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REVIEW OF CONCEPTS AND METHODOLOGY

The term "productivity" is generally used to denote a relationship between output and the associated inputs used in the production process. In this study we are not concerned with the marginal and average productivity concepts used in static equilibrium theory. We are concerned, rather, with the relationship between outputs and inputs, in real terms, over time in a dynamic economy. The basic objective of productivity estimates is to obtain at least rough measures of the impact on production of the investments and other variables that advance knowledge, improve technology and organization, and otherwise enhance the productive efficiency of the factors of production.

The meaning of productivity measures depends on the definitions accorded to output and input, the methodology by which the concepts are statistically implemented, including the weighting patterns used to combine unlike units of outputs and inputs, and the manner in which outputs are related to inputs. We shall consider each of these matters in turn, starting with the notion of the production function, which is the organizing principle behind measurement of the productivity relationship.

Productivity Ratios and the Production Function

The general notion of the production function may be expressed as follows:

$$O = f(I_1, I_2 \ldots I_n)(T). \tag{1}$$

"O" designates the potential or actual physical volume of output. Output may be defined in various ways; the important thing is that, given the output definition, the associated inputs (I) on the right-hand side be defined and measured consistently. In this study we generally take inputs to represent the real potential or actual services of the basic factors of production. Measures of factor service input are consistent with measures of net output, or "value added."

The factor inputs may be defined broadly or narrowly. Broadly, they may include the services of tangible as well as intangible resources—i.e., the stock of productive knowledge incorporated in the labor force and in nonhuman instruments of production, or "disembodied" as in the organization of production. Or, they may be taken to include only the tangible factor inputs unadjusted for changes in knowledge and other factors affecting efficiency. It is the latter approach which is used in this study. The tangible inputs themselves may be measured in terms of various types of labor and nonhuman capital services, or they may be collapsed into the two broad factor classes of labor (L) and capital (K) (which includes land as well as man-made capital goods). Since we have used the convenient two-factor approach, the production function can be narrowed to:

$$O = f(L, K)(T). \qquad (2)$$

The variable "T," sometimes loosely called "technology," really embraces all the forces that influence output in addition to changes in the physical volume of the tangible factor inputs. It is less misleading to refer to T as the "productive efficiency" of the tangible factors, or "total (tangible) factor productivity." Since the intangible capital stock accumulated through investments in research and development, engineering, education and training, and so on is the chief element behind productive efficiency, one would expect T to show much less change if intangible capital inputs were also included along with tangible inputs. But there would still be variations for reasons discussed subsequently.

If one develops time series for O, L, and K, one can measure changes in T either from statistical production functions, using the usual regression techniques, or by computing ratios of output to inputs. Since the latter is the approach generally used in *Productivity Trends* and the present study, we shall compare the two methods.

It is appropriate to start with the widely known Cobb-Douglas function, which is expressed in the following equation:

$$O_t = A_t L_t^b K_t^{1-b} \ . \qquad (3)$$

The symbols are as before, except that A_t, rather than T, is the level of productive efficiency in year t; and b and $1-b$ are the elasticities of output with respect to labor and real capital services, respectively. Under pure competition, neutral technological change, constant returns to scale, and certain other conditions, b and $1-b$, as applied to index numbers of the inputs, indicate the labor and property proportions of factor costs or income. Since the function is defined for the given state of knowledge, if it is to be fitted to logarithmic time series for O, L, and K under conditions of changing technology, provision must be made for estimating the rate of shift in the scalar A as well as the exponent b. One method, noted by Fabricant, is to substitute for A_t the expression $(1 + r)^t$. With t measured in years, the coefficient r measures the average annual (trend) rate of shift in the scalar A as a result of changes in technology and other factors affecting productive efficiency.[1] Presumably, the value for r is the same one would obtain with the slope of a trend line fitted to the index numbers of productivity computed as the ratio of output to a weighted geometric mean of the inputs, using as weights the exponents obtained from the statistical production function.

$$\frac{O_t}{L_t^b K_t^{1-b}} \cdot \tag{4}$$

One trouble with the approach just described is that it yields only the trend rate of productivity advance. An advantage of productivity ratios noted in my earlier study is that they " . . . provide greater flexibility for the analysis of movements and of relationships with other variables."[2]

Yet, as Nelson points out,[3] the period-to-period rates of change in the scalar, or productivity, may be obtained as the difference between rates of change in ouput and in the rates of change in labor and tangible capital inputs, each weighted by its share of income as derived from the statistical production function or directly from national income estimates. That is, when one differentiates the production function shown in equation (3), the result is:

$$\Delta A/A = \Delta O/O - b(\Delta L/L) - (1 - b)(\Delta K/K). \tag{5}$$

Here again, the residual rate of change is presumably the same as would be obtained by directly computing the rate of change in the consistent productivity ratio. Also, we could obtain a productivity time series by successively

[1] This form of the function is presented by Solomon Fabricant in his article "Productivity" in the *International Encyclopedia of the Social Sciences.*

[2] *Productivity Trends,* p. 8. For a recent review of the literature on productivity and production functions, see M. Ishaq Nadiri, "Some Approaches to the Theory and Measurement of Total Factor Productivity," *Journal of Economic Literature,* December 1970.

[3] R. R. Nelson, "Aggregate Production Functions," *The American Economic Review,* September 1964, p. 578.

linking the annual rates of change in the residual to a given base period taken as 100.

The point is that productivity estimates derived from output-input ratios are essentially interchangeable with those derived from statistical production functions, if the component variables and the underlying shape of the relationship are consistently specified. Actually, our total factor productivity ratio is specified somewhat differently from that implied in the Cobb-Douglas production function, as noted by Fabricant (see footnote 1 above). It may be written as follows:

$$\frac{O}{b^* L + (1-b)^* K} \quad . \tag{6}$$

In other words, our total tangible factor input is a weighted arithmetic average of labor and capital inputs. The asterisks indicate that the weights are derived not from a statistical production function but as the estimated shares of factor income; further, the weights are changed periodically and the total input indexes linked together for successive subperiods. We shall now discuss the implications of these differences from the Cobb-Douglas approach.

