours per dollar of capital has the same effect on output as a similar percentage increase in the quantity of capital. Their capital utilization adjustment raises the contribution of their total input series by 0.60 percentage points in their full 1945–65 period and by about 0.58 points in the 1950–62 period.[50] Their method of deriving this adjustment is theoretically unsound, and the statistical procedures they followed to obtain their estimates are altogether untenable. In my view, their capital utilization adjustment should be discarded.

Series for manufacturing equipment powered by electric motors

The starting point for the adjustment was a series contained in a 1963 SURVEY OF CURRENT BUSINESS article by Murray F. Foss [4]. Most production equipment in manufacturing is powered by electric motors. Foss used Census data for electric power consumption and the horsepower of electric motors to estimate the average number of hours per year that electric-power-driven equipment in manufacturing establishments was utilized. He concluded that its utilization increased by an amount on the order of one-third to one-half from the 1920's to the mid-1950's. The dates for which he made actual calculations were the Census years 1929, 1939, and 1954 [4, table 2, line 7]. Growth rates of average equipment hours calculated from his utilization estimates for these years are −0.45 from 1929 to 1939, 2.15 from 1939 to 1954, and 1.10 from 1929 to 1954. Jorgenson and Griliches made a similar comparison of the years 1954 and 1962 [1, table X, line 6]. From 1954 to 1962, the growth rate was 1.33. Jorgenson and Griliches used the 1939–54 rate for all annual changes in the 1945–54 period and the 1954–62 rate for all annual changes after 1954. They thus obtained average rates of increase in utilization of about 1.72 for 1945–65 and 1.60 for 1950–62.

These rates almost certainly are much higher than the trend rate, which is what Jorgenson and Griliches are seeking, or the rate that would be obtained if calculations could be made directly from the terminal years of these periods. The average rate from the depression year 1939 to 1954 must have been greatly raised by the difference in cyclical position; the rate from 1945 or 1950 to 1954 must have been much smaller than the rate over the 1939–54 period as a whole.[51] The rate from 1954, itself a recession year, to 1962 or 1965 probably was also raised by cyclical influences.[52] A minimal downward adjustment of their estimates to eliminate cyclical incomparability in the pre-1954 period could be made by substituting the 1929–54 rate where they use the 1939–54 rate. This would lower the 1945–65 growth rate of utilization from 1.72 to 1.22, and the 1950–62 rate from 1.60 to 1.25. Probably a better procedure would be to use the 1929–62 rate, which is 1.16, as representative of the trend throughout the period, hence for both the 1945–65 and 1950-62 periods; this would cut their 1950–62 rate by more than one-fourth and their

50. The 1945-65 figure of 0.60 points was provided by Jorgenson and Griliches; it can also be approximated from their published data.

The average growth rate of their capital utilization series itself was 1.72 in 1945-65 and 1.60 in 1950-62. (See the following text paragraph.) Multiplication of their 1950-62 growth rate of 1.60 by their average 1950-62 capital-land share of 0.36175 yields an estimated contribution of 0.58 percentage points.

(In this period, the combined contribution of their capital utilization adjustment and the labor hours adjustment was 0.52, thus the contribution of the labor adjustment was apparently about −0.06. I use this figure in section VIII.)

51. Foss himself wrote: "In fact, some of the illustrations in this article suggest that the major change in relative equipment utilization took place during and immediately after World War II, and that changes since then (aside from cyclical movements) have been relatively small" [4, p. 8].

52. Because Jorgenson and Griliches interpolate between far-removed dates rather than use annual estimates, the capital utilization adjustment obviously cannot purport to adjust capital input for shortrun variations in utilization. Jorgenson and Griliches note this and state that it "allows only for the trend in the relative utilization of capital" [1, p. 266]. My objection to their procedure is the same whether one construes their series as representing the trend rate in 1945-65 and 1950-62 or the actual changes from 1945 to 1965 and from 1950 to 1962.

1945-65 rate even more. Overstatement of the increase in this series from the absence of any procedure to deal with the cycle is, however, among the least of my objections to their utilization adjustment, and there is no need to pursue it further.

A second limitation is that the weights used to construct the all-manufacturing utilization series are inappropriate for the use to which Jorgenson and Griliches put it. "Available kilowatt hours of motors" were used as weights to combine utilization ratios for the component industries in obtaining the all-manufacturing utilization series.[53] For use in converting a series for the value of power-driven equipment in manufacturing establishments to a capital input series, the utilization ratios for all manufacturing should be based on the use of the *value* of power-driven equipment in each industry as that industry's weight. This was noted by Foss [4, p. 11] but is not mentioned by Jorgenson and Griliches. A series so constructed is not available for comparison, nor are the value data for power-driven equipment that its construction would require. Perhaps the two sets of weights would yield tolerably similar results; at the 2-digit level, Foss finds, with some exceptions, fair correspondence between distributions of *total fixed* capital and installed horsepower. Nevertheless, the possibility of appreciable error is present in the manufacturing series.

Equipment values are not available for mining either, but similar utilization ratios for the five mineral industries were published separately by Foss. Solely as an illustration that weights *may* matter, I calculated all-mining utilization ratios with alternative proxies for capital values. Use of "available kilowatt hours" as weights yields a 4 percent increase in utilization from 1929 to 1954, whereas use of "electric power consumed by motors" would yield a 16 percent decline. Like the manufacturing series, these calculations used 1929 weights for 1929 and 1954 weights for 1954. I argue subsequently that fixed weight indexes would be more appropriate. I calculated fixed weight indexes using four alternative sets of 1929 weights. Use of "value of machinery and equipment installed during 1929" yields a 14 percent increase in utilization from 1929 to 1954; "available kilowatt hours of motors" a 12 percent increase; "national income originating," a 2 percent increase; and "electric power consumed by motors," a 1 percent decrease. Probably the first two are better proxies than the last two for equipment values, but differences are large and investigation is needed.

In the absence of tests of its effects, the inappropriate weighting of the manufacturing equipment series adds to the reservations about the Jorgenson-Griliches use of this series that is created by their failure to allow for cyclical differences. But there is a fundamental conceptual objection to their use of this series to adjust capital input that would remain if value weights were used and cyclical adjustments were made. To develop this point, I shall proceed as if this had been done.

Conceptual problem of incorporating utilization data

The trend rate of capital utilization provides interesting information. But to integrate this information into the type of classification of growth sources that Jorgenson and Griliches or I employ, one must know the *reasons* that utilization increased and the *amount* due to each reason. Even if one knew exactly how much utilization had changed, in the absence of this additional information he still would not know the amount of the increase in output that (prior to any utilization adjustment) is included in the contribution of input (or any component of input) and the amount that is included in the contribution of output per unit of input. This is a subject that Jorgenson and Griliches do not discuss at all. However, their procedures imply that, prior to the introduction of their capital utilization adjustment, the effects of an increase in capital utilization necessarily appear only in their output per unit of input series.

The average hours "worked" by power-driven equipment in manufacturing establishments (adjusted to eliminate short-term fluctuations) may actually change for quite varied reasons, and these have altogether different implications for the analysis.[54]

1. The effects of some types of change are fully measured by the increase in the capital stock, so that any additional allowance for increased utilization duplicates the change in the capital stock measure. These types can be described as changes in composition of capital, of which three main categories can be distinguished.

(a) At any point in time, producers can select among varieties of equipment with different characteristics that sell at different prices. One characteristic that can be purchased at a higher price is greater reliability: longer use without downtime for regular maintenance or to replace worn-out or defective components or the entire machine. If producers shift to higher priced equipment, average "hours worked" will increase but so will the capital stock series. A priori there is reason to suppose that, as capital has become more abundant relative to labor, the use of more expensive equipment has been one aspect of the rising capital-labor ratio.

(b) At any point in time, different manufacturing industries vary in the hours they use capital. On the assumptions that Jorgenson and Griliches and I accept, the rate of return, as measured by the ratio of net earnings to net value, is, nevertheless, the same in each manufacturing industry. If hours in each industry are unchanged, but the weights of the industries alter, the average hours in manufacturing as a whole will change but capital input should not.

Suppose Industry A and Industry B each have $1 million of equipment, but

53. Foss confirms this statement, which the reader can check by use of Foss's ratios for mineral industries [4, table 5], for which the procedure was similar and for which industry data are shown. For minerals industries, Foss shows a five-industry breakdown. The all-industry utilization ratio in his column 6 is equal to the ratios for the individual industry groups weighted by "available kilowatt hours of motors" as shown in column 2.

54. Not all of these possibilities had occurred to me when I discussed capital utilization in *Why Growth Rates Differ* [2, pp. 154-155]. I would now word that section somewhat differently.

Industry A operates on three labor shifts, or 120 hours a week, and Industry B on one shift of 40 hours, and capital is used during the same time periods. Equilibrium requires the same rate of return in the two industries; otherwise, there would be an incentive for capital to move from one industry to the other. If the rate of return is 10 percent, the product (as indicated by earnings) of the $1 million of equipment in each industry is $100,000. The product of $1 million of equipment per hour it is used in a week must then be three times as high in Industry B as in Industry A ($2,500 against $833.33). This must be the case, or the rates of return would differ. If (because of changes in demand patterns or for other reasons) Industry B gets bigger relative to Industry A, average hours worked by equipment in the two industries combined will decline, whereas if Industry A gets bigger average hours will increase, because Jorgenson and Griliches use a capital utilization series that is constructed with shifting industry weights. They would therefore measure the former development as a decline in equipment input, the latter as an increase. This is a simple "error of aggregation." It results from giving an hour worked by $1 million of equipment in each industry the same weight.

To illustrate, suppose that in a second year the total value of equipment is $2,000,000, as before, but Industry A now has $1,500,000 and Industry B $500,000. Based on the use of capital stock to measure input, without a utilization adjustment, the contribution of equipment to output (in first-year values) remains $200,000; only the division between industries has changed—to $150,000 in Industry A and $50,000 in Industry B. This correct result could also be obtained by correctly weighting hours: The value of equipment (in millions) in each industry is multiplied by average weekly hours, and the contribution to output of an hour worked by $1 million of equipment is counted as $833.33 in Industry A and $2,500 in Industry B. In Industry A, equipment value times hours increased from 120 to 180; multiplication by $833.33 yields an increase in equipment's contribution from $100,000 to $150,000. In Industry B, equipment value times hours dropped from 40 to 20; multiplication by $2,500 yields a drop in the contribution of equipment from $100,000 to $50,000. The total contribution of equipment at first-year values is again $200,000 in both years.

In this example, the Jorgenson-Griliches procedure would erroneously yield an increase in equipment input of 25 percent, instead of no change, because it assigns equal weight to an hour worked in each industry.

Foss has investigated the effects of changes in industry weights in selected periods and concluded that the change in the all-manufacturing utilization ratio he observed chiefly reflected changes in individual industries rather than in industry mix, although he did note that there probably *was* a shift toward continuous process manufacturing industries, particularly aluminum, refined petroleum, and chemicals.

(c) At any point in time, the number of hours that different types of equipment are used varies widely *within* any establishment, firm, or industry. If the composition of assets changes, the average hours worked by all combined will rise or fall even though there is no change for any particular type. The hours for the same type of equipment may also vary among uses, and this distribution may change over time. These cases are identical to that discussed in (b). Greater use does not imply larger earnings per dollar of capital value. Two machines of different types (or of the same type in different uses) must be assumed to contribute equal amounts to production per dollar of value, not per dollar of value mutliplied by hours worked. If this assumption is invalid, rates of return vary and the economic unit is not in equilibrium. The sensitivity of a conglomerate average-hours-worked series to changes in weights of different types of machines, and to changes in weights of different uses of machines, must be high because the range of hours is large. Shifts of this type could well dominate the long-term movement of "average hours" series for individual firms, establishments, and industries.

Unless a capital utilization series can be standardized to eliminate the effects of *all three* types of "mix" changes, it is useless for the purpose to which Jorgenson and Griliches put it. I cannot imagine how such standardization could be achieved. But even if it could, this would surmount only one of the difficulties.

2. The amount of downtime of machines depends in part on the number of workers who operate them (which affects, among other things, the speed of machine operation), their skill, and the care they exercise. It depends also upon the number and skill of the workers who repair machines. The skill of engineers and others employed by equipment suppliers to service customers is often a crucial determinant of the amount of time lost from breakdowns. If machine hours increase because of an increase in the quantity or an improvement in the quality of labor, this is already counted in principle, and one hopes in practice, as a contribution of labor.

3. The amount of downtime depends in part on expenditures for maintenance. A firm presumably attempts to allocate expenditures among maintenance, purchases of new capital goods for replacement, and production labor in such a way as to minimize total cost. Maintenance expenditures may change because the price of maintenance changes relative to prices of capital goods and production workers; in this case, there is no ascertainable contribution to growth. Maintenance expenditures may also change because management devises a better procedure to determine the minimum cost combination. If they increase for this reason, only the *net* benefit remaining after deducting the increase in maintenance costs from the saving in capital and labor costs contributes to an increase in output.[55] Classification of any net benefit is discussed in case 7 below.

4. Downtime depends in part on the inventory of spare parts; any change is already covered as a contribution of

55. Unless output is measured on the Scandinavian "gross-gross-product" basis, which double counts maintenance as well as capital consumption.

inventories. It depends also on the speed with which parts and servicemen can be obtained; this, in turn, depends on capital and labor in the transportation industries, which are already counted as capital and labor input.[56]

5. The hours that machines are used may change because of a change in the average hours worked per worker; in my study I allow, in principle, for this effect in my adjustment of labor input for changes in labor hours of full-time workers [2, p. 61, n. 11]. (I found no significant change in labor hours of full-time workers in the economy as a whole over the period analyzed so this case did not actually affect my estimates.)

6. Machine hours may also change because shift work becomes more or less prevalent *in particular activities*. In my estimates, such a development was regarded as a component source of the change in output per unit of input [2, pp. 152–154, 173–174], and in my international comparisons, I made a specific estimate for this determinant. However, I found no evidence of a significant change in shift work in the United States in 1950–62, and therefore estimated the contribution of changes in shift work to be zero [2, pp. 152–154, 173–174].

7. The hours worked by machines may rise, or in some cases fall, because of advances of knowledge and its dispersion. These may:

(a) Provide more reliable machines without increasing their cost—a development variously described as "unmeasured" quality change in capital goods or "embodied" technical progress. (In practice, "measured" quality change covered in case 1(a) above and "unmeasured" quality change are often intertwined.)

(b) Enable management to make more continuous use of machines. Foss writes:

> "Also of importance over the long run has been the advance in knowledge acquired by management in making more efficient use of machines. One example of this has been the efforts by many firms to smooth out within the year the production peaks which come from seasonal or other short-lived peak loads and which frequently entail the use of standby equipment with relatively low annual utilization. . . . Within particular industries there have undoubtedly been efforts to introduce continuous, automatic operations in which machines tend to be used with a high degree of intensity."

(c) Improve communications and speed transportation of parts and of key personnel needed for repairs, notably by air.

(d) Improve the decisionmaking process generally—notably with respect to determination of the trade-off among costs incurred for maintenance, replacement, downtime, speed of operating machines, waste of materials, and quality of product.

This list of possible reasons for changes in average machine hours may not be exhaustive. But it suffices to make clear that, unless the reasons for changes in capital utilization are known and their effects can be isolated and quantified, data on capital utilization cannot be integrated into a classification of growth sources of the type Jorgenson and Griliches and I use. It is possible that the entire change indicated by the Jorgenson-Griliches series is already reflected in capital and labor input or counterbalanced by higher maintenance costs, and is not a component of the Jorgenson-Griliches output per unit of input series prior to their utilization adjustment, or of my series. Or any or all of it may be a component. Jorgenson and Griliches never mention, and appear unaware of, the range of possibilities.

Among the possible reasons for an increase in capital hours that I have listed, two would or might contribute to a change in output per unit of input as I measure it, and as Jorgenson and Griliches do prior to introduction of their utilization adjustment. The effects of one of these, changes in shift work in particular activities, I estimated [2, pp. 152–154] to be zero in the economy as a whole in 1950–62, though admittedly on the basis of inadequate information; better data may permit more reliable estimation in future years. The other is advances in knowledge and their dispersion. There is no clear presumption that these led to an increase in the hours that capital goods are utilized or that, if they did, the net saving in unit costs bore any systematic relationship to the change in machine hours. But if there was such an effect, it appears in the "advances of knowledge" component of my output per unit of input series. I see scant possibility that it will ever be possible to isolate this effect.

If one could isolate and measure this effect and the shift-work effect, one would have a choice of transferring them to the contribution of capital (evidently the Jorgenson-Griliches preference) or of classifying them as component sources of the growth of output per unit of input. The latter would be my preference because it is not the saving-investment process that governs these income determinants [2, p. 144], and I shall say a little more about this at the end of this article. But it would really make little difference to the sophisticated reader where they were shown because he could move them at will.

