MEASURING CAPITAL INPUT FOR TOTAL FACTOR PRODUCTIVITY ANALYSIS: COMMENTS BY A SOMETIME ESTIMATOR*

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This paper attempts to review and evaluate the concepts of estimating procedures employed in measuring capital input for use in total factor productivity estimation. Where alternative estimating procedures are used an effort is made to determine how sensitive the estimate of capital input is to each alternative. The review and critique are restricted to four estimates of the U.S. economy.

The concern of this paper is the best measure of capital input for the measurement of total factor productivity and how close to this best estimate it is possible to come, given the data and the state of the estimating art. This is only one of numerous analytical and policy uses for estimates of capital input. Among its more frequent uses in recent decades, other than in factor productivity, one would have to mention the formulations of production functions, long term projections within the framework of the input-output matrix, the application of the stock-adjustment principle to cyclical fluctuations, the use of capacity estimates for war mobilization and postwar reconstruction, and the analysis of structural differences and changes within an economy and between economies. It is a tiresome commonplace that typically there is no unique measure of a given variable that is necessarily the best measure for all analytical uses.

Still another commonplace observation needs to be mentioned. The concept of a stock of capital is an elusive one and this imparts an additional difficulty to any attempt to give empirical content to the concept. An estimator venturing into this particular area should be possessed of a temperament that combines skepticism with daring. He must realize that at best the estimates will be crude but will bear the stamp of reasonableness and he is comforted by the knowledge that this same situation is encountered in sciences often thought to be more precise than economics. Yet useful measures and insights emerge from the analysis of these equally elusive concepts. Joan Robinson reminds us of this condition by quoting a passage from K. R. Popper, *The Open Society and its Economics.*

> "The view that the precision of science and of scientific language depends upon the precision of its terms is certainly very plausible, but it is none the less a mere prejudice. Rather, the precision of a language depends just upon the fact that it takes care not to burden its terms with the task of being precise. A term like 'sand-dune' or 'wind' is certainly very vague. (How many inches high must a little sand-hill be in order to be called

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a sand-dune? How quickly must the air move in order to be called a wind?) However, for many of the geologist's purposes, these terms are quite sufficiently precise; and for other purposes, when a higher degree of differentiation is needed, he can always say 'dunes between 4 and 30 feet high' or 'wind of a velocity of between 20 and 40 miles an hour.' And the position in the more exact sciences is analogous. In physical measurements, for instance, we always take care to consider the range within which there may be an error; and precision does not consist in trying to reduce this range to nothing, or in pretending that there is no such range, but rather in its explicit recognition."[1]

This describes the estimator's expectations of the precision required and achieveable.

Professor William Fellner has expressed much the same viewpoint in the matter of estimating the stock of capital.

"Such numerical appraisal of the 'size of the stock' (i.e., in the prices of a given base year) possesses inevitable weaknesses. These are perhaps even more pronounced than the weaknesses of the corresponding procedure for valuing real or physical output. The physical character of the capital goods cannot help changing in the course of the investment process.... With the changing character of the goods produced in successive periods, valuation in constant prices (correcting for price changes) becomes a logically objectionable procedure. Yet when, in the present analysis, we state that the capital stock is rising at a rate different from that at which the supply of cooperating factors increases, then, of course, we mean physical capital. We *must* try to eliminate price changes from our series.

The objection cannot be answered to the satisfaction of the logical purist. If we are concerned with decade comparisons, the physical characteristics of many goods certainly do change.... In all such cases we must require that the general results of the statistical computations should accord with intelligent judgment or common observation. If they do accord with general judgment, we may perhaps rely more confidently on technical procedures for discovering details in a movement which would not be disclosed by common observation alone. This is how we are forced to proceed in such matters." (Emphasis in original.)[2]

Another background consideration needs to be made explicit. That is the predominant character of the economy that shapes the economic values placed on the stock of capital, the object of measurement. The following excerpt from Paul Samuelson's writing sets down the essential premise, at least for market-oriented economies:

"Until the laws of thermodynamics are repealed, I shall continue to relate outputs to inputs—i.e. to believe in production functions. Until factors cease to have their rewards determined by bidding in quasi-competitive

[1]Quoted by Joan Robinson in *The Accumulation of Capital* (Second Edition, Macmillan, New York, 1965) p. viii.

[2]*Trends and Cycles in Economic Activity*, (Henry Holt & Co., Inc. 1956), p. 197.

markets, I shall adhere to (generalized) neoclassical approximations in which relative factor supplies are important in explaining their market remunerations—a many-sectored neoclassical model with heterogeneous capital goods and somewhat limited factor substitutions can fail to have some of the simple properties of the idealized J. B. Clark neoclassical models. Recognizing these complications does not justify nihilism or refuge in theories that neglect short-term microeconomic pricing."[3]

If this premise is not valid for the more industrialized countries outside of the Iron Curtain, I believe there is no logical rationale for the estimation of capital stocks. In any case, this has been explicitly or implicitly the basic assumption of the well-known estimates of capital stocks in the United States.