In the first place, by changing factor input weights occasionally, we avoid the assumption underlying the Cobb-Douglas production function of linear homogeneity with unit elasticity of substitution between the factors. Various statistical studies suggest that in the United States the elasticity of substitution is significantly below 1.0. (See Chapter 4.) Further, the national income estimates for the United States indicate that factor shares have changed over time. For the private domestic economy, the labor share has increased from 67.3 per cent in 1929 to 74.7 per cent in 1957—although this might reflect biased technological change as well as an elasticity of substitution of less than unity coupled with an increase in the quantity of capital per unit of labor input. In any case, we felt it was more realistic to posit a production function that was consistent with changing factor shares of income. It seemed adequate to change weights (for outputs as well as inputs) approximately every decade or so, since the structure of production and production relationships changes slowly, so that average proportions of outputs and inputs may be expected to alter significantly only over intermediate time periods.

Second, we did not obtain the weights for labor and capital in the successive subperiods by fitting statistical production functions to the data. Instead, we relied on the national income estimates of the U.S. Department of Commerce, with a few adjustments. In particular, we had to partition the net income of proprietors between the labor and capital components, as described in the appendix. And in the case of the nonbusiness sectors, we had to impute a net rental value to the capital goods in order to obtain a capital weight.

Actually, the exponents of statistical production functions have sometimes come quite close to the shares revealed by national income estimates. But because of the considerable instability of the coefficients in successive time periods and the variations in coefficients obtained from different types of functions, we have felt that national income estimates provide a better guide to relative shares. Besides, they are more readily accessible.

Finally, the fact that our total input index is a weighted arithmetic mean of the labor and capital input indexes, rather than a weighted geometric mean, implies a logarithmic linear relationship within successive subperiods. Our procedure is the simpler one usually employed in productivity ratios, and is consistent with the weighting procedure implicit in the real product indexes. It is true that it does not allow for the tendency toward diminishing marginal productivity of individual factors, given neutral technological change. But the difference in results of the alternative weighting procedures is small over the subperiods within which fixed weights are used in this study, given the historical differentials in the growth rates of labor and capital. For example, with average annual growth rates of output, labor, and capital taken at 3.5, 1.5, and 3.0 per cent, respectively, the total productivity index using a weighted geometric mean of the inputs (0.8 labor and 0.2 capital) would grow at an average annual rate of 1.70 per cent over successive decades. The growth rate of the productivity index based on inputs combined with arithmetic weights would average 1.68 per cent over one decade, and 1.66 per cent over two decades. Thus, the difference in results of the alternative weighting procedures would not generally show up over the subperiods when the productivity growth rates are rounded to tenths of percentage points.

Concepts and Methodology Underlying the Output and Input Indexes

The definitions and statistical content given to output and input can make much more difference in productivity movements than variations in the form of the underlying output-input relationship. In this section we discuss in some detail the operational concepts of output and of labor and capital inputs used in this study, contrasting them with alternative concepts suggested in the literature, or concepts which are considered possible. We summarize only briefly the sources of the estimates or of the data underlying our own estimates, since these are fully described in the appendix. Alternative time series are available which yield somewhat different results. Generally speaking, differences in the movement of most reasonable alternative series are not great. More important is the fact that the various estimates are subject to margins of error and possible biases that are not generally quantifiable. As pointed out in *Productivity Trends,* the output, input, and productivity indexes are not "precision tools," but they do indicate general orders of magnitudes of change, given the theoretical and conceptual framework within which they have been constructed and in terms of which they must be interpreted. A not unimportant test of their general reliability is provided by the reasonableness of the results obtained from statistical analyses based on productivity estimates and related series.

Output

Levels. There are three main levels at which aggregate output may be measured. The first is total gross output, which includes all goods and services produced without deductions for intermediate products consumed in the production process, or for capital consumption. In this case, the corresponding inputs include not only the gross factor inputs but also real intermediate product inputs. As far as gross product originating in the economy is concerned (or major sectors such as the business economy), inclusion of intermediate inputs obviously involves double counting, since such inputs have already been included in the final products and the factor services required to produce them are likewise included in total factor input. It is the final products included in national product that are the objective of production. These are the goods that satisfy current consumer wants or that add to stocks of productive capacity for satisfying future wants, to use the definition of Kuznets and many earlier national income theorists.[4]

Thus, at the economy-wide level, we are interested in the efficiency with which the basic factor resources are converted into the goods men want, so the appropriate productivity measure relates real (final) product to total factor input. We shall consider shortly the other choice as to whether real

[4] In addition to goods, men also desire maintenance of the social fabric, so the value of all government services (at cost), including national security, is included, not just direct services to consumers and public investment. See the discussion in Appendix A of *Productivity Trends,* pp. 231-39.

product and factor input should be gross or net of real capital consumption.

At the industry (or enterprise) level, the choice is not quite so clear-cut. For production analysis it may be useful in some cases to use total gross output estimates and relate them to factor inputs, plus intermediate inputs purchased outside the industry (or enterprise). The reason is that in production decisions management has to weigh alternative combinations of all inputs in the light of their relative prices so that the least-cost combination may be selected. On the other hand, from a macroeconomic viewpoint, there are persuasive arguments for using real product estimates (i.e., real value added, in which real intermediate costs are deducted from the real value of total gross output). The real industry product estimates in relation to real factor costs alone indicate changes in the efficiency with which the basic factors resident in the industry are used to add value to the intermediate products purchased from other industries. More important, the real industry product estimates are additive to real national product, and productivity in the economy as a whole represents, in effect, a weighted average of productivity in the component industries. For these reasons, our preferred industry measure is real product in relation to total factor input. In the cases of two-digit industries, we have had to use total output measures, but these have been used as proxies for real product and are also related to real factor cost alone for consistency with the sector and one-digit industry measures.