The Jorgenson-Griliches estimates

The Jorgenson-Griliches estimates implicitly assume (1) that the utilization series would be unchanged if weighted by value of power-driven machinery and (2) that the entire effect of increased utilization appears in their productivity measure until they make their utilization adjustment, hence that *only* advances in knowledge and changes in shift work *within industries* affected utilization of manufacturing equipment driven by electric motors. Since they do not diminish the growth of their capital stock series by

56. Parts of points 2 to 4 are nicely illustrated by an advertising letter that happened to reach me as I was writing this section. It states:

"Are you aware that the . . . Corporation has for the past fifteen years been providing preventive and corrective maintenance to a growing number of manufacturers and users of electronic and electromechanical devices?

"Our experience in performing both scheduled and emergency service (supported by factory-trained personnel, local stocking of replacement parts, and quick response to emergency calls) aims to improve your operation in terms of lower 'down-time' and higher reliability."

shortening service lives as they increase capital utilization, they also assume (3) that increased utilization does not cause equipment to wear out more rapidly. (If there is such a user cost, the utilization adjustment duplicates their original estimate of the contribution of capital for this reason.)

I know of no reason to accept this set of assumptions. But it is instructive to calculate what the quantitative importance of the change in utilization of power-driven equipment in manufacturing would be if by chance all these assumptions were correct. First, the weight in total input must be calculated. *All* nonresidential structures and equipment represented 13.6 percent of total input in the private domestic economy in 1950–62, according to my net earnings weights. *All* producers' durables in manufacturing establishments represented about 14 percent of the value of the total stock of private nonresidential structures and equipment, hence 1.9 percent of total input. Machinery in manufacturing establishments driven by electric motors represented at the outside 70 percent of the value of the stock of producers' durables in manufacturing establishments in 1950–62, hence at most 1.4 percent of total input. If the utilization of such machinery increased 1.16 percent a year (the figure I suggested earlier as the trend rate of the utilization series), and if an increase in utilization is treated (as Jorgenson and Griliches *do* treat it) as equivalent to the same percentage increase in the quantity of such equipment, this raises the growth rate of total input (net product basis) in the private domestic economy by 0.016 percentage points (1.4 percent of 1.16 percent) and lowers that of output per unit of input by the same amount. This would be my estimate if I were to accept the Jorgenson-Griliches utilization estimates and their three implicit assumptions mentioned in the preceding paragraph (which, of course, I do not). Even with the Jorgenson-Griliches utilization increase of 1.60 percent a year, the contribution is only 0.022 percentage points in 1950–62. If, as in the Jorgenson-Griliches estimates, depreciation is added to the weights, the calculated contribution to gross product growth would probably come up to 0.03.

How do Jorgenson and Griliches get from 0.03 to 0.58? By introducing the "very strong assumption" (their language) that utilization of *all* types of capital and land in *all* activities increased at the same rate as did machinery in manufacturing establishments driven by electric motors! This assumption is not only "very strong"; it is truly magnificent in its implausibility. Utilization of structures, sites, furniture, and office equipment in manufacturing, of office buildings, of physicians' automobiles, of houses and their sites, of railroad stations, of farmland (have the seasons changed?), of inventories (whatever this may mean), of literally everything has increased, and at the same rate as machinery driven by electric motors in manufacturing establishments!

If one is willing to assume that the change in machinery hours in manufacturing was due only to advances in knowledge and changes in shift work within industries, he might perhaps, I suppose, go even further and assume there was some net increase in *machinery* hours outside manufacturing after 1950, and thus raise the figure derived from the manufacturing series a little. Foss found some examples of machinery in nonmanufacturing industries in which utilization increased from the 1920's to the 1950's as well as some where it did not. For example, in two of five mining industries, utilization of power-driven equipment increased from 1929 to 1954 while in three it declined, although it should be noted again that these years are not cyclically comparable.[57] Locomotive use increased while freight car use decreased. Utilization in electric utilities increased from the late 1930's to 1948, but not from 1948 to 1958. And so on. But even doubling the manufacturing figure would yield no more than 0.06 points in their gross product growth rate. Jorgenson and Griliches have applied the increase in utilization not only to all machinery but to all other types of capital and to land. Since all capital and land received 36.2 percent of their total input weight (inclusive of depreciation as well as indirect taxes), this raised the contribution of the utilization adjustment from 0.03 to 0.58 (36.2 percent of 1.60).

The conclusion to be drawn from the preceding discussion—it seems to me inescapable—is that the Jorgenson-Griliches utilization adjustment must be rejected.

After this summation, it may seem superfluous to mention that the Jorgenson-Griliches procedures also contain an important inconsistency. Houses and sites represent a huge part of the stock of capital and land, and much of the capital utilization adjustment reflects the assumption that the hours houses are used have increased. Even if Jorgenson and Griliches were right to assume that people have been spending an increasing amount of time in their houses, per dollar value in constant prices of house, this would not affect their output measure because (fortunately) OBE does not adjust its deflated consumer expenditure series for housing to allow for the supposed increased utilization, and Jorgenson and Griliches do not adjust the OBE series on this account. Hence, Jorgenson and Griliches are arithmetically wrong to subtract the utilization adjustment for residential structures and the residential portion of their land input from the growth of productivity.[58]

57. The Foss series for all mineral industries rises (but its 1929–54 growth rate is only 0.17 as compared with 1.10 for manufacturing) because of a very sharp increase in nonmetal mining, which receives a rather heavy weight (20 percent of the total in 1929 and 27 in 1954) based on available kilowatt hours of motors.

58. Let me stress that my criticisms of the Jorgenson-Griliches utilization adjustment do not extend to the article by Foss, which I have praised in print on several occasions. Nor do I mean to deny the value and relevance to growth studies of series of the type that Foss prepared for power-driven equipment in manufacturing and mining industries and a few other types of fixed capital and that might be prepared for additional types. Indeed, like Jorgenson and Griliches, I should be very glad to see such studies extended. I believe Foss is correct in suggesting [4, p. 10] their importance for analysis of long-term changes in capital-output ratios. Studies of shift work would be immediately useful. More generally, the fact that capital utilization series do not easily fit into the type of classification discussed in this article does not imply that one cannot fruitfully explore the relationship between changes in capital utilization and economic growth. There may be a valid analogy with studies, obviously valuable, of such questions as: "How does transportation affect growth?" or "How did high wages in the United States affect American as compared with European growth in the nineteenth century?" Studies of these questions, too, do not yield results that fit into the type of classification of growth sources that is examined here.

VIII. The Measurement of Labor Input

JORGENSON and Griliches and I measure labor input in ways that are similar in spirit and general approach. Both our input series take into account employment; hours worked, with an allowance for a productivity offset as hours change; and the education of the labor force. My series allows, in addition, for changes in the distribution of total hours worked among age-sex groups whereas theirs does not, but Jorgenson and Griliches agree that this should be done [1, p. 269].[59] Thus a comparison does not raise major conceptual issues.

However, the data and procedures we actually use to measure labor input differ at almost every step, and it is necessary to consider whether this introduces a difference into our estimates of productivity change. My conclusion is that our labor input series are in rather close agreement with respect to the common elements of our estimates, after allowance for my inclusion of government employees.[60] Their omission of an age-sex measure contributes to their higher estimate of the growth of output per unit of input.

Employment, hours, and education

Because of a difference in classification with respect to employment and hours effects, it is desirable to combine the two for comparison. It is also necessary to build up a comparison in several parts.

My employment series is based on household survey data from the *Monthly Report on the Labor Force.* Jorgenson and Griliches rely on the OBE series for persons engaged in production, which is the sum of its full-time equivalent employees and active proprietors of unincorporated enterprises. This series is mainly constructed from establishment reports.

I have attempted to compare data from the two sources at the all-civilian-employment level to try to determine whether movements of the two series are statistically consistent from 1950 to 1962. My series for civilian employment has a 1950–62 growth rate of 1.03.[61] To obtain a conceptually similar series for comparison, I start with OBE series on persons engaged in production, excluding military employment; substitute the OBE series for full-time and part-time employees for full-time equivalent employees; add my estimates for unpaid family workers; and adjust the 1962 figure to exclude Alaska and Hawaii by application of a 1960 overlap ratio. The resulting series has a 1950–62 growth rate of 1.00. For this timespan, the *statistical* difference between MRLF and OBE data would, by this test, make the Jorgenson-Griliches employment series grow 0.03 less than mine. However, Jorgenson and Griliches omit unpaid family workers. The 1950–62 growth rate of their employment series for private industries would be lowered by 0.06 if my estimates for unpaid family workers were added to their estimates. The two differences together would make their series grow 0.03 more than mine.

We each estimate the effect of changes in hours worked by measuring changes in average hours, and allowing for a productivity offset as hours of full-time workers decline. For civilian workers, my resulting series for the effect of changes in hours upon the work done in a year of employment has a growth rate of −0.25 from 1950 to 1962 [2, table 6–6, and an adjustment to exclude military personnel]. This figure includes the effect of a major increase in part-time employment; in fact, it mainly reflects the effect on hours of an increasing part-time component of employment, as distinguished from changes in hours of full-time workers. Two figures from the Jorgenson-Griliches estimates must be combined for comparison. Their series for the effect of hours on the work done in a year of *full-time* employment has a growth rate of about −0.09 from 1950 to 1962.[62] The increase in part-time work is reflected in the employment component of the Jorgenson-Griliches labor input series because their employment series is computed on a full-time equivalent basis. The 1950–62 growth rate of the OBE persons engaged series for private industries is lower by 0.23 than that of an otherwise similar series in which the OBE series for full-time and part-time employees is substituted for full-time equivalent employees. Thus, the combined effect of changes in full-time hours and increased part-time employment on the Jorgenson-Griliches labor input series is −0.32 (−0.09 plus −0.23), which compares with my −0.25. When the difference of −0.07 is added to the 0.03 difference in the employment growth rates, it appears that the difference between our employment and hours series makes their labor input series grow 0.04 points less than mine. Based on their 1950–62 average labor share, this would make their estimate of the contribution of total input 0.03 points lower, and of output per unit of input 0.03 higher, than use of my series.[63]

59. They also say that the labor input series should, in addition, be standardized by occupation and industry. In my view, this is a conceptual error, but since they did not do this, no discrepancy between our estimates is introduced.

60. To adjust for the difference in the scope of our employment estimates, I use OBE data for general government employment. This is appropriate because these data are consistent with the government product data used in Section I above to reconcile productivity estimates. The difference in the scope of our estimates causes little difficulty in comparing other components of our labor input series because, with unimportant exceptions, we each assume that changes are the same for total private employment as for total civilian employment.

61. Computed from 2, tables 5–1A, 5–1C, 5–1D, and C–1. In my estimates, all series are linked at 1960 to eliminate the effect of adding Alaska and Hawaii to coverage of the data.

62. In footnote 50, I calculated that their hours adjustment for labor amounted to −0.06 percentage points in the growth rate of total input. Division of this amount by their average labor share of 0.638 in 1950–62 yields −0.09.

63. I have not isolated the effect of one of their procedures in this reconciliation of our estimates. Although unpaid family workers are excluded from the Jorgenson-Griliches employment series, they do affect total labor input via the hours estimates. Jorgenson and Griliches inform me that they obtained average hours by dividing the BLS establishment-based series for total manhours worked in the private economy (which includes unpaid family workers) by persons engaged in production (which excludes unpaid family workers). Hence, the decline in the ratio of unpaid family workers to total employment presumably intensifies the decline in their average hours series. This reduces the growth in labor input insofar as it was not offset by their efficiency adjustment.

We each estimate the effect of the rise in education upon the quality of labor. The growth rate of my "education quality" series for civilian employment is 0.75 [2, table 8–5]. Despite procedural differences, their rate is also 0.75 [computed from 1, table VII]. No discrepancy in our labor input series is introduced by education.

Age-sex composition

My "quality index" for changes in the age and sex composition of hours worked by civilian employees has a −0.15 growth rate from 1950 to 1962 [2, table 7–7, and an adjustment to exclude military personnel]. Jorgenson and Griliches omit this labor characteristic from their measure. Based on their average 1950–62 labor share, the omission causes their total input series to grow 0.11 points more than mine from 1950 to 1962, and their output per unit of input series 0.11 points less.

IX. Summary of Statistical Review

AN approximate reconciliation of our output per unit of input estimates can now be compiled. It is provided in table 1.

The initial difference between our estimates is 1.27 percentage points (line 3). When my estimates are adjusted to conform to the definition and scope of output used by Jorgenson and Griliches, and their estimates are adjusted to my time period, the difference is reduced to 1.08 (line 6). If my estimates are adjusted to incorporate revised OBE data for the stock of nonresidential structures and equipment, including use of the OBE Deflation II series for nonresidential structures, the difference between us is widened to 1.12 percentage points (line 9).

I found only one significant difference in our classifications of growth sources, as between input and output per unit of input. My input series is broader in that it includes the effect on labor "quality" of shifts in the age-sex composition of hours worked, whereas such shifts affect the Jorgenson-Griliches series for output per unit of input. This source made a negative contribution to growth in 1950–62, so that adjustment of their output per unit of input series to my classification narrows the difference between us from 1.12 to 1.01 percentage points (line 12).

The remaining 1.01 points, which are divided among components in lines 13 to 20, result from differences in statistical procedures. These are of two types: differences in weights and differences in input measures.

Not all of the difference between our weights is relevant here; the portion that is due to inclusion by Jorgenson and Griliches of depreciation and the portion that is due to their exclusion of government and the international sector are related to the difference in output measures, and their effects were previously eliminated in moving from line 3 to line 6. (There is one exception: The effect on the capital utilization adjustment of including depreciation in the weights was not eliminated and is included in the effect of the capital utilization adjustment in line 18.)

The division of the 1.01 points in lines 13 to 20 is, in principle, that which results from first measuring the effect upon my series of substituting their weights for mine and then measuring the effects of substituting their

Table 1.—Reconciliation of Denison and Jorgenson-Griliches Estimates of the Growth Rate (or Contribution to Growth) of Output per Unit of Input (Percentage points)

Reported output per unit of input growth rates:		
1. Denison, total national income, 1950–62 (p. 1)		1.37
2. Jorgenson-Griliches, private domestic GNP, 1945–65 (p. 1)		.10
3. Difference 1–2		1.27
Rates adjusted for definition and scope of output and time period:		
4. Denison, private domestic GNP, 1950–62 (p. 3)		1.38
5. Jorgenson-Griliches, private domestic GNP, 1950–62 (p. 2)		.30
6. Difference 4–5		1.08
Rate adjusted for new data:		
7. Adjustment of Denison series to incorporate new "structures and equipment" data (p. 14)		.04
8. Denison, private domestic GNP, 1950–62, adjusted, 4+7		1.42
9. Difference 8–5		1.12
Rate adjusted for difference in classification:		
10. Adjustment of Jorgenson-Griliches series to eliminate effect of changes in "labor quality" due to shift in age-sex composition of hours worked a,c (p. 24)		−.11
11. Jorgenson-Griliches, private domestic GNP, 1950–62, classification adjusted 5–10		.41
12. Difference 8–11		1.01
Breakdown of remaining difference of 1.01:		
13. Difference in division of input weights between labor and capital-land b,c (p. 5)		.08
14. Difference in inventory capital stock series d (p. 14)		.03
15. Difference in nonresidential structures and equipment capital stock series d (p. 16)		.07
16. Difference in residential structures procedure d (p. 17)		−.12
17. Jorgenson-Griliches substitutions of price indexes for equipment and inventories, net effect e		.07
Effect via output	−0.09 (p. 18)	
Effect via input a	.16 (p. 17)	
18. Jorgenson-Griliches capital-land utilization adjustment a (p. 18)		.58
19. Difference in estimates of employment and hours (p. 23)		−.03
20. Other differences f		.33

a Amount calculated with Jorgenson-Griliches weights.
b Reflects the net effect on the Jorgenson-Griliches weights of (1) counting as capital-land earnings all indirect taxes and other reconciliation items between factor cost and market price measures and (2) allocating to capital-land earnings a smaller portion than Denison of proprietors' income.
c Calculation based on Denison input series.
d Amount calculated with Denison weights.
e The construction price substitutions had no effect on output. Their effect on input is already taken into account in lines 7, 15, and 16.
f This estimate was obtained as a residual.

To obtain a full reconciliation it would have been necessary after line 9 to measure (1) the changes in my estimates that would have been introduced by my use of the Jorgenson-Griliches weights (except for depreciation) and (2) to measure the effect on their estimates, based on their weights, of the differences between us in measuring inputs. The first could be done for the division of weights between labor and capital-land, but not within the capital-land aggregate. The second could be done for most differences, but lines 14 to 16 were calculated by use of my weights instead of theirs. Line 20 therefore includes:

1. The effects of differences in the allocation of the total capital-land weight among components, including the consequences of the Denison division of the economy among sectors and the Jorgenson-Griliches adjustment for capital gains and taxes.
2. The difference between the amounts shown in lines 14, 15, and 16 and the amounts that would be obtained in these lines if Jorgenson-Griliches weights were used in the calculation instead of the Denison weights.
3. Possible errors in the calculations of amounts shown in several other lines of this table resulting from my use of average 1950–62 weights instead of annual weights (in the case of Jorgenson-Griliches estimates) or 1950–54, 1955–59, and 1960–62 weights (in the case of the Denison estimates) to calculate differences.
4. Rounding discrepancies.

input measures for mine when their weights are used; the breakdown would be different if the order were reversed. Two departures from this principle should be noted. The effect of a different allocation of total net capital-land earnings among components, the principal subject of section IV, was not measured and is included in "other differences" in line 20. Also, the effect of using different capital stock series (or a different method in the case of dwellings) could be measured only with the use of my weights (lines 14, 15, 16), and the difference between these results and those that would be obtained with their weights is also included in "other differences" in line 20.