Another premise for this discussion is that the concept of productivity describes a phenomenon of the real world. And if it is relevant and significant to know how productivity changes over time or its relative level among different economic entities, it is necessary to have a measure of productivity. It follows from this that the measure of a factor input should not be so constructed as to eliminate any evidence of its productivity. This applies equally to a measure of total productivity or of partial productivity, i.e., the productivity of a particular type of input. These obvious comments are necessary because the existence or non-existence of capital productivity, on occasion, has been the subject of critical controversy among some estimators and analysts.

One more preliminary remark. The discussion that follows is restricted to the measurement of capital input for use in the measurement of total factor productivity. No interpretation of the causes of changes in productivity or its effect on prices, costs, and other inputs is attempted. Our purpose is to explore how the capital factor input can be measured so as yield results that are neutral with respect to interpretative conclusions. It is also part of our plan to indicate, wherever the data permit, those steps in the estimating procedure that are specially sensitive to particular methods of measurement. This does not gainsay the importance of having some knowledge of the interpretative literature for only in this way can the estimator be alert to the possible uses to which the estimates may be put.

Some Definitions

In common parlance both terms, "capital" and "productivity," have many meanings. In this particular technical context, however, there is wide agreement on the definitions of these terms. Capital goods are those used to produce other goods and services. As to productivity, it is the concept of output per unit of input. Both definitions are deceivingly simple. When the estimator proceeds to measurement, a host of difficult decisions loom up and must be resolved in a manner that is consistent with the definitions and objective.

At this point we shall merely list the more important estimating decisions that can affect the level and/or relative movement of capital input, and then attempt to deal with each in turn.

[3]Quoted by C. E. Ferguson in his *The Neoclassical Theory of Production and Distribution* (Cambridge University Press, 1965), p. 250.

1. Level of aggregation and industrial classification
2. Components of capital input
3. Vintage problem
4. Reproducible capital: Gross or net of depreciation
5. Survival curve for retirement of particular capital components
6. Statistical procedures for estimating depreciation
7. Correction for price changes
8. Estimates of capacity utilization and their significance
9. Weighting system for aggregating sub-sectors.

Illustrative material is restricted to estimates made for the United States economy—those by Denison, Jorgenson and collaborators, Solow, and Kendrick—simply because these are the only ones with which I have any familiarity.

Frequent reference will be made to the following studies:

1. E. F. Denison,

   The Sources of Economic Growth in the United States and the Alternatives Before Us. Supplementary Paper No. 13 published by Committee for Economic Development, 1962. Hereafter referred to as *The Sources.*

   Why Growth Rates Differ: Postwar Experience in Nine Western Countries. The Brookings Institution, 1967. Hereafter referred to as *Why Growth Rates.*

   "Some Major Issues in Productivity Analyses," *Survey of Current Business,* May 1969, vol. 49, number 5, part II. Hereafter referred to as "Some Major Issues".

2. Dale W. Jorgensen and Zvi Griliches,

   "Sources of Measured Productivity Change," *Review of Economics and Statistics,* vol. LVI, No. 2, May 1966. Also reprinted in *Survey of Current Business,* May 1969, No. 5, Part II. Hereafter referred to as Jorgensen–Griliches.

3. Laurits R. Christensen and Dale W. Jorgenson,

   "The Measurement of U.S. Real Capital Input, 1929–1967," *Review of Income and Wealth,* Series 15, Dec. 1969. Hereafter referred to as Christensen–Jorgenson, "The Measurement."

   "U.S. Real Product and Real Factor Input, 1929–1967," *Review of Income and Wealth,* Series 16, Jan. 1970. Hereafter referred to as Christensen–Jorgenson, "U.S. Real Product and Input."

4. John W. Kendrick,

   Productivity Trends in the United States, National Bureau of Economic Research, Number 71, General Series (Princeton University Press, 1961). Hereafter referred to as *Productivity Trends.*

5. Robert M. Solow,

   "Technical Progress, Capital Formation and Economic Growth," Papers and Proceedings of the Seventy-fourth Annual Meeting, *The American Economic Review,* Vol LII, No. 2, May 1962. Hereafter referred to as "Technical Progress."

Level of Aggregation

There has been a marked preference to analyze factor input and factor productivity and their respective roles in economic growth at the highest, or very high, levels of aggregation for a national economy. The highest level, of course, is the total of the private and public sectors. The next highest level would be that for the entire private sector. The estimator-analyst concerned with the U.S. economy will find ready-made official estimates of capital formation and stocks of capital only for the private sector. That is, there are no official estimates of either capital formation or stocks of capital for the public (governmental) sector. Nor are the services performed by public investment included in output. This holds for all levels of government—local, state, and federal.

On conceptual grounds, aggregation for the private sector is meaningful in economic terms despite the heterogeneity of capital goods and production functions as long as the resource allocations and values of factor inputs are based on essentially free, competitive market prices as defined in the Samuelson quotation. This same assumption does not and cannot apply to the allocation of resources and the value of inputs in the public sector. Imputation of values by analogy with the private sector, except for the possibility of government business enterprises, does not appear to be feasible since capital investment in general government has few, if any, counterparts in the private sector. The prevailing practice among U.S. estimator-analysts is to recognize the serious conceptual and data limitations of measuring capital input in the public sector.