The other major choice must be made between the use of real gross product or real net product, and thus also between real gross or net capital stock on the input side. Here, again, the choice appears clear-cut from the standpoint of economic welfare: the production of capital goods required to offset capital consumption is not desired for its own sake, but is necessary to maintain capital intact. The consensus of national income specialists, likewise, is that NNP rather than GNP is the preferred measure from a welfare standpoint.[5] Because of the difficulties of measuring real capital consumption allowances as distinct from book depreciation, however, real GNP is frequently used as a proxy for real NNP, and we use it as such in our measures. Based on our estimates of real NNP for the private domestic economy and the business economy as a whole (shown in Table A-2), the ratios of real net to

[5] See, for example, Edward F. Denison, *Why Growth Rates Differ*, Washington, The Brookings Institution, 1967, pp. 14-15. As Denison puts it: "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."

gross product varied remarkably little over the entire period 1948-66. For both sectors, the ratios were 0.915 both in 1948 and in 1966. The nonfarm industry product estimates (for which we rely on OBE) are all gross, so we cannot analyze net-gross ratios on an industry basis. Indeed, were real net product data available by industry as well as for the business economy as a whole, we would have used it throughout. But the overall comparison suggests that trends are not significantly affected by use of real gross product estimates in lieu of the theoretically preferable net measures.

Griliches and Jorgenson attempt to rationalize use of real gross product and real gross capital input as preferable to the net measures: "Exclusion of depreciation on capital introduces an entirely arbitrary distinction between labor input and capital input, since the corresponding exclusion of depreciation of the stock of labor services is not carried out."[6]

Most national income specialists believe, however, that, from a welfare viewpoint, the personal consumption outlays required to offset depreciation of human capital (and to maintain it) should be included in NNP.[7] Denison argues as follows: "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."

A formal symmetry between labor and capital can be quite misleading, since man is the end as well as a means of production. On the other hand, from the viewpoint of productive capacity, the notion of human capital consumption has meaning, since over the long run it must be offset in order to maintain total capital intact. Unfortunately, little work has been done on estimating human capital and capital consumption. In view of the lack of estimates in this area, there is some merit in the suggestion of Griliches and Jorgenson that by including depreciation in the weight for capital input the relative weight of labor is reduced, as would be the case if both factor returns were measured net of depreciation. Further, since real gross product measures are used in estimating productivity, it would be of some interest to use real gross capital and total inputs with corresponding gross weights for capital as well as labor. This would make it possible to see the difference in movement between the gross productivity measure and our basic total factor produc-

[6] Dale W. Jorgenson and Zvi Griliches, "The Explanation of Productivity Change," *The Review of Economic Studies*, July 1967, p. 256.

[7] Edward F. Denison, "Some Major Issues in Productivity Analysis: An Examination of Estimates by Jorgenson and Griliches," *Survey of Current Business*, May 1969, Part II, p. 2.

tivity measure, in which capital input is measured net of depreciation and weighted accordingly.

The variant indexes of gross capital input, gross capital productivity, and total gross productivity are presented in the appendix tables. In general, the effect is to produce a somewhat smaller rate of increase in the gross productivity measure than in the standard measure, not because gross capital input rises more than net but because of the greater weight accorded to the capital measures, which generally rise significantly more than labor input.

Aggregation. In order to combine units of the many diverse types of output, market price weights are used to obtain the real product aggregates. For production and productivity analysis a case can be made for using unit factor cost weights. But as a practical matter the differences in movement of real product using the alternative weighting patterns are probably small, and the work of eliminating the differential effects of unit indirect business taxes less subsidies on market prices would be enormous.

Since relative market prices change gradually, the price weights in successive periods were changed in line with the procedures described in *Productivity Trends.* We have used average prices in the boundary years of the following subperiods: 1919-29; 1929-37; 1937-48; and 1948-53. For the final period beginning 1953, we have used 1958 weights in line with current government practice in order to keep the estimates open-ended. This is consistent with our weighting system for inputs. Although there is no unique solution to the "index number problem," it seems appropriate to weight outputs and inputs on the basis of their relative prices in successive subperiods of sufficient length for allowing changes in the structure of production to become perceptible.

In reweighting the estimates for periods prior to 1953, we employed the breakdown of real product by industry, rather than by type-of-product groupings as in *Productivity Trends.* The earlier weight bases tend to produce larger apparent increases in real product than do later bases. This is due to the negative correlation between relative changes in prices and in quantities. But the differences are not large. Since the effects of alternative weight bases on aggregate inputs are in the same direction, the effects on the productivity ratios are even smaller than the effects on output and input separately.

Scope of the Economy, Sector, and Industry Product Estimates. Like any other statistical construct, the national product is what it is defined to be. The United States, and most other countries, largely confine the estimates to legal market transactions. Such transactions are usually clearly economic, involving a quid pro quo, and the market provides an objective means for valuing the goods and factor services. Further, data are generally available for at least a sample of the transactions.

Nevertheless, most countries also include imputed values for certain important nonmarket activities that also seem clearly economic (in that they are undertaken primarily for the sake of the resulting product rather than for the sake of the activity itself, as in social and recreational activities). Imputations in the United States are confined to selected activities for which there are significant market counterparts to provide a means of valuation. Official imputations—of which the major ones are for the rental value of owner-occupied houses, food produced and consumed on farms, and payments in kind—comprised a relatively small share of GNP: about 8.6 per cent in 1929, 5 per cent in 1948, and 7.2 per cent in 1966.