The difference between us of 1.01 points shown in line 12 would be 1.04 were it not for a small offset (line 19) flowing from a difference in our estimates of employment and hours, which I did not evaluate. I have presented what I regard as compelling reasons to consider each of their procedures that contributes to this discrepancy as inferior. Nothing in their article suggests to me a change in my estimates.

Well over half of the entire statistical difference stems from the Jorgenson-Griliches utilization adjustment for capital and land (line 18). If increased utilization of capital and land resulting from advances in knowledge had really contributed 0.58 percentage points to the growth rate, then this amount would be regarded as due to classification rather than to statistical procedure. I have stressed my reasons for concluding that this is not the case. Although the portion of the total gains from advances in knowledge that is transmitted to higher productivity by the mechanism of lengthening capital hours simply cannot be estimated from available information, an amount larger than, say, 0.02 or 0.03 points in the 1950–62 growth rate seems improbable. I therefore classify the Jorgenson-Griliches utilization adjustment of 0.58 as resulting from differences in statistical procedure rather than in classification.

X. Some General Observations

JORGENSON and Griliches draw certain conclusions from their results that I believe to be unsupported and unsupportable.

To introduce this discussion, let me first recall that, in the framework of my estimates, output per unit of input in the private domestic economy may rise, or fall if changes are adverse, for any of a large number of reasons. Seven are perhaps worth listing. Having concluded that Jorgenson and Griliches do not have a broader classification of inputs than mine, I consider that all apply equally to their estimates.

1. Advances in technical, managerial, and organizational knowledge permit more output to be obtained with a given quantity of inputs. The gains may take the form of making possible production of more efficient capital goods at the same cost (resulting in "embodied" technological progress) or they may take any other form. Advances in knowledge, whether transmitted through improvements in capital goods or not, may result from expensive research at one extreme or from completely cost-free accidental discoveries at the other.

2. Knowledge may become more quickly or widely dispersed.

3. Expansion of markets may permit economies of scale.

4. The allocation of resources may move closer to the allocation that would maximize output. Allocation has a myriad of aspects ranging from the distribution of total resources among industries, products, and firms of different size to the placement of each individual worker in the particular job in which his contribution is greatest.

5. Obstacles deliberately imposed by governments, business, or labor unions against the most efficient utilization of resources in the use to which they are put may weaken.

6. The adequacy of government services (roads, police, courts, etc.) that affect private productivity may change.

7. The intensity of utilization of resources may change cyclically with variations in the pressure of demand [2, pp. 273–277, 441–442]. (I try to eliminate the effects in presenting "adjusted" growth rates of output per unit of input.)

My statistical estimates of output per unit of input may also rise or fall because my measures of input are incomplete (for example, I could not measure how hard people work) or inexact. In presenting my estimates, I have always tried to stress the limitations of information and technique, and the fact that one cannot proceed with growth analysis without introducing some assumptions. He can only try to adopt assumptions that are as realistic as he can make them. In this article, I have considered only differences between the Jorgenson-Griliches techniques, data, and assumptions and my own. I have not considered the limitations of techniques and assumptions that we share.

Interpretation of Jorgenson-Griliches results

Jorgenson and Griliches introduce their article by stating that its purpose is to test the hypothesis that "if real product and real factor input are accurately accounted for, the observed growth in total factor productivity is negligible." [1, p. 249] Their small estimate of the rise in total output per unit of input leads them to "conclude that our hypothesis is consistent with the facts." From this conclusion, they draw sweeping inferences. My conclusion is that they obtain their strikingly low estimate of productivity growth not by eliminating errors made in other research but by introducing new errors of their own. If so, the inferences they draw from this finding are also wrong.

I have stressed that the determinants of changes in output per unit of input are the same for the Jorgenson-Griliches series as for mine.[64] I am unable to find anything in their procedures that would have the effect of reclassifying a growth

64. Except that they also include changes in labor quality due to changes in age-sex composition.

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source that I consider to be a component of output per unit of input into a component of input except their wholly unwarranted capital utilization adjustment. Nevertheless, their theoretical discussion suggests that Jorgenson and Griliches would like to reclassify growth sources from productivity to input. Some readers of their article have supposed that they have actually done so; this is understandable because Jorgenson and Griliches are not very clear on this matter.

Their discussion [1, p. 260] of "vintages" of capital goods is likely to mislead the unwary reader. This discussion is concerned with the fact that the design of capital goods improves as time passes. For this reason, an investment of a given sum this year buys a bundle of capital goods that is more productive than the bundle that could have been purchased this year with the same sum of money if capital goods of designs known 10 or 20 years ago were now being produced and were the only types known and available.

Jorgenson and Griliches indicate that, to aggregate capital goods in the capital stock, they would like to treat capital goods of different vintages as different commodities and weight them by their marginal products at a common date, rather than weight them by their costs at a common date as is the general practice in existing capital stock series. This procedure would be equivalent to adjusting existing capital stock series to reflect "unmeasured" quality change; "unmeasured" quality change in the capital stock is defined as the difference in movement between a capital stock series constructed by weighting components by marginal products and a series in which costs are used as weights [2, pp. 134–135, 144–145]. The contribution of "unmeasured" quality change to growth is "embodied technical progress." Thus, the procedure Jorgenson and Griliches recommend would have the effect of transferring "embodied technical progress" from the productivity to the input measure.[65]

It is difficult to read their article without supposing that they actually do make such a transfer.[66] But they stop short of making this claim explicit. In actual fact, I find nothing in their procedures that has the effect of adjusting capital input for the type of quality change that is not reflected in cost differences at a common date, and thus of "embodying" technical progress (nor am I aware of any statistical procedure that could be introduced to do this). I have taken pains to point out that neither their price substitutions nor their use of a fast depreciation (replacement) formula in measuring capital stock has any such effect.

It should also be noted that a distinction they introduce between costly and "costless" advances in "applied technology, managerial efficiency, and industrial organization" [1, p. 250] plays no role in their estimating procedure. They do not capitalize the costs or benefits of research and development, of reallocation of labor, or of any other action that would contribute to an increase in output per unit. Thus, they have transferred none of the gains from costly research or from other expenditures or costly actions out of their estimates of output per unit of input.

Given the characteristics of their productivity estimates that I have described, how is one to interpret the following passage, which appears after their empirical results are presented?

> "Our results suggest that the residual change in total factor productivity, which Denison attributes to Advance in knowledge, is small.[67] Our conclusion is not that advances in knowledge are negligible, but that the accumulation of knowledge is governed by the same economic laws as any other process of capital accumulation. Costs must be incurred if benefits are to be achieved. Although we have made no attempt to isolate the effects of expenditures on research and development from expenditures on other types of current inputs or investment goods, our results suggest that social rates of return to this type of investment are comparable to rates of return on other types of investment. Another implication of our results is that discrepancies between private and social returns to investment in physical capital may play a relatively minor role in explaining economic growth." [1, p. 274]

This quotation seems to contain four statements. Even if the Jorgenson-Griliches statistical results were accurate, they would not, I believe, support all of these statements. Indeed, the interpretation of their residual productivity estimate that is required for it to support the first statement seems directly contrary to the interpretation that would be required for it to lend any support to the other three statements.

The first statement is that the small Jorgenson-Griliches residual does not imply a small contribution to growth from advances in knowledge. This statement could be correct *only* if their procedures *have* the effect of reclassifying much of what I regard as the contribution of output per unit of input to an input contribution. In the absence of such a reclassification, a tiny figure for growth of output per unit of input *would* in fact leave little room for a contribution from advances in knowledge—or from economics of scale, reallocation of resources, or any of the

65. Jorgenson and Griliches would like to allow for "unmeasured quality change" of capital goods in computing the fixed investment components of GNP at constant prices as well as in constructing capital stock series. This would not affect the amount transferred from "GNP per unit of input" to input as "embodied technical progress," but by raising the growth rate of gross product, it would offset to some degree the reduction of the productivity series. However, three points should be noted. (1) The addition to growth of GNP per unit of input would tend to be much smaller, on the average, than the deduction because the ratio of gross fixed investment to GNP is much smaller than the fixed investment share of gross earnings, especially when the latter includes indirect taxes. [See 1, p. 262.] (2) In an analysis of *net* product growth, most of the addition to productivity (but not of the subtraction) would disappear because the increase in the growth rate of gross output in constant prices would be accompanied by a corresponding increase in the growth rate of depreciation in constant prices. (3) The relative size of the positive and negative adjustments to GNP per unit of input would change from time to time unless (a) the rate of "unmeasured quality improvement" were constant over a long period (from the installation date of the oldest capital in the stock when output is first measured to the last date that output is measured) and (b) changes in the share of fixed investment in output synchronized with changes in the share of fixed investment in earnings in some very special way.

66. Their footnote 1 on p. 254, does not contradict this. It merely states that they do not measure embodied technical progress in such a way as to make the change in output per unit of input zero by definition. Their footnote 1, p. 274, refers to errors in capital goods prices, which they try to correct, as "analogous to embodied technical change."

67. Footnote by Denison: Actually, I have attributed to advances in knowledge only part of my estimate of the contribution of output per unit of input.

other sources I have listed as contributing to changes in output per unit of input.

The second statement is that, to obtain important advances in knowledge, commensurate costs must be incurred; costs must be incurred if benefits are to be achieved. This implies that a comparison of costs and gains has been made. Actually, Jorgenson and Griliches provide no estimates at all of the *costs* of obtaining knowledge—e.g., costs of research or exploration. The fact that their residual productivity estimate is small can indicate that *gains* from advances in knowledge—whether costly or costless—are small *only* if Jorgenson and Griliches *have not* transferred gains from advances in knowledge from productivity to input. I would regard as implausible a finding that advances in knowledge have contributed to growth an amount as small as their residual.[68] I have tried to show that their estimate actually results from procedural and statistical errors. But, although I have argued that Jorgenson and Griliches have made no *valid* transfers of growth sources from productivity to input, the actual reason their residual is so very small is their introduction of the capital utilization adjustment. If this adjustment were really accurate and appropriate, they would have counted gains (their estimate implies *most* of the gains) resulting from advances in knowledge as a contribution of capital. If they had succeeded in adjusting capital stock series for unmeasured quality change by their "vintage" approach, this too would have counted gains resulting from advances in knowledge as a contribution of capital.[69]

The third statement is that social rates of return on research and development are comparable to those on other types of investment. This statement, too, does not follow from their results. As just indicated, they provide neither measures of the costs of research and development for comparison with costs of tangible investment, nor measures of the benefits of research and development and of tangible investment.

As to their fourth point, I do not understand how their results could possibly show that discrepancies between private and social returns to investment in physical capital are small. Jorgenson and Griliches must somehow have drawn this inference from the size of their residual. But their introduction of a capital utilization adjustment renders use of their residual for inferences about social rates of return conceptually invalid, just as it does for inferences about returns to research. And even their small residual would be big enough to add greatly to the private rate of return on investment if (improbably) it arose entirely from the discrepancy between public and private returns to investment.

Part of the difficulty with the quotation I have just analyzed stems from the preference of Jorgenson and Griliches for what I regard as an inconvenient classification of growth sources, and this leads me to a final comment on this topic. I believe there is an advantage in matching growth sources with the reasons that income changes, and I have tried to adhere to this principle in my own work. In particular, confusion and misinterpretation are avoided if the contribution of capital is identified with changes in income that result from investment, and that can be altered by changing the amount of investment, and the contribution of advances in knowledge is identified with changes in income that result from advances in technical and managerial knowledge, and that can be altered by changing the state of knowledge. Confusion is hard to avoid if the consequences of advances in knowledge are classified as contributions of capital. This is why I believe it would be unwise, even if they could be isolated, to count as contributions of capital the gains made possible because someone has devised improved designs of capital goods, or found ways to make possible more continuous use of capital goods. Such a classification is an invitation to misinterpretation.

68. It may be noted that Jorgenson and Griliches have estimated that the increase in output per unit of input was negligible over the whole 1929-64 period as well as during the postwar period [5, p. 61]. They clearly believe this to be the typical situation.

69. If the superiority of later "vintages" of capital goods was that they could be used longer hours, the same gains would actually be transferred twice—once by the capital utilization adjustment, and once by the adjustment of the quality of capital.

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The Explanation of Productivity Change

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The Explanation of Productivity Change [1]

But part of the job of economics is weeding out errors. That is much harder than making them, but also more fun.—R. M. Solow

1. INTRODUCTION

Measurement of total factor productivity is based on the economic theory of production. For this purpose the theory consists of a production function with constant returns to scale together with the necessary conditions for producer equilibrium. Quantities of output and input entering the production function are identified with real product and real factor input as measured for social accounting purposes. Marginal rates of substitution are identified with the corresponding price ratios. Employing data on both quantities and prices, movements along the production function may be separated from shifts in the production function. Shifts in the production function are identified with changes in total factor productivity.

Our point of departure is that the economic theory underlying the measurement of real product and real factor input has not been fully exploited. As a result a number of significant errors of measurement have been made in compiling data on the growth of real product and the growth of real factor input. The result of these errors is to introduce serious biases in the measurement of total factor productivity. The allocation of changes in real product and real factor input between movements along a given production function and shifts of the production function must be corrected for bias due to errors of concept and measurement.

The purpose of this paper is to examine a hypothesis concerning the explanation of changes in total factor productivity. This hypothesis may be stated in two alternative and equivalent ways. In the terminology of the theory of production, if quantities of output and input are measured accurately, growth in total output is largely explained by growth in total input. Associated with the theory of production is a system of social accounts for real product and real factor input. The rate of growth of total factor productivity is the difference between the rate of growth of real product and the rate of growth of real factor input. Within the framework of social accounting the hypothesis is that if real product and real factor input are accurately accounted for, the observed growth in total factor productivity is negligible.

We must emphasize that our hypothesis concerning the explanation of real output is testable. By far the largest portion of the literature on total factor productivity is devoted to problems of measurement rather than to problems of explanation. In recognition of this fact changes in total factor productivity have been given such labels as The Residual or The Measure of Our Ignorance. Identification of measured growth in total factor productivity with embodied or disembodied technical change provides methods for measuring technical change, but provides no genuine explanation of the underlying changes in real output and input.[2] Simply relabelling these changes as Technical Progress or Advance of Knowledge leaves the problem of explaining growth in total output unsolved.

[1] The authors' work has been supported by grants from the National Science and Ford Foundations.
[2] See Jorgenson [35] for details.

The plan of this paper is as follows: We first discuss the definition of changes in total factor productivity from the point of view of the economic theory of production. Second, we provide operational definitions for the measurement of prices and quantities that enter into the economic theory of production. These definitions generate a system of social accounts for real product and real factor input and for the measurement of total factor productivity. Within this system we provide an operational definition of total factor productivity. This definition is fundamental to an empirical test of the hypothesis that if real product and real factor input are accurately accounted for, the observed rate of growth of total factor productivity is negligible.

Within our system of social accounts for real product and real factor input we can assess the consequences of errors of measurement that arise from conceptual errors in the separation of the value of transactions into price and quantity. Errors in making this separation may affect real product, real factor input, or both; for example, an error in the measurement of the price of investment goods results in a bias in total output and a bias in the capital accounts that underlie the measurement of total input. Within this system of social accounts we can suggest principles for correct aggregation of inputs and outputs and indicate the consequences of incorrect aggregation. Many of the most important errors of measurement in previous compilations of data on real product and real factor input arise from incorrect aggregation.

Given a system of social accounts for the measurement of total factor productivity we attempt to correct a number of common errors of measurement of real product and real factor input by introducing data that correspond more accurately to the concepts of output and input of the economic theory of production. After correcting for errors of measurement we examine the validity of our hypothesis concerning changes in total factor productivity. We conclude with an evaluation of past research and a discussion of implications of our findings for further research.

2. THEORY

Our definition of changes in total factor productivity is the conventional one. The rate of growth of total factor productivity is defined as the difference between the rate of growth of real product and the rate of growth of real factor input. The rates of growth of real product and real factor input are defined, in turn, as weighted averages of the rates of growth of individual products and factors. The weights are relative shares of each product in the value of total output and of each factor in the value of total input. If a production function has constant returns to scale and if all marginal rates of substitution are equal to the corresponding price ratios, a change in total factor productivity may be identified with a shift in the production function. Changes in real product and real factor input not accompanied by a change in total factor productivity may be identified with movements along a production function.