Denison, Christensen–Jorgenson and Kendrick use the private sector as the highest level of aggregation, and Solow the private sector, excluding the stock of capital owned by private non-profit organizations and capital in the form of dwellings. It should be obvious that whatever the scope of capital input in terms of economic sectors and subsectors, the scope of the output measure should be identical.[4]

Analysis at a high or highest level of aggregation does not necessarily preclude concurrent measurements and analyses at disaggregative levels, i.e., by industry or industry groups. This is the course pursued by Kendrick. A disaggregative approach has the important advantage of enhancing the possibility of providing more numerous and deeper insights because the large variations in behavioral relations are less apt to be submerged in the aggregation process. Awareness of the highly varied relationships should reduce the propensity of analysts for the grossly simplifying assumptions that has rendered so much of capital theory barren and empty. This emphasis on disaggregation gains support from Professor Nadiri's excellent survey of the literature on total factor productivity.

In "Theory and Measurement of Total Factor Productivity" (*Journal of Economic Literature*, Dec. 1970, Vol. VIII, No. 4), Professor Nadiri notes in the concluding paragraph of his discussion on "Growth Accountancy Approach", that

> "It will be most useful if Denison's and Jorgenson's–Griliches' approach is extended to more *disaggregative* levels." (p. 1169, emphasis supplied.)

[4]If there is a good reason for a discrepancy in coverage, the sector covered in only one measure should be handled so as not to affect the ratio of capital or total input to output. Denison chooses this course. See SCB, May 1969, Part II, p. 3.

And in the general conclusion Nadiri returns to the same theme but from a different starting point. Thus,

> "To evaluate correctly the role of technological change, it is necessary to formulate an alternative system of accounting .... Such a conceptual framework should be able to accommodate both the purely technical advancement and the social innovations necessary to adapt to the new technology. This approach requires concentration on more *disaggregative* studies such as micro-economic production functions, inter-industry resource allocation models, location theories, etc." (p. 1171, emphasis supplied.)

At what point disaggregation runs into diminishing returns can be determined by experimentation. In practice, however, it is often determined simply by the degree of disaggregation in the available data.

Specific Content of Capital Input

The level of aggregation probably has had some effect on delimiting the content of capital input. Capital input is typically restricted to some combination of tangible assets although every analyst knows that an enterprise requires financial assets (cash and accounts receivable) as well as tangible assets in order to function. Equally important, financial assets contribute to enterprise profits, which figure, in one way or another, in the estimate of capital services. However, financial assets lead a double life—one entity's claim is another entity's obligation. Thus, at the level of aggregation of the national economy financial claims and obligations cancel each other, except for the net balance of international claims which have been a relatively small part of U.S. stock of capital. If this is the reason for the exclusion of financial capital, it constitutes, in my view, still another argument in favor of a disaggregative approach. I know of no *a priori* reason for thinking that the use of capital input in the form of financial capital is immune to technological innovations. On the contrary, there is evidence, at least for the subsector of U.S. manufacturing, that there have been productivity gains in the use of financial capital since 1929.[5]

There may be another rationale, not explicitly expressed, for restricting capital input to tangible capital. This is the penchant for treating capital input, and indeed output, in constant prices as though they are physical volumes, despite the fact that price-corrected economic values are still economic values.[6] While up to a point this may be a useful expository device, it is, nevertheless, another example of what Alfred North Whitehead has called "the fallacy of misplaced concreteness." For this reason there is a high probability that the use of a physical concept will create confusion. We shall refer to one such instance at a later point.

[5]See Creamer, "Capital Expansion and Capacity in Postwar Manufacturing," *Studies in Business Economics*, No. 72 (NICB, New York, 1961), pp. 41–44.

[6]It was comforting to learn that Joan Robinson had made the same point. "In what unit is 'capital' to be measured? The figures in the time-series are corrected in the first instance in terms of dollars; however they may be deflated or adjusted, the amount of capital in the statistics is a sum of values." Joan Robinson, "The Measure of Capital: The End of the Controversy", *Economic Journal*, September 1971, p. 598.

The foregoing items are relatively unimportant compared with the discussion centered on the extent to which those additions to knowledge affecting productivity are embodied in capital input or remain disembodied. By definition, the measurement of capital input, consisting of tangible capital goods, includes (embodies) those technological innovations that create improvements in processing and in the usefulness of consumer goods and services. Other additions to knowledge-creating innovations, such as management science, the so-called disembodied innovations, are in fact embodied in the minds of individuals engaged in management.[7] This too follows by definition. This being so, a comprehensive measure of labor input would embody these so-called disembodied innovations by allocating an appropriate base-year value-weight to manhours of the managerial employees. In this manner, additions to disembodied knowledge beyond the base-year show up as increments to manhour productivity. This treatment would parallel the preferred treatment (in my view) of capital input, a point that is discussed below.