Obviously, imputations could be expanded much further to include, for major examples, the value of unpaid household labor, schoolwork, volunteer labor, and, on the capital side, imputed rental values of nonbusiness capital goods. In another study for the National Bureau, my associates and I developed estimates of imputed valuations for the above items and several others which together add more than 50 per cent to the GNP in 1966.[8] We have not included these estimates in the present study, however, with the exception of rental values of nonbusiness capital stocks.

The chief reason for not expanding product imputations in a productivity study is that the values are imputed from the cost side. That is, the inputs into nonmarket economic activities are estimated and values assigned on the basis of their opportunity costs. This is basically what is currently done by the Commerce Department in estimating current-dollar product originating in the nonbusiness sectors, although the Department largely confines itself to the labor inputs, neglecting the contribution of the stocks of nonbusiness capital, except for owner-occupied residences. Estimates are not made of the volume of nonmarket outputs and their unit and total values. So only half of the information needed for productivity comparisons is available. Therefore we have not expanded the scope of present official GNP estimates, except as noted.

The exception relates to our inclusion of the gross rental values of the stocks of tangible capital used in the general government sector and in private nonprofit institutions. Already, OBE counts the compensation of employees as product originating in these sectors (and households). But since a major aspect of our study involves estimating capital as well as labor inputs, we have

[8] See *Forty-seventh Annual Report*, National Bureau of Economic Research, June 1967, pp. 9-15.

done so for governments and private nonprofit institutions in order to maintain symmetry with the private business sector. Since returns to capital comprise part of private domestic business product, we have likewise imputed the rental value of the capital inputs in the aforementioned nonbusiness sectors. With product originating in the household sectors confined to paid employees, we have not included the imputed rental value of household durables and inventories, since these are predominantly used by unpaid family labor, the value of which we do not add in this study.

By convention, the Commerce Department deflates product originating in the nonbusiness sectors largely by corresponding input price indexes, so that real product parallels the movement of input without adjustment for productivity change. Likewise, our real rental values of tangible capital parallel the movements of the real capital stocks. Thus, it is clear that productivity analysis is best confined to the private domestic business economy, for which there are relatively independent real product estimates. For analysis of long-run trends, however, we have used the private domestic economy, since adequate input and real product estimates for households and nonprofit institutions are not separately available prior to 1929. We also refer briefly in the next chapter to productivity trends in the economy as a whole, since such estimates are useful for certain purposes so long as one recognizes the downward bias imparted by the conventions used in the nonbusiness sectors.

In addition to varying delimitations of the scope of national product, there are also alternative concepts with regard to the definition of the final products to be included, as opposed to intermediate products considered to be incorporated in the final products. Some items charged off to current expense by business and likewise considered intermediate by OBE might be classified as final—small tools, research and development, welfare services to employees, and entertainment or education provided to the public as part of advertising expense. Some personal outlays might be adjudged intermediate, such as commuting expenses, or personal business expenditures. Even if one considers national security outlays to be final services (as we do on the grounds that national security is a goal of society just like want satisfaction), it is possible to argue that some government services are designed to promote private business and should be viewed as an offset to indirect business taxes. In *Productivity Trends*, in addition to the official GNP estimates, we also presented variant output and productivity estimates based on the work of Simon Kuznets, which excluded a portion of government purchases as being intermediate. The Kuznets estimates, including national security, actually showed much the same movements as the Commerce estimates, due to the relatively small volume of government cost services (which were estimated quite roughly). Since the Kuznets series has not been continued, we do not extend the variant based on his estimates.

Thus, we rely largely on the official national product estimates by sector, but we have pointed out the alternative concepts and definitions that would result in somewhat different movements in the aggregates and probably also in the productivity ratios. All in all, at this stage of our knowledge, it would not be advisable to expand imputations or redefine final product for purposes of productivity analysis. In the area of growth analysis, with particular reference to inputs or real costs, further experimentation can add to our knowledge, judging from preliminary results of the National Bureau's current studies in the national economic accounts referred to above.

Turning to the scope of our industry estimates, from 1948 forward these follow the definitions of the 1957 Standard Industrial Classification (SIC). This is in line with the recent economic censuses and with the 1965 revisions of the OBE national income and product accounts.[9]

We use the OBE estimates of income and product originating by industry for the major SIC one-digit industry groupings and the broad subgroup aggregates which OBE also publishes. Actually, OBE obtained its real industry product estimates on the basis of the difference between real value of total output and real intermediate costs—the so-called "double deflation" method—for only about 50 per cent of the business economy. For most of the other industries, base-period gross product was extrapolated by physical output series, or by the deflated value of total output, on the assumption that net-gross ratios did not change significantly. In the remaining industries, current-dollar gross product was deflated directly by output price indexes or, in a few cases, by input price indexes, which may result in a downward bias in the resulting real product series, as noted in the next section.

For the two-digit industries, we have used production indexes that, in the case of manufacturing and mining, have been "benchmarked" on the periodic economic censuses. The OBE does not regularly publish real product estimates at the two-digit level. Those that have been published on an occasional basis reveal some erratic movements, which may be expected from the double-deflation approach when the underlying data are imperfect. So even if the real product estimates for two-digit industries were regularly available, there would be some advantage in using gross production indexes due to their greater stability. The trends of aggregates based on the two types of measures

[9] *The National Income and Product Accounts of the United States, 1929-1965*, Statistical Tables, a supplement to *The Survey of Current Business*, U.S. Department of Commerce, 1966.

are compared in the appendix (pp. 194-95). The aggregates based on gross production indexes have a slightly higher trend in the postwar period. This should be kept in mind if one compares, in Part III of the appendix, productivity in two-digit industries with industry-group or industry-sector aggregates that are based on real product estimates.

Output Units. It would be ideal for the economic statistician if output units of various types were standardized and unchanging through time. Further, if he had complete physical volume data and unit values in the base period, or value data and corresponding price indexes for deflation, he would have no problem in obtaining weighted production aggregates.