Our definition of change in total factor productivity is the same as that suggested by Abramovitz (1), namely, " . . . the effect of ' costless ' advances in applied technology managerial efficiency, and industrial organization (cost—the employment of scarce resources with alternative uses—is, after all, the touchstone of an ' input ') . . . " [1] Of course, changes in total factor productivity or shifts in a given production function may be accompanied by movements along a production function. For example, changes in applied technology may be associated with the construction of new types of capital equipment. The alteration in patterns of productive activity must be separated into the part which is " costless", representing a shift in the production function, and the part which represents the employment of scarce resources with alternative uses, representing movements along the production function.

[1] Abramovitz [1, p. 764].

On the output side the quantitites that enter into the economic theory of production correspond to real product as measured for the purposes of social accounting. Similarly, on the input side these quantities correspond to real factor input, also as measured for the purposes of social accounting. The prices that enter the economic theory of production are identified with the implicit deflators that underlie conversion of the value of total output and total input into real terms. The notion of real product is a familiar one to social accountants and has been adopted by most Western countries as the appropriate measure of the level of aggregate economic activity. The notion of real factor input is somewhat less familiar, since social accounting for factor input is usually carried out only in value terms or current prices. However, it is obvious that income streams recorded in value terms correspond to transactions in the services of productive factors. The value of these transactions may be separated into price and quantity and the resulting data may be employed to construct social accounts for factor input in constant prices. This type of social accounting is implicit in all attempts to measure total factor productivity.

The prices and quantities that enter into the economic theory of production will be given in terms of social accounts for total output and total input in current and constant prices. We observe that our measurement of total factor productivity is subject to all the well-known limitations of social accounting. Only the results of economic activities with some counterpart in market transactions are included in the accounts. No attempt is made to measure social benefits or social costs if these diverge from the corresponding private benefits or private costs. Throughout this study we adhere to the basic framework of social accounting. The measurement of both output and input is based entirely on market transactions; all prices reflect private benefits and private costs. That part of any alteration in the pattern of productive activity that is " costless " from the point of view of market transactions is attributed to change in total factor productivity. Thus the social accounting framework provides a definition of total factor productivity as the ratio of real product to real factor input.

To represent the system of social accounts that provides the basis for measuring total factor productivity, we introduce the following notation:

Y_i—quantity of the ith output,

X_j—quantity of the jth input,

q_i—price of the ith output,

p_j—price of the jth input.

Where there are m outputs and n inputs, the fundamental identity for each accounting period is that the value of output is equal to the value of input:

$$q_1Y_1+q_2Y_2+\ldots+q_mY_m = p_1X_1+p_2X_2+\ldots+p_nX_n. \qquad \ldots(1)$$

This accounting identity is important in defining an appropriate method for measuring total factor productivity; it also provides a useful check on the consistency of any proposed definitions of total output and total input.

To define total factor productivity we first differentiate (1) totally with respect to time and divide both sides by the corresponding total value. The result is an identity between a weighted average of the sum of rates of growth of output prices and quantities and a weighted average of the sum of rates of growth of input prices and quantities:

$$\Sigma w_i\left[\frac{\dot{q}_i}{q_i}+\frac{\dot{Y}_i}{Y_i}\right]=\Sigma v_j\left[\frac{\dot{p}_j}{p_j}+\frac{\dot{X}_j}{X_j}\right], \qquad \ldots(2)$$

with weights $\{w_i\}$ and $\{v_j\}$ given by the relative shares of the value of the ith output in the value of total output and the value of jth input in the value of total input:

$$w_i=\frac{q_iY_i}{\Sigma q_iY_i}, \quad v_j=\frac{p_jX_j}{\Sigma p_jX_j}.$$

To verify that both sides of (2) are weighted averages, we observe that:

$$w_i \geqq 0, \; i = 1 \ldots m;$$
$$v_j \geqq 0, \; j = 1 \ldots n;$$
$$\Sigma w_i = \Sigma v_j = 1.$$

A useful index of the quantity of total output may be defined in terms of the weighted average of the rates of growth of the individual outputs from (2); denoting this index of output by Y, the rate of growth of this index is

$$\frac{\dot{Y}}{Y} = \Sigma w_i \frac{\dot{Y}_i}{Y_i};$$

an analogous index of the quantity of total input, say X, has rate of growth

$$\frac{\dot{X}}{X} = \Sigma v_j \frac{\dot{X}_j}{X_j}.$$

These quantity indexes are familiar as Divisia quantity indexes; the corresponding Divisia price indexes for total output and total input, say q and p, have rates of growth:

$$\frac{\dot{q}}{q} = \Sigma w_i \frac{\dot{q}_i}{q_i},$$

$$\frac{\dot{p}}{p} = \Sigma v_j \frac{\dot{p}_j}{p_j},$$

respectively.[1]

In terms of Divisia index numbers a natural definition of total factor productivity, say P, is the ratio of the quantity of total output to the quantity of total input:

$$P = \frac{Y}{X}. \qquad \ldots(3)$$

Using the definitions of Divisia quantity indexes, Y and X, the rate of growth of total factor productivity may be expressed as:

$$\frac{\dot{P}}{P} = \frac{\dot{Y}}{Y} - \frac{\dot{X}}{X} = \Sigma w_i \frac{\dot{Y}_i}{Y_i} - \Sigma v_j \frac{\dot{X}_j}{X_j}. \qquad \ldots(4)$$

or, alternatively, as:

$$\frac{\dot{P}}{P} = \frac{\dot{p}}{p} - \frac{\dot{q}}{q} = \Sigma v_j \frac{\dot{p}_j}{p_j} - \Sigma w_i \frac{\dot{q}_i}{q_i}.$$

These two definitions of total factor productivity are dual to each other and are equivalent by (2). In general, any index of total factor productivity can be computed either from indexes of the quantity of total output and total input or from the corresponding price indexes.[2]

Up to this point we have defined total factor productivity as the ratio of certain index numbers of total output and total input. An economic interpretation of this definition may be obtained from the theory of production. The theory includes a production function

[1] Divisia [17, 19]. Application of these indexes to the measurement of total factor productivity is suggested by Divisia in a later publication [18, pp. 53-54]. The economic interpretation of Divisia indexes of total factor productivity has been discussed by Solow [61] and Richter [52].

[2] The basic duality relationship for indexes of total factor productivity has been discussed by Siegel, 57, 58].

characterized by constant returns to scale; writing this function in implicit form, we have:

$$F(Y_1, Y_2, \ldots, Y_m; X_1, X_2, \ldots, X_n) = 0.$$

Shifts in the production function may be defined in terms of appropriate weighted average rates of growth of outputs and inputs,

$$G\dot{F} = \sum\left(\frac{F_i Y_i}{\Sigma F_i Y_i} \cdot \frac{\dot{Y}_i}{Y_i}\right) - \sum\left(\frac{F_j X_j}{\Sigma F_j X_j} \cdot \frac{\dot{X}_j}{X_j}\right), \qquad \ldots(5)$$

where $F_i = \frac{\partial F}{\partial Y_i}$, $F_j = \frac{\partial F}{\partial X_j}$ and:

$$\frac{1}{G} = \Sigma F_i Y_i = -\Sigma F_j X_j.$$

Changes in total factor productivity may be identified with shifts of the production function as opposed to movements along the production function by adding the necessary conditions for producer equilibrium—all marginal rates of transformation between pairs of inputs and outputs are equal to the corresponding price ratios—

$$\frac{\partial Y_i}{\partial X_j} = -\frac{F_j}{F_i} = \frac{p_j}{q_i}; \quad \frac{\partial Y_i}{\partial Y_k} = -\frac{F_k}{F_i} = \frac{q_i}{q_k}; \quad \frac{\partial X_j}{\partial X_l} = -\frac{F_l}{F_j} = \frac{p_l}{p_j}; \quad (i, k = 1 \ldots m; \quad j, l = 1 \ldots n).$$

Combining these conditions with the definition (5) of shifts in the production function, we obtain the definition (4) of total factor productivity:

$$G\dot{F} = \frac{\dot{P}}{P}.$$

The rate of growth of total factor productivity is zero if and only if the shift in the production function is zero.

The complete theory of production consists of a production function with constant returns to scale together with the necessary conditions for producer equilibrium. This theory of production implies the existence of a factor price frontier relating the prices of output to the prices of input. The dual to the definition (4) of total factor productivity may be identified with shifts in the factor price frontier.[1]

The economic interpretation of the index of total factor productivity is essential in measuring changes in total factor productivity by means of Divisia index numbers. As is well known,[2] the Divisia index of total factor productivity is a line integral so that its value normally depends on the path of integration; even if the path returns to its initial value the index of total factor productivity may increase or decrease. However, if price ratios are identified with marginal rates of transformation of a production function with constant returns to scale, the index will remain constant if the shift in the production function is zero.[3]

From either of the two definitions of the index of total factor productivity we have given it is obvious that the rate of growth of this index is not zero by definition. Even for a production function characterized by constant returns to scale with all factors paid the value of their marginal products, the rate of growth of real product may exceed or fall short of the rate of growth of real factor input; similarly, the rate of growth of the

[1] The notion of a factor price frontier has been discussed by Samuelson [54]; the factor price frontier is employed in defining changes in total factor productivity by Diamond [16] and by Phelps and Phelps [51].

[2] See, for example, Wold [64].

[3] See Richter [52]. We are indebted to W. M. Gorman for bringing this fact to our attention.

price of real factor input may exceed or fall short of the rate of growth of the price of real product.[1]

The economic theory of production on which our interpretation of changes in total factor productivity rests is not the only possible theory of production. From the definition of shifts in the production function (5) it is clear that the production function may be considered in isolation from the necessary conditions for producer equilibrium, provided that alternative operational definitions of the marginal rates of transformation are introduced. Such a production function may incorporate the effects of increasing returns to scale, externalities, and disequilibrium. Changes in total factor productivity in our sense could then be interpreted as movements along the production function in this more general sense.

To provide a basis for assessing the role of errors of measurement in explaining observed changes in total factor productivity, we first set out principles for measuring total output and total input. The measurement of flows of output and labour services is, at least conceptually, straightforward. Beginning with data on the value of transactions in each type of output and each type of labour service, this value is separated into a price and a quantity. A quantity index of total output is constructed from the quantities of each output, using the relative shares of the value of each output in the value of total output as weights. Similarly, a quantity index of total labour input is constructed from the quantities of each labour service, using the relative shares of the value of each labour service in the value of all labour services as weights.

If capital services were bought and sold by distinct economic units in the same way as labour services, there would be no conceptual or empirical difference between the construction of a quantity index of total capital input and the construction of the corresponding index of total labour input. Beginning with data on the value of transactions in each type of capital service, this value could be separated into a price of capital service or rental and a quantity of capital service in, say, machine hours. These data would correspond to the value of transactions in each type of labour service which could be separated into a price of labour service or wage and a quantity of labour service in, say, man hours. A quantity index of total capital input would be constructed from the quantities of each type of capital service, using the relative shares of the rental value of each capital service in the rental value of all capital services as weights.

The measurement of capital services is less straightforward than the measurement of labour services because the consumer of a capital service is usually also the supplier of the

[1] It is essential to distinguish our basic hypothesis from a misinterpretation of it recently advanced by Denison:

> Since advances in knowledge cannot increase national product without raising the marginal product of one or more factors of production, they of course disappear as a source of growth if an increase in a factor's marginal product resulting from the advance of knowledge is counted as an increase in the quantity of factor input [14, p. 76].

In terms of our social accounting framework Denison suggests that we measure factor input as the sum of the increase in both prices and quantities; denoting the index of input implied by Denison's interpretation by X^D, gives:

$$\frac{\dot{X}^D}{X^D} = \Sigma v_j \frac{\dot{p}_j}{p_j} + \Sigma v_j \frac{\dot{X}_j}{X_j};$$

the corresponding index of output, say Y^D, would then be defined as:

$$\frac{\dot{Y}^D}{Y^D} = \Sigma w_i \frac{\dot{q}_i}{q_i} + \Sigma w_i \frac{\dot{Y}_i}{Y_i};$$

The resulting index of total factor productivity, say P^D, is constant by definition:

$$\frac{\dot{P}^D}{P^D} = \frac{\dot{Y}^D}{Y^D} - \frac{\dot{X}^D}{X^D} = 0.$$

By comparing this definition with our definition (4), the error in Denison's interpretation of our hypothesis is easily seen.

service; the whole transaction is recorded only in the internal accounts of individual economic units. The obstacles to extracting this information for purposes of social accounting are almost insuperable; the information must be obtained by a relatively lengthy chain of indirect inference. The data with which the calculation begins are the values of transactions in new investment goods. These values must be separated into a price and quantity of investment goods. Second, the quantity of new investment goods reduced by the quantity of old investment goods replaced must be added to accumulated stocks. Third, the quantity of capital services corresponding to each stock must be calculated.[1]

Paralleling the calculation of quantities of capital services beginning with the quantities of new investment goods, the prices of capital services must be calculated beginning with the prices of new investment goods. Finally, a quantity index of total capital input must be constructed from the quantities of each type of capital service, using the relative shares of the implicit rental value of each capital service in the implicit rental value of all capital services as weights. The implicit rental value of each capital service is obtained by simply multiplying the quantity of that service by the corresponding price. At this final stage the construction of a quantity index of total capital input is formally identical to the construction of a quantity index of total labour input or total output. The chief difference between the construction of price and quantity indexes of total capital input and any other aggregation problem is in the circuitous route by which the necessary data are obtained.

The details of the calculation of a price and quantity of capital services from data on the values of transactions in new investment goods depend on empirical hypotheses about the rate of replacement of old investment goods and the quantity of capital services corresponding to a given stock of capital. In studies of total factor productivity it is conventional to assume that capital services are proportional to capital stock. Where independent data on rates of utilization of capital are available, this assumption can be dispensed with. A number of hypotheses about the rate of replacement of old investment goods have been used in the literature: (1) Accounting depreciation measured by the straight-line method is set equal to replacement, possibly with a correction for changes in prices. (2) Gross investment in some earlier period is set equal to replacement. (3) A weighted average of past investment with weights derived from studies of the " survival curves " of individual pieces of equipment[2] is set equal to replacement. From a formal point of view, the last of these hypotheses includes the first two as special cases.

We assume that the proportion of an investment replaced in a given interval of time declines exponentially over time. A theoretical justification for this assumption is that replacement of investment goods is a recurrent event. An initial investment generates a series of replacement investments over time; each replacement generates a new series of replacements, and so on; this process repeats itself indefinitely. The appropriate model for replacement of investment goods is not the distribution over time of replacements for a given investment, but rather the distribution over time of the infinite stream of replacements generated by a given investment. The distribution of replacements for such an infinite stream approaches a constant fraction of the accumulated stock of investment goods for any " survival curve " of individual pieces of equipment and for any initial age distribution of the accumulated stock, whether the stock is constant or growing. But this is precisely the relationship between replacement and accumulated stock if an exponentially declining proportion of any given investment is replaced in a given interval of time.

The quantity of capital services corresponding to each stock could be measured directly, at least in principle. The stock of equipment would be measured in numbers of

[1] Here we assume that the " quantity " of a particular type of capital as an asset is proportional to its " quantity " as a service, whatever the age of the capital. If this condition is not satisfied, capital of each distinct age must be treated as a distinct asset and service. Output at each point of time consists of the usual output plus " aged " capital stock.

[2] Studies in which these three methods have been employed are (1) Jaszi, Wasson, and Grose [33], Goldsmith [25], and Kuznets [39]; (2) Meyer and Kuh [44] and Denison [15]; (3) Terborgh [63].

machines while the service flow would be measured in machine hours, just as the stock of labour is measured in numbers of men while the flow of labour services is measured in man hours. While the stock of equipment may be calculated by cumulating the net flow of investment goods, the relative utilization of this equipment must be estimated in order to convert stocks into flows of equipment services. For the purposes of this study we assume that the relative utilization of all capital goods is the same; we estimate the relative utilization of capital from the relative utilization of power sources. An adjustment for the relative utilization of equipment is essential in order to preserve comparability among our measurements of output, labour input, and capital input.

To represent the capital accounts which provide the basis for measuring total capital input, we introduce the following notation:

I_k—quantity of output of the kth investment good,

K_k—quantity of input of the kth capital service.

As before, we use the notation:

q_k—price of the kth investment good,

p_k—price of the kth capital service.

Under the assumption that the proportion of an investment replaced in a given interval of time declines exponentially, the cumulated stock of past investments in the kth capital good, net of replacements, satisfies the well-known relationship:

$$I_k = \dot{K}_k + \delta_k K_k, \qquad \text{...(6)}$$

where δ_k is the instantaneous rate of replacement of the kth investment good. Similarly, in the absence of direct taxation the price of the kth capital service satisfies the relationship:

$$p_k = q_k \left[r + \delta_k - \frac{\dot{q}_k}{q_k} \right], \qquad \text{...(7)}$$

where r is the rate of return on all capital, δ_k is the rate of replacement of the kth investment good, and $\dot{q}_k/q_k$ is the rate of capital gain on that good. Given these relationships between the price and quantity of investment goods and the price and quantity of the corresponding capital services, the only data beyond values of transactions in new investment goods required for the construction of price and quantity indexes of total capital input are rates of replacement for each distinct investment good and the rate of return on all capital. We turn now to the problem of measuring the rate of return.