Tangible capital consists of structures, machinery and equipment, inventories, land improvements, and land. Thus the category embraces reproducible and non-reproducible items. Each of the four analysts uses a somewhat different combination of tangible capital as his measure of capital input. Solow's measure of capital input is the most restrictive of the four. It is composed of depreciable capital (structures and equipment) of the profit-making sector. Kendrick and Denison define the content of capital input in essentially identical terms, particularly if one combines Denison's estimate of land with his estimate of reproducible capital. Jorgenson's specifications for capital input parallel those of Denison and Kendrick except for his inclusion of consumer's durable goods. This is a puzzling addition. No explanation for its inclusion is offered despite its omission from the Jorgenson-Griliches measure of capital input in their earlier article in the *Review of Economic Studies* (July 1967). It is certainly inconsistent with the underlying definition of a capital good—one that is used to produce other goods and services. Moreover, it is inconsistent with their own (Christensen–Jorgenson) statement that "the main analytical use of the production account is in the study of producer behavior. Revenue and outlay must be measured from the producer's point of view."[8] Are the users of consumers durables producers? Needless to say, the inclusion of consumers' durables in capital input is no small amount. In terms of their estimates it accounts for nearly 14% of the stock of capital in 1958.[9] Moreover, the inclusion of consumers' durables in the capital stock understates aggregate total factor productivity since the methodology of estimates is such that this sector makes no contribution to productivity.[10]

[7]In an earlier article, Joan Robinson has at least questioned the reality of the disembodied concept. It appeared as a parenthetical remark: "the value of equipment-absorbing disembodied progress (if there is such a thing) . . . ," "Capital Theory Up to Date," *Canadian Journal of Economics*, III, No. 2, May 1970, p. 316.

[8]*Op. cit.*, "U.S. Real Product and Input, 1929–1967," p. 21.

[9]Table 3, p. 301. It should be mentioned that an appropriate adjustment, at least conceptually, is made by Christensen and Jorgenson to the official output estimate.

[10]Edward F. Denison called this point to my attention.

While there can be no quarrel with the inclusion of inventories in capital input, one may quarrel with combining inventories with fixed capital (depreciable) and non-reproducible capital (land). As a capital input, inventories do not share the basic character of fixed capital—the giving up of services over a long period of years, from about 40 years, on the average, for structures and about 8 to 20 years for many types of machinery. This is another way, of course, of saying they are depreciable. Inventories in the possession of business enterprises, on the other hand, yield their services in a single using and for this reason typically are "turned-over" several times in one year. This last characteristic qualifies inventories to be classified as circulating (or working) capital together with financial claims of cash and accounts and notes receivable.

The basic difference between fixed and circulating capital means that the pricing of each type is subject to different considerations and therefore adjusting for price changes requires a different set of deflators.[11]

The Vintage Problem

The vintage of capital, as all who are familiar with the theory or measurement of capital know, refers to the use at any given time of structures and machinery that had been acquired on different dates in the past. Since technological innovation is a continuous process, there is a high probability that the more recent the purchase the more technological innovations are embodied in the capital components. Thus, all capital as it ages not only loses some value owing to physical wear and tear but also because of increasing obsolescence. How to allow for the loss in value owing to the obsolescence factor constitutes the core of the vintage problem.[12] It also intrudes prominently into the decision of which variant of capital input, gross or net of depreciation, is most appropriate for inclusion in the measurement of total factor productivity. Unfortunately, it intrudes but does not clearly point the way to the answer. In any case, there is no unanimity of decision among the four analysts whose estimates are under examination.

Real Depreciable Capital, Gross or Net of Depreciation

This category is far and away the most important component of tangible capital, representing about two-thirds of the total. Its magnitude, as well as the complexity of the vintage problem, explains why estimate of real depreciable capital has deservedly occupied center stage in the discussion of capital input measurement.

[11]Dr. A. L. Gaathon succinctly summarizes the differences in the pricing considerations: "... changes in the volume (of inventories of raw materials, and finished and semi-finished products) are to a large degree subject to transitory influences such as credit conditions and short term expectations of price changes or shortages, whereas fixed capital formation is determined in the main by long-term considerations such as the prospective net yield of additions to capacity." (*Economic Productivity in Israel*, (Praeger Publishers, N.Y. 1971), p. 25).

[12]Labor input also has a vintage problem but of a different character. A cohort of new entrants into the labor force typically will improve its productivity as it ages owing to learning by doing and the accumulation of general experience, knowledge, and wisdom. This process may continue for several decades, then reach a plateau, and later still reverse direction. The ages associated with these inflection points seem to be a positive function of the age of the analyst.

Both Denison and Solow use the gross capital concept but only Denison argues his case. Kendrick argues for and uses capital net of depreciation. The practice of Christensen–Jorgenson on this score requires a certain amount of textual criticism, as Denison has noted.[13] The weight of the exegetical evidence suggests their estimate of capital input has as one of its ingredients the stock of capital net of depreciation. Thus Christensen–Jorgenson write "as benchmarks for capital stock of each type we take the 1929 value—in constant prices for double declining balance depreciation."[14] Their reasons for this choice are not given. Thus, one possibility of getting at the reasons for choosing gross or net capital is to review the arguments and counter-arguments of Denison and Kendrick.