In the real world, however, the ceaseless changes that frequently benefit consumers create problems for the statistician. Certain goods are custom-built and services adapted to individual requirements, the quality of many goods and services may improve—or at least change—with time, and new products may appear while old ones disappear. Further, quantity as well as value and price data may leave much to be desired, particularly in the finance and services industries.

These problems were discussed in some detail in the text and appendixes of *Productivity Trends.* In brief, our conclusion is that real product estimates tend to understate somewhat the growth of output and productivity.

With regard to nonstandard products, the use of cost indexes (including wage rates) as deflators of value estimates imparts a downward bias insofar as productivity has increased in a particular industry. The areas involved are mainly parts of construction, shipbuilding, aircraft manufacturing, machine building, and some of the services areas—although, when households and nonprofit institutions are excluded, price indexes are available to deflate most of the remaining private service outlays. Some offset to the upward bias of cost deflators is provided by the fact that price indexes for the standardized portion of the output of some industries are also used to deflate the value of the custom-built portion, as in the case of machinery. It seems likely that productivity increases less in custom work than in standardized production, lending a downward bias to the price indexes.

New products that appear after a base period are usually assigned the same ratio to the average price of like goods as they had in the first year of significant commercial production. This convention would have little effect on real product other than some understatement of the increase in the small amounts produced prior to the beginning of full commercial production, when price data collection would begin. This assumes that the relative price of new products typically declines during the developmental phase.

Much more important than the new product phenomenon is the improvement in quality of existing products. Indeed, it is sometimes hard to draw a dividing line between improved versions of old products and new products. One must also distinguish between the improvement of given product lines and a relative shift of purchases toward higher-quality, higher-price lines. The latter phenomenon is reflected in increases in real product obtained by price deflation, since the price data underlying the indexes relate to homogeneous items with given specifications.

Two chief methods are used to deal with quality changes in the price indexes used for deflation. According to one method, the price agency attempts to divide the price change associated with a new model between that which represents an increase in unit real costs and that which is the "pure" price change. In this way, deflated product reflects improvements in products that are associated with unit real cost differentials. To the extent that quality improvements exceed real cost changes, the real product estimates have a downward bias.

This may be offset to some extent by the other way in which model and quality changes are handled. The new price may be directly linked to the old, so that the entire price increase of a new model shows up as an increase in real product. In an inflationary era, as that under study in the present volume, this method may tend to overstate quality improvements, or at least understate it less than the first method.

Not all model changes represent quality improvements, of course, particularly those which are largely stylistic. And some goods and services have undoubtedly deteriorated over time. But the consensus of observers is that, on balance, quality has increased more than the changes in unit real costs of improved products. Thus, real product and productivity measures probably tend to have some downward bias on this score, which, insofar as the bias differs among products, affects industry comparisons. Unfortunately, however, we cannot quantify the extent of the quality bias, which is even difficult to define in measurable terms due to the highly subjective element involved.

Tangible Factor Inputs

The general discussion in this and the following two sections on labor and nonlabor inputs is confined to the basic factors of production. The concepts and measurement of intermediate inputs have already been treated in the preceding section on output, since intermediate product inputs of one industry are simultaneously the outputs of other industries.

Definition of Factor Stocks and Inputs. Factor services or "inputs," as we view them, represent the time available for use in production of the stocks of the tangible labor and nonlabor factors of production weighted by the base-period value products per unit of the available factor time. The nonlabor factor comprises man-made capital goods—structures, equipment, and inventories—and "land," which comprises all natural resources stocks. We do not distinguish between land and man-made capital goods, since they are alike in all important economic respects. When we refer to "capital" generally, or "property," we mean the total of the nonhuman factor. We shall refer to the human factor as "labor," for short.

It is useful to distinguish between the human and nonhuman tangible factor categories (labor and capital), despite their basic similarities as agents of production, because of even more important dissimilarities. Property is owned, and can be sold as well as leased, whereas human beings are free agents and only their services can be sold. The source of labor compensation is work, whereas the source of property income is prior savings. The division of national income between labor and nonlabor compensation is basic to studies of income distribution by function and size, reflecting the inevitably man-centered focus of the social sciences. Accordingly, we measure factor stocks and inputs in terms of this fundamental dichotomy.

In our definition of factor inputs, we referred to the time available for use in production of the factor stocks. As discussed in *Productivity Trends,* this points up a basic asymmetry between labor and capital. Productive human capital is obviously not coterminous with the population. Substantial portions of the population—the very young, the very old, and the infirm—are unable to work. Of those able to work, a certain proportion become members of the labor force. Of the total labor force, at any time there is some portion of voluntary or involuntary unemployment. We would count as productive human capital only the employed labor force, and, to obtain the time rate of use, count the man-hours "at work" during the periods for which output is measured—years, in this study.

While at the workplace, men may be more or less fully and efficiently utilized, at any given level of technology. As matters of both principle and expediency, we do not try to adjust man-hours at work for the degree or intensity of utilization. We count only the man-hours at work; changes in the utilization factor would show up as changes in the productivity ratio.

It is useful, however, to construct measures relating to labor utilization rates which may help explain changes in productivity. The ratio of employment (or unemployment) to labor force is one such variable, since employees, particularly nonproduction workers, are often not utilized as fully while at work in periods of decelerated growth or contraction as they are in periods of expansion. Deviations from trend of average hours worked would tend to measure the same phenomenon. As a trend factor, however, the decline in average hours worked per week and per year has been considered by some to enhance the efficiency of man-hours worked up to some point. Denison has tried to allow for this effect in his measures of labor input.[10] Apart from the fact that such estimates are speculative, we prefer to let the effects of changing average hours worked show up in the productivity ratios, and use average hours series as a possible explanatory variable. A preferable variable would be a direct measure of the average hourly intensity or relative efficiency with which people work, at successive levels of technology. Although "work measurement" attempts to get at this factor for selected individuals and groups at the establishment level, it would be impossible to obtain aggregate measures for entire industries or the business economy as a whole.