First, to measure the values of output and input it is customary to exclude the value of capital gains from the value of input rather than to include the value of such gains in the value of output. This convention has the virtue that the value of output may be calculated directly from the values of transactions. Second, to measure total factor productivity, depreciation is frequently excluded from both input and output; this convention is adopted, for example, by Kendrick [37]. Exclusion of depreciation on capital introduces an entirely arbitrary distinction between labour input and capital input, since the corresponding exclusion of depreciation of the stock of labour services is not carried out.[1] To calculate the rate of return on all capital, our procedure is to subtract from the value of output plus capital gains the value of labour input and of replacement. This results in the rate of return multiplied by the value of accumulated stocks. The rate of return is calculated by dividing this quantity by the value of the stock.[2] The

[1] This point is made by Domar [21].

[2] Domar's procedure [21, p. 717, fn. 3] fails to correct for capital gains. Implicitly, Domar is assuming either no capital gains or that all capital gains are included in the value of output, whether realized or not.

implicit rental value of the kth capital good is:

$$p_k K_k = q_k \left[r + \delta_k - \frac{\dot{q}_k}{q_k} \right] K_k.$$

To calculate price and quantity indexes for total capital input, the prices and quantities of each type of capital service are aggregated, using the relative shares of the implicit rental value of each capital service in the implicit rental value of all capital services as weights.

An almost universal conceptual error in the measurement of capital input is to confuse the aggregation of capital stock with the aggregation of capital service. This error may be exemplified by the following passage from a recent paper by Kendrick [38] devoted to theoretical aspects of capital measurement:

> . . . the prices of the underlying capital goods, as established in markets or imputed by owners, can be appropriately combined (with variable quantity weights) to provide a deflator to convert capital values into physical volumes of the various types of underlying capital goods at base-period prices. Or, the result can be achieved directly by weighting quantities by constant prices.
>
> As I view it, this is the most meaningful way to measure " real capital stock," since the weighted aggregate measures the physical complex of capital goods in terms of its estimated ability to contribute to production as of the base period.[1]

The " ability to contribute to production " is, of course, measured by the price of capital services, not the price of investment goods.[2]

We have already noted that direct observations are usually available only for values of transactions; the separation of these values into prices and quantities is based on much less complete information and usually involves indirect inferences; the presence of systematic errors in this separation is widely recognized. For output of consumption goods or input of labour services an error in separating the value of transactions into price and quantity results in an error in measurement of the price and quantity of total output or total labour input and in the measurement of total factor productivity. For example, suppose that the rate of growth of the price of a particular type of labour service is measured with an error; since all relative value shares remain the same, the resulting error in the price of total labour input has a rate of growth equal to the rate of growth of the error multiplied by the relative share of the labour service. The quantity of total labour input is measured with an error which is equal in magnitude but opposite in sign. The error in measurement of the rate of growth of total factor productivity is equal to the negative of the rate of growth of the error in the quantity of total labour input multiplied by the relative share of labour. The effects of an error in the rate of growth of the price of a particular type of consumption good are entirely analogous; of course, an upward bias in the rate of growth of output increases the measured rate of growth of total factor productivity, while an upward bias in the rate of growth of input decreases the measured rate of growth.

An error in the separation of the value of transactions in new investment goods into the price and quantity of investment goods will result in errors in measurement of the price and quantity of investment goods, of the price and quantity of capital services and of total

1 Kendrick [38, p. 106]; see the comments by Griliches [27, p. 129]. Kendrick takes a similar position in a more recent paper [36]; see the comments by Jorgenson [35]. The treatment of capital input outlined above is based on our earlier paper [31]. The data have been revised to reflect recent revisions in the U.S. national accounts.

2 The answer to Mrs. Robinson's [53] rhetorical question, " what units is capital measured in? " is dual to the measurement of the price of capital services. Given either an appropriate measure of the flow of capital services or a measure of its price, the other measure may be obtained from the value of income from capital. Since this procedure is valid only if the necessary conditions for producer equilibrium are satisfied, the resulting quantity of capital may not be employed to *test* the marginal productivity theory of distribution, as Mrs. Robinson and others have pointed out.

factor productivity. To measure the bias in the rate of growth of the quantity of investment goods, we let Q^* be the relative error in the measurement of the price of investment goods, I^* the " quantity " of investment goods output, calculated using the erroneous " price " of investment goods, and I the actual quantity of investment goods output. The bias in the rate of growth of investment goods output is then:

$$\frac{\dot{I}^*}{I^*} - \frac{\dot{I}}{I} = -\frac{\dot{Q}^*}{Q^*}. \qquad \ldots(8)$$

The rate of growth of this bias is negative if the rate of growth of the error in measurement of the price of investment goods is positive, and vice-versa. If we let K^* be the " quantity " of capital calculated using the erroneous " price " of investment goods and K the actual quantity of capital:

$$K^* = \int_{-\infty}^{t} e^{-\delta(t-s)} I^*(s)ds = \int_{-\infty}^{t} e^{-\delta(t-s)} \frac{I(s)}{Q^*(s)}\, ds.$$

The bias in the rate of growth of the quantity of capital services is then:

$$\frac{\dot{K}^*}{K^*} - \frac{\dot{K}}{K} = \frac{I}{Q^*K^*} - \frac{I}{K} = \frac{I}{\int_{-\infty}^{t} e^{-\delta(t-s)} \frac{Q^*(t)}{Q^*(s)} I(s)ds} - \frac{I}{\int_{-\infty}^{t} e^{-\delta(t-s)} I(s)ds}, \qquad \ldots(9)$$

which is negative if the rate of growth of the error in measurement of the price of investment goods is positive, and vice-versa.

To calculate the error of measurement in total factor productivity, we let C represent the quantity of consumption goods and L the quantity of labour input; second, we let w_I represent the relative share of the value of investment goods in the value of total output and w_C the relative share of consumption goods; finally, we let v_K represent the relative share of the value of capital input in the value of total input and v_L the relative share of labour. The rate of growth of total factor productivity may be represented as:

$$\frac{\dot{P}}{P} = w_I \frac{\dot{I}}{I} + w_C \frac{\dot{C}}{C} - v_K \frac{\dot{K}}{K} - v_L \frac{\dot{L}}{L}.$$

If we let P^* represent the measured index of total factor productivity using the erroneous " price " of investment goods:

$$\frac{\dot{P}^*}{P^*} = w_I \frac{\dot{I}^*}{I^*} + w_C \frac{\dot{C}}{C} - v_K \frac{\dot{K}^*}{K^*} - v_L \frac{\dot{L}}{L}.$$

Subtracting the first of these expressions from the second we obtain the bias in the rate of growth of total factor productivity:

$$\frac{\dot{P}^*}{P^*} - \frac{\dot{P}}{P} = w_I \left[\frac{\dot{I}^*}{I^*} - \frac{\dot{I}}{I}\right] - v_K \left[\frac{\dot{K}^*}{K^*} - \frac{\dot{K}}{K}\right].$$

Substituting expressions (9) and (8) for the biases in the measured rates of growth of capital input and the output of investment goods, we have:

$$\frac{\dot{P}^*}{P^*} - \frac{\dot{P}}{P} = -w_I \frac{\dot{Q}^*}{Q^*} - v_K \left(\frac{I}{\int_{-\infty}^{t} e^{-\delta(t-s)} \frac{Q^*(t)}{Q^*(s)} I(s)ds} - \frac{I}{\int_{-\infty}^{t} e^{-\delta(t-s)} I(s)ds} \right). \qquad \ldots(10)$$

If investment and the error in measurement are growing at constant rates, the biases in the rates of growth of the quantity of investment goods produced and the quantity of capital services are equal, so that the net effect is equal to the rate of growth in the error in measurement of the price of investment goods multiplied by the difference between the capital share in total input and the investment share in total output.[1]

A second source of errors in measurement arises from limitations on the number of separate inputs that may be distinguished empirically. The choice of commodity groups to serve as distinct " inputs " and " outputs " involves aggregation within each group by simply adding together the quantities of all commodities within the group and aggregation among groups by computation of the usual Divisia quantity index. The resulting price and quantity indexes are Divisia price and quantity indexes of the individual commodities only if the rates of growth either of prices or of quantities within each group are identical.

Errors of aggregation in studies of total factor productivity have not gone unnoticed; however, these errors are frequently mislabelled as "quality change". Quality change in this sense occurs whenever the rates of growth of quantities within each separate group are not identical. For example, if high quality items grow faster than items of low quality, the rate of growth of the group is biased downward relative to an index treating high and low quality items as separate commodities. To eliminate this bias it is necessary to construct the index of input or output for the group as a Divisia index of the individual items within the group. Elimination of " quality change " in the sense of aggregation bias is essential to accurate social accounting and to measurement of changes in total factor productivity. Separate accounts should be maintained for as many product and factor input categories as possible. An attempt should be made to exploit available detail in any empirical measurement of real product, real factor input, and total factor productivity.

In some contexts the choice of an appropriate unit for the measurement of quantities of real product or real factor input is not obvious. For example, fuel may be measured in tons or in B.T.U. equivalents, tractor services may be measured in tractor hours or in horsepower hours, and so on. Measures of real product and real factor input may be adjusted for " quality change " by converting one unit of measurement to another. This procedure conforms to the principles of social accounting we have outlined and their interpretation in terms of the economic theory of production if the adjustment for quality change corrects errors of aggregation. In the examples we have given, if the marginal products of different types of fuel always move in proportion when fuel is measured in B.T.U. equivalents but fail to do so when fuel is measured in tons, the appropriate unit for the measurement of fuel is the B.T.U. Similarly, if the marginal products of tractor services measured in horsepower hours always move in proportion, but when measured in tractor hours fail to do so, tractor services should be measured in horsepower hours.

The appropriateness of any proposed adjustment for quality change may be confronted with empirical evidence on the marginal products of individual items within a commodity group. Under the assumption that these products are equal to the corresponding price ratios this evidence takes the form of data on relative price movements for the individual items. Under a more general set of assumptions the marginal products might be calculated from an econometric production function. The latter treatment would be especially useful for " linking in " new factors and products since the relevant prices cannot be observed until the new factors and products appear in the market. Any change in measured total factor productivity resulting from adjustments for quality change is explained by evidence on the movement of marginal products and is not the result of an arbitrary choice of definitions. The choice of appropriate units for measurement of

[1] Domar [22, p. 587, formula (5)] considers a special case of this problem in which capital " is imported from the outside". This specialization is unnecessary, as suggested in the text. A more detailed discussion of this issue is presented by Jorgenson [35].

For constant rates of growth of the relative error in the investment goods price index and the level of investment, formula (10) may be expressed in closed form:

$$\frac{\dot{P}^*}{P^*} - \frac{\dot{P}}{P} = -w_I \frac{\dot{Q}^*}{Q^*} + v_K \frac{\dot{Q}^*}{Q^*},$$
$$= (v_K - w_I) \frac{\dot{Q}^*}{Q^*}.$$

real product and real factor input may go beyond selection among alternative scalar measured such as B.T.U. equivalents or tons; a commodity may be regarded as multi-dimensional and an appropriate unit of measurement may be defined implicitly by taking prices as given by so-called " hedonic " price indexes. The critical property of such price indexes is that when prices are given by a " hedonic " price index for the commodities within a group, all such commodities have marginal rates of transformation vis-à-vis commodities outside the group that move in proportion to each other. Insofar as this property is substantiated by empirical evidence, adjustment of the commodity group for "quality change" by means of such a price index is entirely legitimate and amounts to correcting an error of aggregation.[1] This is not to say that any proposed adjustment for quality change is legitimate. The appropriateness of each adjustment must be judged on the basis of the evidence. If no fresh evidence is employed, the choice of appropriate units is entirely arbitrary and any change in measured total factor productivity resulting from adjustment for "quality change" is simply definitional.

" Quality change " is sometimes used to describe a special type of aggregation error, namely, the error that arises in aggregating investment goods of different vintages by simply adding together quantities of investment goods of each vintage. If the quality of investment goods, as measured by the marginal productivity of capital, is not constant over all vintages, this procedure results in aggregation errors. An appropriate index of capital services may be constructed by treating each vintage of investment goods as a separate commodity. To construct such an index empirically, data on the marginal productivity of capital of each vintage at each point of time are required. If independent data on relative prices of capital services of different vintages are used in the construction of such a capital services index, any resulting reduction in measured productivity growth is not tautological. Only where the change in quality is measured indirectly from the resulting increase in total factor productivity, as suggested by Solow [60], does such a procedure result in the elimination of productivity change by definition.[2]

3. MEASUREMENT

3.1. *Initial estimates*

We can now investigate the extent to which measured changes in total factor productivity are due to errors of measurement. We begin by constructing indexes of total output and total input for the United States for the twenty-year period following World War II, 1945-65, without correcting for errors of measurement. As an initial index of total output we take U.S. private domestic product in constant prices as measured in the U.S. national product accounts [48]. As an index of total input we take the sum of labour and capital services in constant prices. Labour and capital services are assumed to be proportional to stocks of labour and capital, respectively. The stock of labour is taken to be the number of persons engaged in the private domestic sector of the U.S. economy. The stock of capital is the sum of land, plant, equipment, and inventories employed in this sector.[3] The rate of growth of total factor productivity is equal to the difference in the rates of growth of total output and total input.

Indexes of total output, total input, and total factor productivity are given in Table I. The average annual rate of growth of total output over the period 1945-65 is 3·49 per cent. The average rate of growth of total input is 1·83 per cent. The average rate of growth of total factor productivity is 1·60 per cent. The rate of growth of total input explains 52·4

[1] See Griliches [28] and the references given there.

[2] Jorgenson [35].

[3] To make stocks of labour and capital precisely analogous, it would be necessary to go even further. Unemployed workers should be included in the stock of labour since unemployed machines are included in the stock of capital. Workers should be aggregated by means of discounted lifetime incomes since capital goods are aggregated by means of asset prices.

TABLE I

Total output, input, and factor productivity, U.S. private domestic economy, 1945-65, initial estimates

	1	2	3
1945	0·699	0·786	0·891
1946	0·680	0·817	0·836
1947	0·695	0·854	0·818
1948	0·729	0·876	0·836
1949	0·726	0·867	0·841
1950	0·801	0·891	0·901
1951	0·852	0·928	0·919
1952	0·873	0·947	0·924
1953	0·917	0·966	0·951
1954	0·904	0·954	0·949
1955	0·981	0·976	1·005
1956	0·999	1·001	0·998
1957	1·013	1·012	1·000
1958	1·000	1·000	1·000
1959	1·069	1·019	1·048
1960	1·096	1·036	1·057
1961	1·115	1·039	1·072
1962	1·189	1·057	1·123
1963	1·240	1·074	1·152
1964	1·307	1·097	1·188
1965	1·387	1·129	1·224

1. Output. 2. Input. 3. Productivity.

per cent of the growth in output; the remainder is explained by changes in total factor productivity.

3.2. *Errors of aggregation*

The first error of measurement to be eliminated is an error of aggregation. This error results from aggregating labour and capital services by summing quantities in constant prices. To eliminate the error, we replace our initial index of total input by a Divisia index of labour and capital input, as suggested by Solow [61]. A similar error results from aggregating consumption and investment goods output by adding together quantities in constant prices. This error may be eliminated by replacing our initial index of total output by a Divisia index of consumption and investment goods output. Indexes of total output, total input, and total factor productivity with these errors of aggregation eliminated are presented in Table II.

The average annual rate of growth of total output over the period 1945-65 with the error in aggregation of consumption and investment goods output eliminated is 3·39 per cent. The average rate of growth of total input with the error in aggregation of labour and capital services eliminated is 1·84 per cent. The resulting rate of growth of total factor productivity is 1·49 per cent. We conclude that these errors in aggregation result in an overstatement of the initial rate of growth of total factor productivity. With these errors eliminated total input explains 54·3 per cent of the growth in total output. This result may be compared with the 52·4 per cent of the growth in total output explained initially.

3.3. *Investment goods prices*

We have demonstrated that an error in the measurement of investment goods prices results in errors in the measurement of total output, total input, and total factor productivity.

Roughly speaking, a positive bias in the rate of growth of the investment goods price index results in a positive bias in the rate of growth of total factor productivity, provided that the share of capital in the value of input exceeds the share of investment in the value of output. This condition is fulfilled for the U.S. private domestic sector throughout the period, 1945-65. Hence, we must examine the indexes of investment goods prices that underlie our measurement for possible sources of bias.