Despite different choices both have the same starting point—Denison explicitly and Kendrick implicitly. The concept to be given empirical content is the one formulated by A. C. Pigou.

Denison cites the following passage:

> "When any discarding has occurred in order to make good the depletion of capital implied in it, *that quantity of resources must be engaged which would suffice in actual current conditions of technique to reproduce the discarded element.* But the direction in which the quantity of resources is engaged should be determined without reference to what the discarded element has been; it should be so chosen that the maximum possible addition is made to the present value of the stock of capital . . . Here we have a clear principle. A basis for it may be found in the concept of capital as an entity capable of maintaining its quantity while altering its form and by nature always drawn to those forms on which, so to speak, the sun of profit is at the time shining." (Italics added by Denison)[15]

The essential constraint that flows from the Pigou formulation is that the capital series must register only the contribution of the growth of capital inputs in the productive process and exclude the contribution of technological progress. That is, any increase in factor productivity (in this case, capital) should not appear as growth of input.

The measure, however, must reflect the change in capital inputs stemming from the changing composition of structures and equipment when their components are classified by the length of expected lives when new and the change in their average ages. Thus far Denison and Kendrick are in agreement but part company thereafter.

[13] *Op. cit.*, "Some Major Issues" p. 15.

[14] "The Measurement," p. 295. But much of the confusion in their estimates has been engendered by their use of 'replacement' in a special sense and their differentiating it from the conventional use of 'depreciation.' In a paper presented to the U.S. Conference on Research in Income and Wealth in November 1971 Jorgenson elaborates on his meaning of the terms. He writes there (p. 55), "Replacement represents the *change in quantity* of existing capital goods due to a decline in relative efficiency. Depreciation represents the change in the *price* of existing capital goods due to present and all future declines in efficiency." (Emphasis supplied.) These distinctions appear to me to be highly artificial constructs that are not operational and do not enter into the investment decisions of entrepreneurs. They may assist Jorgenson in pursuing with formal consistency his will-of-the-wisp of the physical quantity of capital. This illustrates, in my view, the danger of entrapment in the fallacy of misplaced concreteness.

[15] Denison, *The Sources*, p. 195. The Pigou quote is taken from his "Net Income and Capital Depletion," *Economic Journal*, June 1935, p. 239.

The next step is the choice of measure of capital services from the series available—the gross capital stock, the net capital stock or capital consumption. Denison reaches his conclusion by the following reasoning:

> "Suppose there were no change in the economy except in structures and equipment, including the absence of technological progress so that tools produced in one year were no better (when new) than those produced in another year. Suppose also that each individual capital good yields equal services throughout its useful life, the straight-line depreciation assumption. I seek a measure of capital input that, under the assumed conditions, will move like the national income produced by capital so that no change will occur in computed output per unit of input.[16]

Under these highly restrictive assumptions and with the help of illustrative arithmetic computations Denison concludes:

> "my choice as a measure of capital input for depreciable assets is 'real' (deflated) gross capital stock"[17]

If the conclusion depends (as it does) on highly artificial assumptions, there is a high probability that the conclusion will be misleading. The capital input measure must be applied to contemporary market-oriented economies in which technological innovations are the rule. The problem is devising a measure of capital input for such an economic environment, not one for a non-existent economy where there is an "absence of technological progress" and where "no change will occur in computed output per unit of input." That is, what constitutes an excellent expository device for emphasizing that quality improvement per se is not to be translated into capital increments, does not necessarily provide a logical basis for measurement in the context of the actual operations of the economy.

Kendrick also believes, as does Denison, that real stocks of capital should be measured as

> "to eliminate the effect of price changes in such wise that a new unit of a given type of plant or equipment is accorded the same base-period value, or weight, in all periods. Changes in the productive efficiency of new models as compared with the base-period model of a particular item of equipment are not reflected in the real value of the item (unless more resources are used). This is desirable from the viewpoint of productivity analysis, for the increased efficiency should show up in the output-input ratio."[18]

On the basis of this Pigovian assumption, Kendrick concludes that:

> "Real stocks net of accumulated depreciation allowances are taken as a better measure of a basic capacity to contribute to production and revenue than gross stocks (i.e., the number of items in use each weighted by base-period price regardless of age). Studies have shown that the gross output capacity of various types of machinery tends to fall with age, and the repair

[16] *Ibid.*, p. 98.