In contrast to the human population, the entire living population of capital goods (those that have not been discarded, including items in active "standby" status) is available for productive use at all times, and involves a per annum cost, regardless of degree of use. The purpose of capital assets is for use in production of current output and income. The degree of capital utilization reflects the degree of efficiency of enterprises and the social economy generally. Hence, in converting capital stocks into inputs, we do not adjust capital for changes in rates of capacity utilization, and thus these are reflected in changes in the productivity ratios.[11]

Efforts to measure the percentage utilization of the productive capacity of real capital stocks are to be welcomed as adding to our information on explanatory variables. Unfortunately, no reliable long-run measures of this variable are available either for the business economy or for most of its industrial divisions. Griliches and Jorgenson, for example, attempted to devise such a measure for purposes of converting a real capital input series to a utilization basis, as opposed to the availability basis employed in this study. Their measure showed a significant increase over the period, reducing their magnitude for total factor productivity by an average of 0.6 per cent a year.[12] But as Denison has argued, the statistical basis of their measure is

[10] Edward F. Denison, *The Sources of Economic Growth in the United States and the Alternatives Before Us*, Supplementary Paper 13, New York, Committee for Economic Development, 1962, pp. 265-66.

[11] In *Productivity Trends* (pp. 76-77) a variant productivity measure is presented for the private economy from a "social cost" viewpoint, in which all available labor is counted as input, so that changes in rates of utilization of labor show up in the productivity ratio. Productivity trends are not affected, however. Lack of data prevents this approach from being implemented on an industry basis.

[12] D. W. Jorgenson and Z. Griliches, "The Explanation of Productivity Change," 1967, reprinted with corrections in *The Survey of Current Business*, May 1969, Part II. Jorgenson has subsequently reduced the scope and magnitude of his capacity utilization

very tenuous, and it is extremely doubtful that there has been nearly as large a secular increase in the rate of utilization of capacity in the entire private domestic economy as their measure shows.[13]

Thus, to our theoretical argument for not adjusting real capital stock and input for changing rates of utilization is added the pragmatic consideration that adequate measures are not yet available. Such a measure would be very useful as one of the several variables discussed later which may help to explain the movements of total factor productivity as we measure it. Those investigators who wish to use it for adjusting capital input should be careful to provide it as a separate component of the input measure, so that its influence may be isolated. It should be noted that the unadjusted capital series generally rise significantly in relation to labor inputs in recession years.

Finally, there is the question of using real gross or net stocks of capital as the appropriate base from which to estimate depreciable capital inputs. In principle, this issue is distinct from the matter of weights–it will be recalled that our basic capital input series incorporate net capital compensation weights, with a variant measure using gross weights that include capital consumption allowances. In the latter measure, we use real gross stocks. That is, the full value of the depreciable capital units at base-period prices are carried until they are discarded from stock. From a productivity standpoint, this implies that their output-producing capacity is maintained over their lifetime. But even with adequate maintenance and repair, it is probable that output-producing capacity of depreciable units does decline somewhat as these age–due to physical deterioration, increased downtime for repair, and creeping obsolescence which may result in shifts of the assets to less productive uses. Under these circumstances, an increase in the average age of depreciable assets would tend to be associated with decreases in productivity, other things being equal, and vice versa. This suggests that a time series on the average age of depreciable assets would be a useful explanatory variable in causal analysis. (See Chapter 4.)

In our basic capital and associated productivity measures, we used real net

adjustment; see L. R. Christensen and Dale W. Jorgenson, "U.S. Real Product and Real Factor Input, 1929-1967," Discussion Paper No. 109, Harvard Institute of Economic Research, February 1970.

[13] "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." Denison, *Survey of Current Business*, May 1969, Part II, p. 21.

stocks of depreciable units, with consistent net capital compensation weights. Available evidence suggests that a declining balance method of estimating depreciation is appropriate when it is desired to approximate the decline in value of durable goods as they age.[14] But it is not plausible that the output-producing capacity (as distinct from the present value of the future net income stream) declines more in early years than in later years. Accordingly, we have used real net stock estimates for the private economy and the component industries based on straight-line depreciation, as in *Productivity Trends.*

In effect, this means that we have employed a type of "vintage weighting" of depreciable assets. That is, fixed capital goods of different ages are treated as separate goods, with progressively declining price weights for successive age categories. Thus, an increase in the average age of the stock would be reflected in a decline in the ratio of real net stocks to gross stocks, reflecting the probable decline in output-producing capacity, other things being equal.

Actually, even though use of straight-line depreciation means a smaller proportionate decline in net stock in early years and a larger proportionate decline in later years, it probably tends to overstate the overall decline in output-producing capacity of depreciable assets as they age. Goldsmith has suggested that an average of real gross and net stocks is more appropriate for productivity analysis than either separately, and Denison uses a weighted average of real gross and net stocks in his empirical work. We do not make use of such a variant, but since we present both real net and gross capital stock estimates, the reader is enabled to experiment with combinations if he wishes. Actually, the overall net-gross ratios generally have not changed greatly during the period under study. In the private domestic economy as a whole, real net capital stocks and input rose about 3½ per cent more than the real gross capital measure between 1948 and 1966 (see Tables A-19 and A-19a).