Except for the price index for road construction the price indexes for structures that underlie the U.S. national accounts are indexes of the cost of input rather than the price of output. In the absence of changes in total factor productivity properly constructed

TABLE II

Total output, input, and factor productivity, U.S. private domestic economy, 1945-65, *errors of aggregation eliminated*

	1	2	3
1945	0·713	0·783	0·912
1946	0·679	0·810	0·841
1947	0·694	0·847	0·824
1948	0·727	0·870	0·840
1949	0·727	0·864	0·845
1950	0·800	0·888	0·903
1951	0·851	0·925	0·921
1952	0·873	0·945	0·926
1953	0·918	0·964	0·953
1954	0·905	0·954	0·950
1955	0·981	0·976	1·005
1956	0·999	1·001	0·998
1957	1·013	1·012	1·000
1958	1·000	1·000	1·000
1959	1·070	1·019	1·049
1960	1·096	1·036	1·057
1961	1·115	1·038	1·073
1962	1·189	1·057	1·124
1963	1·240	1·073	1·153
1964	1·307	1·096	1·189
1965	1·387	1·128	1·225

1. Output. 2. Input. 3. Productivity.

price indexes for construction input would parallel the movements of price indexes for output. This is assured by the dual to the usual definition of total factor productivity (3). Dacy [12] has shown that the rate of growth of the price of inputs in highway construction is considerably greater than that of the price of construction output. Dacy's output price index grows from 0·805 to 0·982 from 1947 through 1959, while the input price index grows from 0·615 to 1·024 in the same period, both on a base 1·000 in 1958.[1] This empirical finding is simply another way of looking at the positive residual between rates of growth of total output and total input where total factor productivity is measured with error. Input price indexes are subject to the same errors of aggregation as the corresponding quantity indexes. Since input quantity indexes grow too slowly, input price indexes grow too rapidly.

[1] The growth of the output price index may be compared with that for personal consumption expenditures, which grows from 76·5 to 108·6 from 1947 through 1959. The close parallel between the output price index for construction and the price of consumption goods suggests an explanation for the difference in rates of growth of prices of consumption and investment goods described by Gordon [26]. This difference results from the error of measurement in using an input price index in place of an output price index for investment goods. If this error is corrected, the difference vanishes.

The use of input prices in place of output prices for structures results in an important error of measurement. To eliminate this error it is necessary to use an output price index in measuring prices of both investment goods output and capital services input. An index of this type has been constructed for the OBE 1966 Capital Stock Study [49]. Components of this index include the Bureau of Public Roads price index for highway structures, the Bell System price index for telephone buildings, and the Bureau of Reclamation price indexes for pumping plants and power plants. The resulting composite index may be compared with the implicit deflator for new construction from the U.S. national accounts [48]. The implicit deflator grows from 0·686 to 1·029 during the period 1947 through 1959 while the OBE Capital Goods Study price index for new construction output grows

TABLE III

Alternative investment deflators

	1	2	3	4	5	6
1945	0·544	0·510	0·759	0·517	0·633	0·357
1946	0·594	0·570	0·768	0·575	0·705	0·638
1947	0·721	0·686	0·827	0·646	0·786	2·310
1948	0·749	0·770	0·863	0·703	0·827	1·023
1949	0·743	0·755	0·868	0·736	0·818	0·788
1950	0·763	0·791	0·878	0·752	0·823	0·818
1951	0·836	0·847	0·942	0·809	0·879	0·945
1952	0·881	0·876	0·954	0·822	0·896	0·949
1953	0·895	0·889	0·943	0·835	0·903	0·497
1954	0·897	0·886	0·929	0·840	0·914	0·772
1955	0·902	0·910	0·919	0·859	0·921	0·931
1956	0·959	0·956	0·949	0·918	0·945	0·978
1957	1·001	0·992	0·984	0·975	0·978	1·113
1958	1·000	1·000	1·000	1·000	1·000	0·994
1959	1·006	1·029	1·014	1·020	1·012	0·991
1960	1·005	1·042	1·009	1·022	1·026	1·020
1961	1·008	1·053	1·006	1·021	1·037	1·011
1962	1·024	1·069	1·008	1·023	1·048	1·001
1963	1·038	1·089	1·004	1·023	1·059	1·011
1964	1·059	1·119	1·004	1·031	1·071	1·014
1965	1·089	1·149	0·995	1·038	1·089	1·032

1. Structures II.
2. Structures I.
3. Equipment II.
4. Equipment I.
5. Inventories II.
6. Inventories I.

from 0·762 to 0·958 during the same period. Thus the relative bias in the input price index for all new construction as a measure of the price of construction output is roughly comparable to the relative bias in Dacy's input price index for highway construction as a measure of the price of highway construction output. The input price index, labelled Structures I, and the output price index, labelled Structures II, are given in Table III.

The price indexes for equipment that underlie the U.S. national accounts are based primarily on data from the wholesale price index of the Bureau of Labour Statistics [6]. Since expenditures on the wholesale price index are less than those on the consumers' price index [4], adjustments for quality change are less frequent and less detailed. A direct comparison of the durables components of the wholesale and consumers' price indexes gives some notion of the relative bias. The wholesale price index increases from 0·646 to 1·023 and the consumers' price index increases from 0·858 to 1·022 over the period 1947 to 1959, both on a base of 1·000 in 1958. A direct comparison of components common to both indexes reveals essentially the same relationship. To correct for bias in the implicit deflator for producers' durables, we substitute for this deflator the implicit deflator for consumers' durables. The deflator for producers' durables increased from 0·646 in 1947 to 1·020 in 1959. Over this same period the deflator for consumers' durables increased from 0·827 to 1·014, both on a base of 1·000 in 1958. Thus the relative bias in the producers' durables price index as revealed by a comparison with components common to the wholesale and consumers' price indexes may be corrected by simply substituting the implicit deflator for consumers' durables for the producers' durables deflator. Both indexes are given in Table III; the producers' durables index is labelled Equipment I while the consumers' durables index is labelled Equipment II.

The durables component of the consumers' price index was itself subject to considerable upward bias in recent years. The consumers' price index for new automobiles increased 62 per cent from 1947 to 1959. It has been estimated that correcting this index for quality change would reduce this increase to only 31 per cent in the same period.[1] In view of the upward bias in the consumers' price index our adjustment for bias in the producers' durables price index is conservative. In order to reduce the error of measurement further, detailed research like that already carried out for automobiles is required for each class of producers' durable equipment.

The price indexes for change in business inventories from the U.S. national accounts contain year-to-year fluctuations that result from changes in the composition of investment in inventories; these changes are much more substantial than the corresponding changes in the composition of inventory stocks. The implicit deflator for change in inventories is not published; however, it may be computed from data on change in inventories in current and constant dollars. Changes that amount to nearly doubling or halving the index occur from 1946 to 1947, 1947 to 1948, and 1951 to 1952. The value of the index is 0·357 in 1945, 0·638 in 1946 and 2·310 in 1947, all on a base of 1·000 (or, to be exact, 0·994) in 1958. The index drops to 1·023 in 1948 and 0·788 in 1949. A less extreme but equally substantial movement in the index occurs from 1952 through 1957. Changes in the implicit deflator of this magnitude cannot represent movements in the price of all stocks of inventories considered as investment goods. To represent these movements more accurately, we replace the implicit deflator for change in inventories by the deflator for private domestic consumption expenditures. The level of this index generally coincides with that of the implicit deflator for change in business inventories; however, the fluctuations are much less. Both indexes are given in Table III; the implicit deflator for change in business inventories is labelled Inventories I while the implicit deflator for private domestic consumption expenditures is labelled Inventories II.

Indexes of total input, total output, and total factor productivity with errors in the measurement of prices of investment goods eliminated are presented in Table IV. The average rate of growth of total output over the period 1945-65 with these errors of measurement removed is 3·59 per cent. This rate of growth may be compared with the original rate of growth of total output of 3·49 per cent or with the rate of growth of 3·39 per cent for total output with errors of aggregation removed. The average rate of growth of total input over this period is 2·19 per cent. The original rate of growth of total input is 1·83 per cent; with errors of aggregation removed the rate of growth of total input is 1·84 per cent. The rate of growth of total factor productivity is 1·41 per cent. With errors in measurement of the prices of investment goods eliminated the rate of growth of total input explains 61·0 per cent of the rate of growth of total output.

3.4. *Measurement of services*

Up to this point we have assumed that labour and capital services are proportional to stocks of labour and capital. This assumption is obviously incorrect. In principle flows of capital and labour services could be measured directly. In fact it is necessary to

[1] Griliches [28, Table 8, last column, p. 397].

infer the relative utilization of stocks of capital and labour from somewhat fragmentary data. Okun [50] has attempted to circumvent the problem of direct observation of labour and capital services by assuming that the relative utilization of both labour and capital is a function of the unemployment rate for labour so that the gap between actual and " potential " output, that is, output at full utilization of both factors, may be expressed in terms of the unemployment rate. A similar notion has been used by Solow [62] to adjust stocks of labour and capital for relative utilization. Most of the available capacity utilization measures are based on the relationship of actual output to output at full utilization of both labour and capital, so that these measures also attempt to adjust both labour and capital simultaneously.

TABLE IV

Total output, input, and factor productivity, U.S. private domestic economy, 1945-65, *errors in investment goods prices eliminated*

	1	2	3
1945	0·692	0·759	0·913
1946	0·662	0·786	0·846
1947	0·679	0·822	0·829
1948	0·718	0·845	0·853
1949	0·717	0·842	0·854
1950	0·798	0·867	0·922
1951	0·839	0·908	0·925
1952	0·858	0·930	0·925
1953	0·905	0·950	0·954
1954	0·900	0·942	0·957
1955	0·982	0·966	1·016
1956	0·995	0·996	0·999
1957	1·009	1·010	1·000
1958	1·000	1·000	1·000
1959	1·076	1·022	1·052
1960	1·107	1·042	1·061
1961	1·127	1·049	1·073
1962	1·199	1·071	1·117
1963	1·249	1·091	1·142
1964	1·319	1·117	1·177
1965	1·400	1·153	1·209

1. Output. 2. Input. 3. Productivity.

Our approach to the problem of relative utilization is somewhat more direct in that we attempt to adjust capital and labour for relative utilization separately. Of course, this adjustment gives rise to a new concept of " potential " or capacity output, but we do not pursue this notion further in this paper. Our first assumption is that the relative utilization of capital is the same for all capital goods; while this is a very strong assumption it is weaker than the assumption underlying the Okun-Solow approach in which the relative utilization of capital and labour depends on that of labour. We estimate the relative utilization of capital from the relative utilization of power sources.[1] Data on the relative utilization of electric motors provides an indicator of the relative utilization of capital in manufacturing, since electric motors are the predominant source of power there. We assume that relative utilization of capital goods in the manufacturing and non-manufacturing sectors is the same. When more complete data become available, this assumption can be replaced by less restrictive assumptions. Unfortunately, this adjustment

[1] Foss [24]. See the Statistical Appendix for further details.

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allows only for the trend in the relative utilization of capital; it does not adjust for short-term cyclical variations in capacity utilization. Thus we are unable to attain the objective of complete comparability between measures of labour and capital input.

The assumption that labour services are proportional to the stock of labour is obviously incorrect. On the other hand, the assumption that labour services can be measured directly from data on man-hours is equally incorrect, as Denison [14] has pointed out. The intensity of effort varies with the number of hours worked per week, so that labour input can be measured accurately only if data on man-hours are corrected for the effects of variations in the number of hours per man on labour intensity. Denison [15] suggests that the stock of labour provides an upper bound for labour services while the number of man-hours provides a lower bound. He estimates labour input by correcting man-hours for variations in labour intensity. We employ Denison's correction for intensity,

TABLE V

Total input and factor productivity, U.S. private domestic economy, 1945-65, *errors in relative utilization eliminated*

	1	2
1945	0·716	0·968
1946	0·742	0·895
1947	0·777	0·877
1948	0·801	0·899
1949	0·802	0·897
1950	0·830	0·963
1951	0·873	0·963
1952	0·899	0·956
1953	0·924	0·980
1954	0·923	0·976
1955	0·959	1·023
1956	0·994	1·001
1957	1·009	1·000
1958	1·000	1·000
1959	1·035	1·038
1960	1·057	1·046
1961	1·067	1·054
1962	1·089	1·098
1963	1·114	1·118
1964	1·146	1·147
1965	1·189	1·172

1. Input. 2. Productivity.

but we apply this correction to actual hours per man rather than potential hours per man. Thus, our measure of labour input reflects short-run variations in labour intensity.

The assumption that labour and capital services are proportional to stocks of labour and capital results in an error in separating a given value of transactions into a price and a quantity. To correct this error we multiply the number of persons engaged by hours per man. The resulting index of man-hours is then corrected for variations in labour intensity. The corresponding error for capital is corrected by multiplying the stock of capital by the relative utilization of capital. Indexes of total input and total factor productivity after these errors have been eliminated are presented for the period 1945-65 in Table V. The average annual rate of growth of total output is the same as before these corrections, 3·59 per cent per year. The average rate of growth of total input is 2·57 per cent. The resulting average rate of growth of total factor productivity is 0·96 per cent. Total input now explains 71·6 per cent of the rate of growth in total output.

3.5. *Capital services*

In converting estimates of capital stock into estimates of capital services we have disregarded an important conceptual error in the aggregation of capital services. While investment goods output must be aggregated by means of investment goods or asset prices, capital services must be aggregated by means of service prices.

The prices of capital services are related to the prices of the corresponding investment goods; in fact, the asset price is simply the discounted value of all future capital services. Asset prices for different investment goods are not proportional to service prices because of differences in rates of replacement and rates of capital gain or loss among capital goods. Implicitly, we have assumed that these prices are proportional; to eliminate the resulting error in measurement, it is necessary to compute service prices and to use these prices in aggregating capital services.

We have already outlined a method for computing the price of capital services in the absence of direct taxation of business income. In the presence of direct taxes we may distinguish between the price of capital services before and after taxes. The expression (7) given above for the price of capital services is the price after taxes. The price of capital services before taxes is:

$$p_k = q_k \left[\frac{1-uv}{1-u} r + \frac{1-uw}{1-u} \delta_k - \frac{1-ux}{1-u} \frac{\dot{q}_k}{q_k} \right] \qquad \text{...(11)}$$

where u is the rate of direct taxation, v the proportion of return to capital allowable as a charge against income for tax purposes, w the proportion of replacement allowable for tax purposes, and x the proportion of capital gains included in income for tax purposes

We estimate the variables describing the tax structure as follows: The rate of direct taxation is the ratio of profits tax liability to profits before taxes. The proportion of the return to capital allowable for tax purposes is the ratio of net interest to the total return to capital. Total return to capital is the after tax rate of return, r, multiplied by the current value of capital stock. The proportion of replacement allowable for tax purposes is the ratio of capital consumption allowances to the current value of replacement. The proportion of capital gains included in income is zero by the conventions of the U.S. national accounts. Given the value of direct taxes we estimate the after tax rate of return by subtracting from the value of output plus capital gains the value of labour input, replacement, and direct taxes. This results in the total return to capital. The rate of return is calculated by dividing this quantity by the current value of the stock of capital. Given data on the rate of return and the variables describing the tax structure, we calculate the price of capital services before taxes for each investment good.[1] These prices of capital services are used in the calculation of indexes of capital input, total input, and total factor productivity.

For the U.S. private domestic economy it is possible to distinguish five classes of investment goods—land, residential and non-residential structures, equipment, and inventories. Although it is also possible to distinguish a number of sub-classes within each of these groupings, we will employ only the five major groups in calculating an index of total capital input. For each group we first compute a before tax service price analogous to (11). We then compute an index of capital input as a Divisia index of the services of land, structures, equipment and inventories. In constructing this index we eliminate the conceptual error that arises from the implicit assumption that service prices are proportional to asset prices for different investment goods. In eliminating this conceptual error we also eliminate the error of aggregation that results from adding together capital services in constant prices to obtain an index of total capital input. To eliminate the corresponding error in our index of investment goods output we replace our initial index by a Divisia index of investment in structures, equipment, and inventories. Indexes of total output, total input and total factor productivity resulting from the elimination of these errors are

[1] Further details are given in the Statistical Appendix.

presented in Table VI. The after tax rate of return implicit in the new index of capital input is also given in Table VI.

The average rate of growth of total output over the period 1945-65 with the error in aggregation of investment goods eliminated is 3·59. This rate of growth is essentially the same as for total output with errors in the aggregation of consumption and investment goods and errors in the measurement of investment goods prices eliminated. The average rate of growth of total input with errors in aggregation of capital services eliminated is 2·97 per cent. This rate of growth may be compared with the initial rate of growth of 1·83 per cent.

TABLE VI

Total input and factor productivity, U.S. private domestic economy, 1945-65, *errors in aggregation of capital input eliminated; implicit rate of return after taxes*

	1	2	3	4
1945	0·692	0·671	1·030	0·158
1946	0·661	0·698	0·950	0·198
1947	0·678	0·735	0·926	0·237
1948	0·717	0·765	0·940	0·223
1949	0·716	0·773	0·930	0·126
1950	0·797	0·804	0·992	0·095
1951	0·837	0·850	0·986	0·242
1952	0·857	0·880	0·976	0·143
1953	0·905	0·908	0·997	0·091
1954	0·900	0·911	0·988	0·078
1955	0·982	0·951	1·032	0·113
1956	0·995	0·987	1·008	0·175
1957	1·009	1·005	1·004	0·138
1958	1·000	1·000	1·000	0·107
1959	1·077	1·039	1·035	0·097
1960	1·107	1·063	1·040	0·105
1961	1·127	1·076	1·046	0·118
1962	1·199	1·099	1·089	0·138
1963	1·250	1·126	1·107	0·131
1964	1·320	1·160	1·134	0·127
1965	1·401	1·206	1·157	0·141

1. Output. 2. Input. 3. Productivity. 4. Rate of return.

The resulting rate of growth of total factor productivity is 0·58 per cent. The index of total factor productivity with these errors eliminated is presented in Table VI. With these errors eliminated total input explains 82·7 per cent of the growth in total output. The original index of total input explains 52·4 per cent of this growth.