[17] *Idem.*

[18] Kendrick, *Productivity Trends*, p. 35.

and maintenance charges rise so that the contribution to net revenue falls even more. More significantly, the marginal revenue products of older types of equipment are less than those of new, improved types because of technological advance and resulting obsolescence. This development occurs sporadically as far as a particular type of equipment is concerned, but may be assumed to occur gradually with respect to all the capital goods of an industry. The effect on the real marginal revenue product of groups of items over time is roughly approximated by the gradual decline in the depreciated real value of stock shown by the usual depreciation accounting procedures reflected in the national accounts."[19]

Part of the difficulty in judging whether theoretical considerations strongly support the use of real gross or net stocks may well be the failure to focus continuously on the particular final objective of the analysis. Three of the four estimates (the time reference of Solow's is not readily apparent to me) are centered on long-term relationships between inputs and outputs. Does net or gross capital stock best serve this specific purpose? Denison, as we have already noted, favors the gross concept. He rejects the use of the net concept in rather strong terms:

"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*." (Italics added.)[20]

However, the question at issue is not current production but long term movement of output to input.

On this point too Dr. Gaathon has a helpful summary. He observes

"The preference for gross over net capital is justified when the contribution of capital to *current* output is measured. For the longer-term view, it is the aggregate of capital services still unspent, rather than their current output, that is relevant, and the net concept is therefore the appropriate one. In other words, while over a fairly short period it is meaningful to compare output with capital input measured as a function of all assets still alive, over a longer period the capacity of the stock, measured by its life expectation, becomes relevant." (Italics in the original).[21]

It appears that Denison has had some second thoughts on what is conceptually correct. In *Why Growth Rates Differ* he acknowledges "that the ability of capital goods to contribute to production typically does decline during their service lives but not very much. I suggested 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.[22]

[19] *Idem.* On this last point Kendrick cites George Terborgh, *Realistic Depreciation Policy*, Chicago, Machinery and Allied Products Institute, 1954.

[20] "Some Major Issues," p. 14.

[21] *Op. cit.*, pp. 31–32.

[22] "Some Major Issues," p. 14.

Although this cannot be read as a confession of error, it does represent a softening of his former rigid position.

It should be obvious that one's preference for real capital stocks net of depreciation for the purpose at hand in no sense undercuts Salter's demonstration that gross capital formation is the agent (means) of embodying technological innovations into the capital structure.[23] Equally obvious, this in itself does not justify the use of gross capital stock as a measure of capital input for long-term movements in total factor productivity.

While the discussion of what constitutes conceptual rectitude has generated a considerable literature in the past decade or two, has this been excessive in view of the size of the difference in the movement of capital input measure by gross stocks and net stocks? Obviously, the levels are substantially different but what about relative change over (say) a two-decade period, which has vastly more analytical interest than does the level? The few computations based on the OBE capital stock estimates in Table 1 do indicate significant differences. It should be stressed that the only difference between these gross and net capital stock estimates is depreciation. That is, in both sets of estimates service lives are equal to 85 percent of those in Bulletin F (the guidelines used by the Internal Revenue Service) and the dispersion of discards around the service life is assumed to be represented by the Winfrey distribution. The deflator (constant cost 2) is identical for both sets of estimates.[24]

While there is aggreement between gross and net capital stocks in direction of movement, the differences in degree of movement are substantial, particularly when stocks of structures and equipment are examined separately. Since depreciation reserves have a relatively stable movement (being a function of time and past accumulations) and amount to about 45% of gross capital stock, one would expect the residual (net capital stocks) to have wider amplitude of movement; and this is confirmed by these computations in seven of the eight possible comparisons.[25] (We exclude the combined total of structures and equipment because the changing mix affects the results.)

In any case, the size of the differences in relative changes does suggest that the discussion over the conceptual correctness of gross versus net capital stocks is worthwhile and should be pushed until there is widespread agreement. For the difference that gets reflected in the respective measures of capital input does make a difference and the bias is not constant.

Survival Curve of Depreciable Assets

The choice of the appropriate survival curve for depreciable assets must be faced by the estimator regardless of his choice of gross or net capital stock

[23]Salter, W. E. G., *Productivity and Technical Change* (Cambridge University Press, 1966), p. 63.

[24]The series are fully described by Robert C. Wasson, John C. Musgrave and Claudia Harkins in "Alternative Estimates of Fixed Business Capital in the U.S. 1925–1968," *Survey of Current Business*, April 1970, pp. 18–36.

[25]For a formal demonstration of the relationship between gross stocks, depreciation reserves and net stocks under varying assumptions of service lives and rates of growth see Helen Stone Tice, "Depreciation, Obsolescence and the Measurement of the Aggregate Capital Stock of the United States 1900–1962," *The Review of Income and Wealth* Series 13, No. 2, June 1967, pp. 119–154.