Finally, we must stress that the real capital stock and input estimates have not been adjusted for changes in the quality of individual new capital goods as models change. The price deflators result in increases only when the unit real cost of new models increase as compared with the models being supplanted. The productive efficiency of newer models in terms of output-producing capacity may increase considerably more, of course. But as Denison pointed out long ago, to adjust capital outlays, stocks, and inputs for changing productive efficiency would lead to essentially uninteresting results in analy-

14 See George Terborgh, *Realistic Depreciation Policy*, Chicago, Machinery and Allied Products Institute, 1954.

sis of production and productivity.[15] Measures of the advance in productive knowledge, as embodied in human and nonhuman capital and as reflected in organization of production, would be of great interest, however, as a major force helping to explain productivity advance as we measure it. We refer to preliminary results of experimental measures of this type in Chapter 4.

The real reproducible capital stock estimates for the private domestic business economy, by farm and nonfarm components, are from the Office of Business Economics. Our preferred variant for the depreciable asset component was based on Treasury Bulletin "F" service lives less 15 per cent, the Winfrey S-3 retirement curve, and "constant cost 2," which adjusts the nonfarm construction cost deflator for upward bias; the net stock estimates are those calculated under straight-line depreciation. The trends of these estimates are compared with trends in other variants of the gross and net stock in the appendix (Table A-ii). Since the depreciable stock estimates are obtained by OBE via the perpetual inventory method and their own real gross investment series, they are consistent with the real product estimates. The real private inventory estimates, farm and nonfarm, are also derived from OBE estimates by cumulating the real net changes forward and back from the real inventory stock estimates for the base period. The land estimates are based largely on the estimates and methodology developed by Raymond Goldsmith, as cited in the appendix (p. 159). Despite Goldsmith's ingenuity, due to poverty of basic data, the land series are probably the weakest portion of the capital stock estimates.

The real nonfarm depreciable capital estimates by industry are drawn largely from the work of Daniel Creamer and Michael Gort (see pp. 200-208). Although based on different sources and methods from the aggregate estimates prepared by OBE, they appear to reconcile quite closely (see Table A-xii in the appendix).

Factor Inputs. To obtain factor inputs at constant prices, the hours that tangible stocks are available for use in the various industries are in effect multiplied by base-period average hourly compensation. In the case of labor, man-hours worked by industry are weighted by base-period average hourly labor compensation. Persons engaged in production (comprising all classes of employees, plus proprietors, self-employed, and unpaid family workers) are multiplied by average hours worked per year, by industry. The labor compensation weights include not only wages and salaries but all supplements, as

[15] Edward F. Denison, "Theoretical Aspects of Quality Change, Capital Consumption, and Net Capital Formation," *Problems of Capital Formation*, Studies in Income and Wealth, Volume Nineteen, Princeton University Press for NBER, 1957.

estimated by OBE, plus imputed compensation for hours worked by proprietors and unpaid family workers. Industry factor weights are not intended as a means of adjusting for quality, but only as a means of making the business economy measures an internal weighted mean of the component industry measures. As such the labor input estimates reflect interindustry shifts.[16] The weighted man-hour aggregate could alternatively be obtained by deflating labor compensation by a composite variable-man-hour-weighted average hourly compensation index.

The real capital stock estimates are weighted directly by the base-period percentage rates of return in the component sectors. The estimates of capital compensation (interest, net rents and royalties, and profits) are on a before-tax basis, as is labor compensation, and are likewise obtained from the OBE national income accounts. Profits include not only corporate profits but the nonlabor portion of net proprietors' income, estimated as described in the appendix. For our basic capital input measure, capital compensation after capital consumption allowances is related to the real net capital stock. For purposes of weighting real gross capital input to obtain the gross input and productivity variants, gross capital compensation, including depreciation and other capital consumption allowances, is used to obtain the gross rate of return in the base period.

The real capital input estimates so obtained are equivalent to those that might be computed by deflating gross and net capital compensation by indexes of gross and net rental rates. Such price deflators represent a composite of the replacement prices of the underlying capital assets and the net or gross rates of return on the net or gross capital stocks.[17] These rental rates may be construed as an average hourly rental charge for machines or other types of real capital; but since we maintain that, in contrast to labor stocks, capital is in principle available for use throughout the period, we may as well conceive of them as monthly, quarterly, or annual rental rates.

It has been suggested that the asset price indexes should be adjusted for the element that reflects expected capital gains over and above the expected net income stream from use of the assets in production. Since our depreciable asset price indexes represent replacement costs rather than actual market prices, this would not appear to be an appropriate adjustment, even if

[16] See p. 157. Interoccupational shifts are not reflected. For a discussion of the latter, see R. L. Raimon and V. Stoikov, "The Quality of the Labor Force," *Industrial and Labor Relations Review*, April 1967, p. 3

[17] See John W. Kendrick and Ryuzo Sato, "Factor Prices, Productivity, and Economic Growth," *American Economic Review*, December 1963, p. 977.

feasible.[18] The asset most likely to be significantly affected by a speculative element in pricing is land. But the estimates used for land values, as described in the appendix, are generally regarded as conservative, and in the present unsatisfactory state of knowledge concerning asset prices, particularly land values, it is not at all certain that the relative prices and price movements reflect a speculative element.

Within the several broad sectors for which separate capital weights are applied, it is assumed that the net rates of return on the various types of assets are the same, so that, in effect, net earnings are assumed to be allocated among them in proportion to base-period net asset values in our basic measures. Griliches and Jorgenson would have used gross capital compensation (rental) weights, and thus would have weighted depreciable assets more heavily than nondepreciable ones. But since our basic measures attempt to relate net output to real factor cost exclusive of nonhuman capital consumption, their procedure would not be appropriate.[19]

When gross capital weights are employed, one might weight the depreciable and nondepreciable assets separately, adding the capital consumption rate to the net capital compensation rates only in the case of the former types of assets. Capital movements would be affected to the extent that capital composition changed. It is uncertain in practice how much difference such an internal weighting scheme would make—it might be significant in agriculture, for example. But since the gross capital and productivity estimates have a subsidiary place in this study, we have not undertaken the lengthy procedure involved in weighting by type of asset within the several sectors.