3.6. *Labour services*

We have eliminated errors of aggregation that arise in combining capital services into an index of total capital input. Similar errors arise in combining different categories of labour services into an index of total labour input. Implicitly, we have assumed that the price per man-hour for each category of labour services is the same; to eliminate the resulting error of measurement it is necessary to use prices per man-hour for each category in computing an index of total labour input. Second, to eliminate the error of aggregation that results from adding together labour services in constant prices, we replace our initial index of labour input by a Divisia index of the individual categories of labour services.

The Divisia index of total labour input is based on a weighted average of the rates of growth of different categories of labour, using the relative shares in total labour compensation as weights. To represent our index of total labour input, we let L_l represent the quantity of input of the lth labour service, measured in man-hours. The rate of growth of the index of total labour input, say L, is:

$$\frac{\dot{L}}{L} = \Sigma v_l \frac{\dot{L}_l}{L_l}$$

where v_l is the relative share of the lth category of labour in the total value of labour input. The number of man-hours for each labour service is the product of the number of men, say n_l, and hours per man, say h_l; using this notation the index of total labour input may be rewritten:

$$\frac{\dot{L}}{L} = \Sigma v_l \frac{\dot{n}_l}{n_l} + \Sigma v_l \frac{\dot{h}_l}{h_l}.$$

For comparison with our initial indexes of labour input we separate the rate of growth of the index of labour input into three components—change in the total number of men, change in hours per man, and change in labour input per man-hour. We have assumed that the number of hours per man is the same for all categories of labour services, say H. Letting N represent the total number of men and e_l the proportion of the workers in the lth category of labour serivces, we may write the index of total labour input in the form:

$$\frac{\dot{L}}{L} = \frac{\dot{H}}{H} + \frac{\dot{N}}{N} + \Sigma v_l \frac{\dot{e}_l}{e_l}. \qquad \ldots(12)$$

Our initial index of labour input was simply N, the number of persons engaged; we corrected this index by taking into account the number of hours per man, H. To eliminate the remaining errors of aggregation we must correct the rate of growth of man-hours by adding to it an index of labour input per man-hour. The third term in the expression (12) for total labour input given above provides such an index. We will let E represent this index, so that:

$$\frac{\dot{E}}{E} = \Sigma v_l \frac{\dot{e}_l}{e_l}. \qquad \ldots(13)$$

For computational purposes it is convenient to note that the index may be rewitten in the form:

$$\frac{\dot{E}}{E} = \Sigma \frac{p_l}{\Sigma p_l e_l} \dot{e}_l = \Sigma p'_l \dot{e}_l,$$

where p_l is the price of the lth category of labour services and p'_l is the relative price. The relative price is the ratio of the price of the lth category of labour services to the average price of labour services, $\Sigma p_l e_l$.

In principle it would be desirable to distinguish among categories of labour services classified by age, sex, occupation, number of years schooling completed, industry of employment, and so on. An index of labour input per man-hour based on such a breakdown requires detailed research far beyond the scope of this study. We will compute such an index only for males and only for categories of labour broken down by the number of school years completed. The basic computation is presented in Table VII. Data on relative prices for labour services are available for the years 1939, 1949, 1956, 1958, 1959 and 1963.[1] Combining these prices with changes in the distribution of the labour force provides a measure of the change in labour input per man-hour.[2]

[1] Additional details on relative prices for labour services are presented in the Statistical Appendix, Table XII.

[2] Additional details on the distribution of the labour force are presented in the Statistical Appendix, Table XI.

TABLE VII

Relative prices, changes in distribution of the labour force, and indexes of labour-input per man-hour, U.S. males, the civilian labour force,* 1940-64

School year completed	p_i'	Δe_i	p_i'	Δe_i	p_i'	Δe_i	p_i'	Δe_i	p_i'	Δe_i	p_i'	Δe_i
	1939	1940-48	1949	1948-52	1956	1952-57	1958	1957-59	1959	1959-62	1963	1962-65
Elementary 0-4	0·497	−2·3	0·521	−0·3	0·452	−1·3	0·409	−0·8	0·498	−0·8	0·407	−0·8
5-6 or 5-7	0·672	−3·1	0·685	−0·5	0·624	−0·2	0·565	−1·0	0·688	−0·9	0·562	−1·5
7-8 or 8	0·887	−6·8	0·813	−1·8	0·796	−3·3	0·753	−1·2	0·801	−1·9	0·731	−1·2
High School 1-3	1·030	2·4	0·974	−1·3	0·955	0·7	0·923	0·6	0·912	−0·6	0·886	−0·3
4	1·241	7·0	1·143	1·0	1·159	2·6	1·113	0·9	1·039	1·6	1·087	3·2
College 1-3	1·442	1·4	1·336	1·2	1·356	0·2	1·392	0·7	1·255	1·3	1·269	0·0
4+ or 4	1·947	1·3	1·866	1·6	1·810	1·3	1·840	0·9	1·569	1·0	1·571	0·2
5+	...	...	...	...	...	...	...	...	1·888	0·3	1·730	0·4
Percentage change in labour input per man-hour		6·45		2·50		2·97		2·39		2·36		2·13
Annual percentage change		0·78		0·62		0·59		1·20		0·79		0·72

SOURCE: Derived from Tables 11 and 12, Statistical Appendix.

* The relative prices are computed using the appropriate beginning period distribution of the labour force as weights.

Indexes of total input and total factor productivity with errors in the aggregation of labour services eliminated are presented in Table VIII. The average rate of growth of total input over the period 1945-65 with the error in aggregation of labour services eliminated is 3·47. This rate of growth may be compared with the initial rate of growth of total input of 1·83 per cent. The resulting rate of growth of total factor productivity is 0·10 per cent. With these errors eliminated total input explains 96·7 per cent of the growth in total output.

TABLE VIII

Total input and factor productivity, U.S. private domestic economy 1945-65, *errors in aggregation of labour input eliminated*

	1	2
1945	0·634	1·090
1946	0·661	1·001
1947	0·700	0·971
1948	0·732	0·981
1949	0·743	0·966
1950	0·776	1·026
1951	0·823	1·017
1952	0·857	1·002
1953	0·887	1·020
1954	0·894	1·007
1955	0·936	1·048
1956	0·976	1·019
1957	0·997	1·012
1958	1·000	1·000
1959	1·047	1·027
1960	1·077	1·027
1961	1·096	1·027
1962	1·125	1·064
1963	1·158	1·076
1964	1·200	1·096
1965	1·255	1·112

1. Input. 2. Productivity.

4. SUMMARY AND CONCLUSION

4.1. *Summary*

The purpose of this paper has been to examine the hypothesis that if quantities of output and input are measured accurately, growth in total output may be largely explained by growth in total input. The results are given in Table IX and Charts 1, 2 and 3. We first present our initial estimates of rates of growth of output, input, and total factor productivity. These estimates include many of the errors made in attempts to measure total factor productivity without fully exploiting the economic theory underlying the social accounting concepts of real product and real factor input. We begin by eliminating errors of aggregation in combining investment and consumption goods and labour and capital services. We then eliminate errors of measurement in the prices of investment goods arising from the use of prices for inputs into the investment goods sector rather than outputs from this sector. We remove errors arising from the assumption that the flow of services is proportional to stocks of labour and capital by introducing direct observations on the rates of utilization of labour and capital stock. We present rates of growth that result from correct aggregation of investment goods and capital services. Finally, we give rates of growth that result from correcting the aggregation of labour services.

The rate of growth of input initially explains 52·4 per cent of the rate of growth of output. After elimination of aggregation errors and correction for changes in rates of utilization of labour and capital stock the rate of growth of input explains 96·7 per cent of the rate of growth of output; change in total factor productivity explains the rest. In the terminology of the theory of production, movements along a given production function explain 96·7 per cent of the observed changes in the pattern of productivity activity; shifts in the production function explain what remains.

This computation is based on the 1945-65 period, measuring total factor productivity peak to peak. If one were to choose a different set of years, the numerical results would be slightly different, but their main thrust would be the same. For example, starting with the Post-Korean peak year of 1953, the rate of growth of input initially explains only 37·3 per cent of the rate of growth of output. After all the corrections the rate of growth of input explains 79·2 per cent of the growth in output between 1953 and 1965, reducing the estimated rate of change in total factor productivity from 2·12 per cent per year to

TABLE IX

Total output, input, and factor productivity, U.S. private domestic economy, 1945-65, *average annual rates of growth*

	Output	Input	Productivity
1. Initial estimates	3·49	1·83	1·60
Estimates after correction for:			
2. Errors of aggregation	3·39	1·84	1·49
3. Errors in investment goods prices	3·59	2·12	1·41
4. Errors in relative utilization	3·59	2·57	0·96
5. Errors in aggregation of capital services	3·59	2·97	0·58
6. Errors in aggregation of labour services	3·59	3·47	0·10

0·72. We conclude that our hypothesis is consistent with the facts. If the economic theory underlying the measurement of real product and real factor input is properly exploited, the role to be assigned to growth in total factor productivity is small.

4.2. *Evaluation of past research*

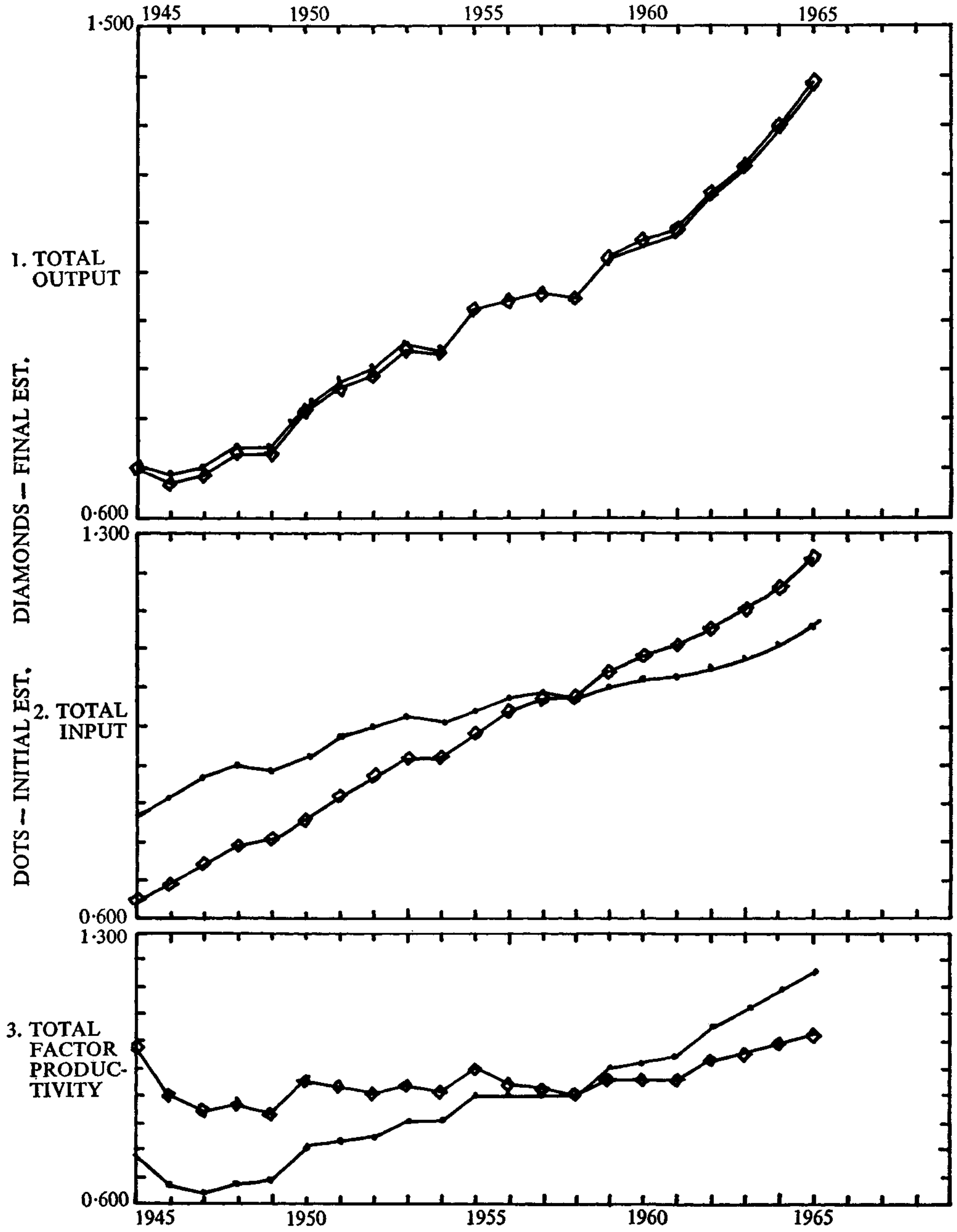
Our conclusion that most of the growth in total output may be explained by growth in total input is just the reverse of the conclusion drawn from the great body of past research on total factor productivity, the research of Schmookler [55], Mills [46], Fabricant [23], Abramovitz [2], Solow [61], and Kendrick [37]. These conclusions, stated by Abramovitz, are " . . . that to explain a very large part of the growth of total output and the great bulk of output *per capita*, we must explain the increase in output per unit of conventionally measured inputs. . . " [1]. This conclusion results from inadequacies in the basic economic theory underlying the social accounts employed in productivity measurements. The increase in output per unit of conventionally measured inputs is characterized by very substantial errors of measurement, equal in magnitude to the alleged increase in productivity. We have given a concrete and detailed list of errors of this type.

Our results differ from those of Denison [15] in that we correct changes in total factor productivity for errors in the measurement of output, capital services, and labour services, while Denison corrects only for errors in the measurement of labour services.

[1] Abramovitz [1, p. 776].

To get some idea of the relative importance of errors in the measurement of labour and errors in the measurement of output and capital, we may observe that the rate of growth of total factor productivity is reduced from 1·60 per cent per year to 0·10 per cent per year. Of the total reduction of 1·50 per cent per year errors in the measurement of output and capital account for 1·17 per cent per year while errors in the measurement of labour

INDEXES OF TOTAL OUTPUT, TOTAL INPUT AND TOTAL FACTOR PRODUCTIVITY (1958 = 1·0), U.S. PRIVATE DOMESTIC ECONOMY, 1945-1965



account for 0·33 per cent per year. We conclude that errors of measurement of the type left uncorrected by Denison are far more important than the type of errors he corrects.[1]

Our results suggest that the residual change in total factor productivity, which Denison attributes to Advance in Knowledge, is small. Our conclusion is not that advances in knowledge are negligible, but that the accumulation of knowledge is governed by the same economic laws as any other process of capital accumulation. Costs must be incurred if benefits are to be achieved. Although we have made no attempt to isolate the effects of expenditures on research and development from expenditures on other types of current inputs or investment goods, our results suggest that social rates of return to this type of investment are comparable to rates of return on other types of investment. Of course, our inference is indirect and a better test of this proposition could be provided by direct observation of private and social rates of return to investment in scientific research and development activities. Unfortunately, many of the direct observations on these rates of return available in the literature attribute all or part of the measured increase in total factor productivity to investment in research and development;[2] since these measured increases are subject to all the errors of measurement we have enumerated, satisfactory direct tests of the hypothesis that private and social rates of return to research and development investment are equal to private rates of return to other types of investment are not yet available.

Another implication of our results is that discrepancies between private and social returns to investment in physical capital may play a relatively minor role in explaining economic growth. Under the operational definitions of total factor productivity we have adopted, a positive discrepancy between social and private rates of return would appear as a downward bias in the rate of growth of input, hence an upward bias in the rate of growth of total factor productivity. The effects of such discrepancies are lumped together with the effects of other sources of growth in total factor productivity we have measured. The fact that the growth of the resulting index is small indicates that the contribution of investment to economic growth is largely compensated by the private returns to investment. This implication of our findings is inconsistent with explanations of economic growth such as Arrow's model of learning by doing [3], which are based on a higher social than private rate of return to physical capital.[3]

Of course, ours is not the first explanation of productivity change that does not rely primarily on discrepancies between private and social rates of return. An explanation of this type has been proposed by Solow [60], namely, embodied technical change. As Solow [59] points out, explanation of measured changes in total factor productivity as embodied technical change does not require discrepancies between private and social rates of return: ". . . the fact of expectable obsolescence reduces the private rate of return on saving below the marginal product of capital as one might ordinarily calculate it. But this discrepancy is fully reflected in a parallel difference between the marginal product of

[1] Errors in the aggregation of labour services account for 0·48 per cent per year, but this is offset by errors of measurement in the relative utilization of labour of −0·15 per cent per year so that the net correction for errors of measurement of labour is 0·33 per cent per year.