TABLE 1

REAL GROSS AND NET STOCKS OF CAPITAL IN U.S. INDUSTRIES, 1929, 1948, AND 1968

	Real Stocks in Billions of 1958 Dollars		Per cent Change from Preceding Benchmark	
		Structures		
	Gross	Net	Gross	Net
1929	259.8	143.3	—	—
1948	245.4	115.5	−5.5	−19.4
1968	432.3	260.3	76.2	125.4
		Machinery and Equipment		
1929	139.2	72.9	—	—
1948	172.5	102.0	23.9	39.9
1968	449.6	251.5	160.6	146.6

Source: Wasson, Robert C., Musgrave, John C., and Harkings, Claudia, "Alternative Estimates of Fixed Business Capital in the U.S. 1925–1968," *Survey of Current Business*, April, 1970. Tables 2 and 3. Constant Cost 2 variant is used. Net stocks are based on straight line depreciation.

as a measure of capital input—that is, if both estimates are based on the perpetual inventory method.[26] This arises from the necessity of determining when a purchase of a capital component has been physically discarded because its economic value has been fully used up. One possibility is to assume that each capital asset is not discarded until the final year of its expected service life at the time of purchase. This is the one-horse-shay assumption. Clearly this is not a realistic description of actual practice, and has been supplanted by the assumption that discards are dispersed in a given pattern around the average expected life. In the official U.S. estimates the practice is to assume that the distribution of discards (removals from gross stocks) around average expected service lives follows the path of an empirically derived curve established by Winfrey—hence the phrase, Winfrey distribution.

Once again, the four U.S. estimates, on which we focus, do not employ an identical assumption in this matter. Denison in *The Sources* (but not in *Why Growth Rates*) and Solow make use of the capital stock estimates of Machinery and Allied Products Institute (MAPI) which are based on a survival curve developed by George Terborgh. It entails a narrower dispersion around the average expected life than the Winfrey curve. Christensen–Jorgenson are in effect using the Winfrey distribution since their estimates are based on the official OBE estimates. Kendrick, who relies principally on Goldsmith's estimates for his national aggregate (but not for industry sub-totals) in effect used the one-horse-shay assumption implicit in Goldsmith's estimates.

Denison, in the course of tracking down the differences between his attribution of the sources of growth and those of Jorgenson–Griliches demonstrates

[26]When capital stock estimates are based upon enterprise balance sheets, there is no need for the estimator to impose his own notion of the rate of discards from the gross stocks. To me, this represents an advantage of the balance sheet approach.

the difference in the rate of growth of capital when the Winfrey distribution is used in place of the MAPI distribution. This *difference is negligible.*[27]

There remains, however, the question whether the Winfrey distribution is a reasonable approximation to typical business practice, particularly over the last four decades. An examination of Winfrey's report discloses that the empirical basis of his distribution is his analysis of a sample of equipment retirements that are heavily weighted with railroad ties, trestles, and power generating equipment. Moreover, these retirements occurred over the period 1869 and 1934.[28] Clearly this is an area that calls for new research.

Depreciation Formula

The analyst who concludes that the conceptually correct measure of capital input in total factor productivity is the real capital stock net of depreciation must then decide the rate at which capital components use up their economic value over the course of their expected service lives—in other words, a depreciation formula. In the postwar World War II period there has been a growing recognition of the proposition that capital goods contribute to output at a faster rate in the earlier years of their service lives than in the later years. Since 1953, U.S. tax authorities have approved two formulas that incorporate this proposition—double declining balance and sum of the year's digits—in addition to the conventional straight line formula which allows for a constant annual loss of value.

For obvious reasons, the level of net stocks is sensitive to the depreciation formula employed. But once again the much more important consideration for factor productivity analysis is the relative change. And once more the capital stock estimates of OBE have illustrative value. Robert Wasson and his associates have computed separate estimates of net capital stocks of structures and equipment in constant prices for the private sector of the U.S. economy using two different depreciation formulas, straight line and double declining balance.[29] The service lives assumptions and Winfrey distribution are identical for both net capital estimates. Computations of relative change based on these OBE estimates are shown in Table 2. For relative changes ranging from one to two decades the differences attributable to these two depreciation formulas are negligible. That is, relative changes over a decade or so in real net capital stocks are *not* sensitive to any depreciation formula that would be seriously considered by an analyst.

Deflation of Capital Stock Components

Regardless of the final form of the capital input statistic, the derivation of

[27]"Some Major Issues," p. 14.

[28]Robley Winfrey, "Statistical Analysis of Industrial Property Retirement," Iowa Engineering Experiment Station Bulletin 125, 1935, Table 27, pp. 142–49. Another empirical effort is by E. B. Kurtz, *Life Expectancy of Physical Property* (New York, 1930). Of this effort Tibor Barna notes, "Kurtz brought together a number of studies but they relate typically to small and standardized assets, mainly in the public utility field, such as telegraph poles and electric bulbs." See Barna, "On Measuring Capital" in *Theory of Capital,* Lutz and Hague, editors (New York, 1961), p. 85.

[29]For the length of time period used the formula of the sum of the years' digits would differ very little from the formula of double declining balance.