Total Factor Productivity: Characteristics and Meaning

Total factor productivity may be viewed as the relationship between real product and real tangible factor cost. So expressed, the measures flow directly from the national income and product accounts, in the aggregate and by sector and industry.[20]

18 See Denison, *Survey of Current Business,* May 1969, Part II, pp. 8-9.

19 With regard to this point and some earlier ones, the following statement by Denison (ibid., p. 13) is pertinent: "Jorgenson and Griliches 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. 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."

20 For a discussion of the usefulness of the economic accounts as a framework for productivity measurement and analysis, see my Introduction to *Output, Input, and*

The use of the national income and product accounts as the framework for our output, input, and productivity estimates contributes greatly to the consistency of the estimates. The Department of Commerce economic accounts are used to provide not only weights for outputs and inputs but also the more aggregative output (real product) estimates and important components of the labor and capital input estimates. The scope of the sector and industry output and input estimates is the same; and since income and product are estimated within an accounting framework, the magnitudes of the two sets of estimates are broadly consistent. That is, although the current dollar estimates of income and product are drawn from largely independent sources, the aggregates of each reconcile within relatively small net margins of error, as indicated by the statistical discrepancies. This is true not only with respect to the aggregates but also for the sum of the industry income and product estimates, which represents an alternative statistical approach to obtaining business economy aggregates. Here, again, the statistical discrepancies are not large, indicating broad consistency between the aggregate and industry estimates. Within the industry groupings, too, income and product reconcile closely.

If, as is customary, GNP or NNP estimates at market prices are deflated by market price indexes, the resulting real product estimates may be reduced by the base-period ratio of indirect business taxes less subsidies to gross or net product in order to approximate real product at factor cost, which lends the desirable attribute of equality with real factor cost, gross or net, in the base period. Factor cost or income, after division into the labor and property components, may be deflated by composite price indexes for the labor and capital inputs, as discussed above. To reiterate, the same result is obtained in this study by extrapolating base-period labor and property compensation through the measures of real labor and capital input.

The application of base-period factor compensation weights to factor input units, unadjusted for changes in quality or efficiency, results in productivity ratios with the following general meaning. Real product in the given year indicates what the factor cost requirements would have been assuming the base-period conditions of productive efficiency, compared with what they actually were (given-year real factor cost), reflecting the effects of technological change and other variables affecting productive efficiency. Or, to state the same notion differently, the productivity ratio indicates the relation of real

Productivity Measurement, Studies in Income and Wealth, Vol. 25, Princeton University Press for NBER, 1961. This approach has subsequently been stressed by Z. Griliches and D. Jorgenson, although their suggested deflation procedure differs from mine.

product in the given year to the real product that would have been produced (real factor cost) if the productive efficiency of the factors had been the same in the given year as in the base year.

It may be helpful to look at some of the characteristics of the total factor productivity measures as background for the quantitative analysis of subsequent chapters. Our basic measure of productivity is the index number of the ratio of real product to real factor cost (see Table 2-1, column 3). The index

TABLE 2-1

Private Domestic Business Economy:
Changes in Real Product, Factor Cost, and Productivity, 1958-66

	1958	1966		Average Annual Rates of Change (Per Cent)
	Billions of Dollars	Billions of Dollars	Index, 1958=100	
1. Net product, at factor cost	312.2	519.9	166.5	6.6
2. Implicit product price deflator (1 ÷ 3)[b]			110.4	1.2
3. Real product	312.2	471.1[a]	150.9	5.3
4. Implicit factor price deflator (1 ÷ 5)[b]			138.4	4.2
5. Real factor cost	312.2	375.6[a]	120.3	2.3
6. Total factor productivity (3 ÷ 5)[b]			125.4	2.9
7. Factor product price ratio (4 ÷ 2)[b]			125.4	2.9
8. Productivity increment (3 - 5)		95.5[a]		

Source: Line 1: U.S. Department of Commerce estimates of national income originating in the private domestic business economy, adjusted as indicated in the appendix (pp. 149-51); line 3: net product (factor income) in 1958 extrapolated to 1966 by the real product estimates underlying Table A-20, less real capital consumption allowances; line 5: Table A-20, index number of total factor input for 1966 (1958=100) applied to base-period factor cost.

[a] Billions of 1958 dollars.

[b] This holds for rates of change when 100 is first added to each rate.

number for total factor productivity in 1966 (1958=100) is 125.4, which means an average annual rate of increase of 2.9 per cent (line 6, column 4). This is approximately equal to the difference between the rates of change in real product (5.3 per cent) and in real factor cost (2.3 per cent). Actually, the relationship is multiplicative when 100 is added to each of the percentage rates of change (102.9 $\times$ 102.3 = 105.3); but when the rates of change of input and productivity are small, they are additive to the rate of change in real product with ±0.1 per cent.

Note also that since NNP at factor cost and national income are equal in current prices, the total factor productivity ratio must equal the ratio of the factor cost deflator to the product price deflator (column 3: line 4 ÷ line 2 = line 3 ÷ line 5 = line 6 = line 7). Another way of looking at this relation is that factor prices rise by more than product prices to the degree that total factor productivity advances. In fact, this is the means by which the market distributes productivity gains. The relation also indicates that the impact of the rise in factor prices on product prices is mitigated to the degree that productivity advances. None of these statements implies a causal relationship; they all merely verbalize truistic relationships.

A final way in which we may regard productivity advance is as an increment in the given period over and above what real product would have been at base-period efficiency (column 2: line 8 = line 3–5). The increment represents the same per cent increase over base-period real product as is indicated by total factor productivity, of course. But the advantage of calculating a productivity increment in real dollars is that its distribution between the factors of production can be calculated, as was done in *Productivity Trends*. The size of the productivity increment obviously depends on the period chosen as a base for comparing the given period.