An alternative interpretation of our results may be provided by analogy with the conceptual framework for technical change discussed by Diamond [16]. Errors of measurement in the growth of labour services may be denoted labour-diminishing errors of measurement; capital-diminishing errors of measurement may be separated into embodied and disembodied errors. Errors in capital due to errors in the measurement of prices of investment goods are analogous to embodied technical change. Finally, some of the errors in measurement affect levels of output; these errors may be denoted output-diminishing errors of measurement.

A decomposition of total errors of measurement into labour-diminishing, capital-diminishing, embodied and disembodied, and output-diminishing is as follows: Labour-diminishing errors of measurement contribute 0·33 per cent per year to the initial measured rate of growth of total factor productivity. Embodied capital-diminishing errors contribute 0·28 per cent per year and disembodied capital-diminishing errors contribute 0·99 per cent per year. Finally, output-diminishing errors of measurement of 0·10 per cent per year must be set off against the input-diminishing errors totalling 1·60 per cent per year.

[2] See, for example, the studies of Minasian [47] and Mansfield [42].

[3] See Levhari [40, 41] for an elaboration of this point.

capital and the social rate of return on saving. So . . . the private and social rates of return coincide"[1]. In referring to " capital as one might ordinarily calculate it ", Solow explicitly does not identify quality-corrected or " surrogate " capital with capital input and " surrogate " investment with investment goods output. In Solow's framework the marginal product of " surrogate " capital is precisely equal to the private and social rate of return on saving. The difference between Solow's point of view and ours is that the private and social rates of return are equal by definition in his framework, where the equality between private and social rates of return is a testable hypothesis within our framework.[2]

4.3. *Implications for future research*

The problem of measuring total factor productivity is, at bottom, the same as the estimation of national product and national factor input in constant prices. The implication of our findings is that the predominant part of economic growth may be explained within a conventional social accounting framework. Of course, precise measurement of productivity change requires attention to reliability as well as accuracy. Our catalogue of errors of measurement could serve as an agenda for correction of errors in the measurement of output and for incorporation of the measurement of input into a unified social accounting framework. Given time and resources we could attempt to raise all of our measurements to the high standards of the U.S. National Product Accounts in current prices. This could be done with some difficulty for rates of relative utilization of labour and capital stock and the prices of investment goods, which require the introduction of new data into the social accounts. The elimination of aggregation errors in measuring capital services and investment goods requires a conceptual change to bring these concepts into closer correspondence with the economic theory of production. The measurement of appropriate indexes of labour input, corrected for errors of aggregation, necessitates fuller exploitation of existing data on wage differentials by education, occupation, sex, and so on.

The most serious weakness of the present study is in the use of long-term trends in the relative utilization of capital and labour to adjust capital input and labour input to concepts appropriate to the underlying theory of production. As a result of discrepancies between these trends and year-to-year variations in relative utilization of capital and labour, substantial errors of measurement have remained in the resulting index of total factor productivity. Examination of any of the alternative indexes we have presented reveals substantial unexplained cyclical variation in total factor productivity. An item of highest priority in future research is to incorporate more accurate data on annual variations in relative utilization. Hopefully, elimination of these remaining errors will make it possible to explain cyclical changes in total factor productivity along the same lines as our present explanation of secular changes. Cyclical changes are very substantial so that even our secular measurements could be improved with better data. For example, the use of the period 1945-58, a peak in total factor productivity to a trough, reveals a drop in total factor productivity of nine per cent; the use of the period 1949-65, a trough to a peak, yields an increase in total factor productivity of eleven and a half per cent.

In compiling data on labour input we have relied upon observed prices of different types of labour services. Given a broader accounting framework it would be possible to treat human capital in a manner that is symmetric with our measurement of physical capital. Investment in human capital could be cumulated into stocks along the lines suggested by Schultz [56]. The flow of investment could be treated as part of total output. The rate of return to this investment could then be measured and compared with the rate of return to physical capital. Similarly, investment in scientific research and development could be separated from expenditures on current account and cumulated into stocks.

[1] Solow [59, p. 58-59].
[2] For further discussion of this point, see Jorgenson [35].

The rate of return to research activity could then be computed. In both of these calculations it would be important not to rely on erroneously measured residual growth in total output for measurement of the social return to investment.

It is obvious that further disaggregation of our measurements would be valuable in order to provide a more stringent test of the basic hypothesis that growth in output may be explained by growth in input. The most important disaggregation of this type is to estimate levels of output and input by individual industries. The statistical raw material for disaggregation by industry is already available for stocks of labour and capital and levels of output. However, data for relative utilization of labour and capital and for disaggregation of different types of labour and capital within industry groups would have to be developed. Once these data are available, it will be possible to estimate rates of return to capital for individual industries and to study the effects of the distribution of productive factors among industries along the lines suggested by Massell [43]. The fact that past observations do not reveal significant changes in productivity does not imply that the existing allocation of productive resources is efficient relative to allocations that could be brought about by policy changes. In such a study it might be useful to extend the scope of productivity measurements to include the government sector. This would be particularly desirable if educational investment, which is largely produced in that sector, is to be incorporated into total output.

Finally, our results suggest a new point of departure for econometric studies of production function at every level of aggregation. While some existing studies [29, 30] employ data on output, labour, and capital corrected for errors of measurement along the lines we have suggested, most estimates of production functions are based on substantial errors of measurement. Econometric production functions are not an alternative to our methods for measuring total factor productivity, but rather supplement these methods in a number of important respects. Such production functions provide one means of testing the assumptions of constant returns to scale and equality between price ratios and marginal rates of transformation that underlie our measurement. A complete test of the hypothesis that growth in total output may be explained by growth in total input requires the measurement of input within a unified social accounting framework, the measurement of rates of return to both human and physical capital, further disaggregation, and new econometric studies of production functions. A start has been made on this task, but much interesting and potentially fruitful research remains to be done.

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STATISTICAL APPENDIX

1. As our initial estimate of output we employ gross private domestic product which is defined as gross national product less gross product, general government, and gross product, rest of the world, all in constant prices of 1958. These data are obtained from the U.S. national accounts. Our second estimate of output requires data on gross private domestic investment and gross private domestic consumption, defined as gross private domestic product less gross private domestic investment, in both current and constant prices of 1958. These data are also obtained from the U.S. national accounts.

As our initial estimate of labour input we employ private domestic persons engaged, defined as persons engaged for the national economy less persons engaged, general government, and persons engaged, rest of the world. These data are obtained from the U.S. national accounts [48]. Our initial estimate of capital input is obtained by the perpetual inventory method based on double declining balance estimates of replacement. For structures and equipment the lifetimes of individual assets are based on the " Bulletin F lives " employed by Jaszi, Wasson and Grose [33]. Data for gross private domestic investment prior to 1929 are unpublished estimates that underlie the capital stock estimates of Jaszi, Wasson and Grose [33]. For inventories and land, the initial values of capital stock in constant prices of 1958 are derived from Goldsmith [25]. The stock of land in constant prices is assumed to be unchanged throughout the period we consider. Estimates of the value of land in current prices are obtained from Goldsmith [25].

The estimates of gross private domestic investment are subsequently revised by introducing alternative deflators to those employed in the U.S. national accounts. These deflators are given in Table III of the text. Gross private domestic consumption is left unchanged in this calculation. We compute stocks of land, structures, residential and non-residential, equipment, and inventories separately for each set of deflators. The basic formula is:

$$K_{t+1} = I_t + (1-\delta)K_t, \qquad \text{...(14)}$$

where I_t is the value of gross private domestic investment for each category in constant prices. The initial (1929) value of capital stock in constant prices of 1958 and the depreciation rates are as follows:

	National accounts deflators		Alternative deflators	
	K_{1929}	δ	K_{1929}	δ
Land	254,700	0	254,700	0
Structures				
Residential	183,234	0·0386	162,708	0·0384
Non-residential	163,205	0·0513	142,670	0·0509
Equipment	74,851	0·1325	51,701	0·1226
Inventories	48,504	0	48,504	0

2. In dropping the assumption that services are proportional to stock for both labour and capital, we require data on hours/man and hours/machine. The data on hours/man are derived from Kendrick's data on man-hours in the U.S. private domestic economy, extended through 1965.

To estimate hours/machine we first estimate the relative utilization of electric motors in manufacturing. Estimates have been given by Foss [24] for 1929, 1939 and 1954. We have updated these estimates to 1962. The basic computation is given in Table X. The 1954 data and the basic method of computation are taken from Foss [24, Table II, p. 11]. The 1954 data differ from the figures given by Foss due to a revision of the 1954 horsepower data by the Bureau of the Census and omission of the " fractional horsepower motors " adjustment. The latter, applied to both 1954 and 1962, would not have affected the estimated change in relative utilization. The horsepower data for 1962 and 1954 are from the 1963 *Census of Manufactures* [7], " Power Equipment in Manufacturing Industries," MC63(1)-6. Consumption of electric energy is taken from the 1962 *Survey of Manufactures* [11], Chapter 6. The 1962 total (388·2) is reduced by the consumption of electric power for nuclear energy (51.5) as shown in Series S81-93 of Bureau of the Census, *Continuation to* 1962 *of Historical Statistics of the U.S.* [9].

3. To estimate service prices for capital from the formula (11) given in the text we require data on the tax structure and on the rate of return. The variable u, the rate of direct taxation, is the ratio of corporate profits tax liability to total net private property income. These data are from the U.S. national accounts. The variable v, the proportion of return to capital allowable as a charge against income for tax purposes, is the ratio of

private domestic net interest to the after tax rate of return, r, multiplied by the current value of capital stock. Private domestic net interest is net interest less net interest for the rest of the world sector. These data are taken from the U.S. national accounts. We discuss estimation of the after tax rate of return below. The current value of capital stock is the sum of stock in land, structures, equipment, and inventories. Each of the four components is the product of the corresponding stock in constant prices of 1958, multiplied by the investment deflator for the component. Finally, the variable w, the proportion of replacement allowable for tax purposes, is the ratio of capital consumption allowances to the current value of replacement. Capital consumption allowances are taken from the U.S. national accounts. The current value of replacement is the sum of replacement in

TABLE X

Relative utilization of electric motors, manufacturing, 1954 *and* 1962

	Unit	1954	1962
1. Horsepower of electric motors, total	Thousand horsepower	91,505	126,783
2. Available kilowatt-hours of motors (line 1 × 7261)	Billions of kilowatt-hours	664·4	920·6
3. Electric power actually consumed, all purposes	Billions of kilowatt-hours	222·1	336·7
4. Per cent power used for electric motors	...	64·6	65·6
5. Power consumed by motors (line 3 × line 4)	Billions of killowatt-hours	143·5	220·9
6. Per cent utilization (line 5/line 2 × 100)	...	21·6	24·0
7. Number of equivalent 40 hour weeks (line 6 × 4·2/100	...	0·907	1·008
8. Index	1954 = 100	100·0	111·1

Line 2: The adjustment is derived as follows: It is assumed " that each electric motor could work continuously throughout the year . . ., 8760 . . . . Horsepower hours are converted to kilowatt-hours; . . . 1 horsepower-hour = 0·746 kilowatt hours. The result [is] . . . adjusted upward by dividing through 0·9, since modern electric motors have an efficiency of approximately 90 per cent. . . . " Foss [23, p. 11]. 8760 × 0·746/0·9 = 7261.

Line 4: Per cent power used for electric motors in 1962 computed using the industry distribution in 1945 given by Foss [24] in his Table I, and the 1962 consumption of total electric power by industries from the 1962 *Survey of Manufacturers* [11, Chapter 6].

Line 7: There are 4·2 forty-hour shifts in a full week of 168 hours.

current prices for structures and equipment. Replacement in current prices is the product of replacement in constant prices of 1958 and the investment deflator for the corresponding component. Replacement in constant prices is a by-product of the calculation of capital stock by formula (14) given above. Replacement is simply δK_t, where K_t is capital stock in constant prices.

To estimate the rate of return we define the value of capital services for land, structures, equipment and inventories as the product of the service price (11) and the corresponding stock in constant prices. Setting this equal to total income from property, we solve for the rate of return. Total income from property is gross private domestic product in current prices less private domestic labour income. Private domestic labour income is private domestic compensation of employees from the U.S. national accounts multiplied by the ratio of private domestic persons engaged in production to private domestic full-time equivalent employees, both from *The National Income and Product Accounts of the United States,* 1929-1965 [49]. This amounts to assuming that self-employed individuals have the same average labour income as employees.

The final formula for the rate of return is then the ratio of total income from property less profits tax liability less the current value of replacement plus the current value of capital gain to the current value of capital stock. The current value of capital gain is the sum of capital gains for all assets; the capital gain for each asset is the product of the rate of growth of the corresponding investment deflator and the value of the asset in constant prices of 1958.

4. The basic sources of data underlying Table VII of the text are summarized in Tables XI and XII. Table XI presents estimates of the distribution of the male labour force by school years completed for 1940, 1948, 1952, 1957, 1959, 1962 and 1964. These data are taken from various issues of the *Special Labor Force Reports* [5] and *Current*

TABLE XI

Civilian labour force, males 18 *to* 64 *years old, by educational attainment per cent distribution by years of school completed*

School year completed	1940	1948	1952	1957	1959	1959†	1962†	1965†
Elementary 0-4	10·2	7.9	7·6	6·3	5·5	5·9	5·1	4·3
5-6 or 5-7*	10·2	7·1	6·6 11·6	11·4	10·4	10·7	9·8	8·3
7-8 or 8*	33·7	26·9	25·1 20·1	16·8	15·6	15·8	13·9	12·7
High School 1-3	18·3	20·7	19·4	20·1	20·7	19·8	19·2	18·9
4	16·6	23·6	24·6	27·2	28·1	27·5	29·1	32·3
College 1-3	5·7	7·1	8·3	8·5	9·2	9·4	10·6	10·6
4+ or 4	5·4	6·7	8·3	9·6	10·5	6·3	7·3	7·5
5+	...	...	...	...	...	4·7	5·0	5·4

SOURCE: The basic data for columns 1, 3, 4, 5 and 6 are taken from U.S. Department of Labor, *Special Labor Force Report* [5], No. 1, " Educational Attainment of Workers, 1959 ". The 5-8 years class is broken down into the 5-7 and 8 (5-6 and 7-8 for 1940, 1948, and 1952) on the basis of data provided in *Current Population Report* [10], Series P-50, Nos. 14, 49 and 78. The 1940 data were broken down using the 1940 *Census of Population* [8], Vol. III, Part 1, Table 13. The 1952 breakdown for translating the 5-7 class into 5-6 and 7-8 was done using the information on the educational attainment of all males by single years of school completed from the 1950 *Census of Population* [8], Detailed Characteristics, U.S. Summary. The 1962 data are from *Special Labor Force Report* [5], No. 30, and the 1965 figures are from *Special Labor Force Report* [11], No. 65, " Educational Attainment of Workers, March 1965 ".

* 5-6 and 7-8 for 1940, 1948 and the first part of 1952, 5-7 and 8 thereafter.

† Employed, 18 years and over.

TABLE XII

Mean annual earnings of males, 25 *years and over by school years completed, selected years*

School year completed	1939	1949	1956	1958	1959	1963
Elementary 0-4	665	1724	2127	2046	2935	2465
5-6 or 5-7	900	2268	2927	2829	4058	3409
7-8 or 8	1188	2693 2829	3732	3769	4725	4432
High School 1-3	1379	3226	4480	4618	5379	5370
4	1661	3784	5439	5567	6132	6588
College 1-3	1931	4423	6363	6966	7401	7693
4+ or 4	2607	6179	8490	9206	9255	9523
5+	...	...	...	...	11,136	10,487

SOURCE: Columns 1, 2, 3, 4, H. P. Miller [45, Table 1, p. 966]. Column 5 from 1960 *Census of Population* [8], PC(2)-7B, " Occupation by Earnings and Education ". Column 6 computed from *Current Population Reports* [10], Series P-60, No. 43, Table 22, using midpoints of class intervals and $44,000 for the over $25,000 class. The total elementary figure in 1940 broken down on the basis of data from the 1940 *Census of Population* [8]. The " less than 8 years " figure in 1949 split on the basis of data given in H. S. Houthakker [32]. In 1956, 1958, 1959 and 1963, split on the basis of data on earnings of males 25-64 from the 1959 1-in-a-1000 Census sample. We are indebted to G. Hanoch for providing us with this tabulation.

Earnings in 1939 and 1959; total income in 1949, 1958 and 1963.

Population Reports [10], with some additional data from the 1940, 1950 and 1960 *Census of Population* [8] used to break down several classes into sub-classes. We could have used data from the 1950 and 1960 Censuses on educational attainment. The increase in the number of links did not seem to offset the decrease in comparability that would be introduced by the use of different sources of data. Table II presents estimates of the mean incomes of males (25 years and over) for these classes. These data are largely taken from Miller [45], supplemented by Census and *Current Population Reports* [10] data. Table VI of the text presents the relative incomes, the first differences of the educational distribution, and the computation of an appropriate index of the change in the average education per man.

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