TABLE 2

ALTERNATIVE ESTIMATES OF REAL NET STOCKS OF CAPITAL FOR U.S. INDUSTRIES BASED ON STRAIGHT LINE AND DOUBLE DECLINING BALANCE DEPRECIATION, SELECTED PEAK YEARS 1929–1968

	Based on (Billions of 1958 Dollars)		Index Based on	
	Straight Line Depreciation	Double Declining Balance	Straight Line Depreciation	Double Declining Balance
	Real Net Stocks of Structures			
1929	143.3	117.2	100	100
1948	115.5	93.1	80.6	79.4
1957	168.8	140.1	117.8	119.5
1968	260.3	215.1	181.6	183.5
	Real Net Stocks of Machinery & Equipment			
1929	72.9	57.4	100	100
1948	102.0	83.1	139.9	144.8
1957	158.8	125.2	217.8	218.1
1968	251.5	199.6	345.0	347.7

Source: Same as for Table 1.

the estimate in constant prices typically is based on the summing of components each expressed in constant prices. The U.S. estimator-analyst has a limited choice among appropriate price indexes for use as capital deflators. This clearly emerges from a review of three of our four estimates—Solow does not state how he has deflated his estimates except to indicate that separate deflators were used for nonresidential structures and for machinery and equipment.

With respect to nonresidential structures, the available deflators, until recently, have been composed of prices of inputs into construction, principally cost of labor and materials. This sort of index, it is widely recognized, has serious deficiencies on conceptual grounds. For example, either no allowance, or in one or two indexes an arbitrary allowance, was made for changing productivity in the construction industry (one factor that could cause a divergence between prices of inputs and the final product). Another serious omission was deliberate change in the profit margin of construction contractors. However, until OBE, which labels this type constant cost 1, had prepared its constant cost 2, which is a closer approximation to a construction price index, the estimator was obliged to use constant cost 1 deflator for the lack of a better one. When Denison and Kendrick were writing their monographs, only the constant cost 1 deflator was available. The constant cost 2 index was available to Jorgenson-Griliches and to Christensen–Jorgenson.

The effect of using the constant cost 2 deflator in place of constant cost 1 is to reduce modestly the relative decline in the real stocks of structures between 1929 and 1948 and to enlarge moderately the relative rise in the two decades following 1948 (See Table 3). Even so, as Denison has shown,[30] these differences of themselves would not cause one to alter his analysis.

[30] "Some Major Issues," pp. 14–16.

TABLE 3

OBE ESTIMATES OF REAL GROSS STOCKS OF NONRESIDENTIAL STRUCTURES IN THE PRIVATE SECTOR BASED ON CONSTANT COST 1 AND CONSTANT COST 2 DEFLATORS, AT BUSINESS CYCLE PEAKS, 1929–1968

	Gross Stocks of Nonresidential Structures			
	Billions of Dollars		Per cent Change from Preceding Year	
Business Cycle Peaks[a]	Constant Cost 1	Constant Cost 2	Constant Cost 1	Constant Cost 2
1929	297.0	259.8	—	—
1937	287.7	254.9	−3.1	−1.9
1948	271.0	245.4	−5.8	−3.7
1953	290.9	267.7	7.3	9.1
1957	322.1	301.1	10.7	12.5
1960	344.9	327.5	7.1	8.8
1968	434.2	432.3	25.9	32.0

Source: Wasson *et al.*, *op. cit.*, Table 2, p. 24.

[a]The immediate post-World War II peak is omitted and 1968, though not a peak year, is last year available in the source used.

In the deflation of the stocks of machinery and equipment also the choice of deflator has been severely restricted. Regardless of the label, the deflators for the most part are some combination of the relevant wholesale price indexes of the Bureau of Labor Statistics (BLS). Denison in *The Source*, which antedates the OBE capital stock estimates, adapts the capital estimates of the Machinery and Allied Products Institute (MAPI).[31] These estimates are deflated by the GNP implicit deflator.[32] The investment component of this deflator is based to a large extent on the BLS wholesale price indexes. This is also the case with the deflators used by the OBE in the derivation of their constant cost estimates of gross and net stocks of equipment which, in turn, are used by Christensen–Jorgenson.[33]

The BLS wholesale price indexes are also implicit in Kendrick's procedure. He uses Raymond Goldsmith's estimates for the national economy and the latter's constant cost estimates of equipment are based essentially on the BLS indexes.

This brief review of adjustment for price changes suggests that the measurement of capital input—at least, the reproducible segment—is not sensitive to those available deflators that have any logical claim to be used.

[31]*The Source*, *op. cit.*, p. 98.

[32]MAPI, *60 Years of Business Capital Formation*, footnote 1, p. 3. The reason for preferring the GNP implicit deflator to the producers durable price index is given only in a mimeographed supplement available on request. I have not read the supplement.

[33]Their use of the OBE deflators is a decided improvement over the use of the deflator for consumers durables employed earlier by Jorgenson–Griliches. The substitution probably is in response to Denison's criticism of the earlier procedure. See "Some Major Issues," p.16.

In the matter of land, all estimators, except Denison, resort to a procedure introduced by Goldsmith. In the absence of any usable price indexes for land, it is assumed that the ratio of the value of land to structures in current prices also applies in constant prices. Because of this estimating convention, land as such makes no contribution to total factor productivity. This is also true of Denison's procedure. He assumes, "Since about 1890 . . . the land area available to the American economy has not changed. A constant index of 100 may therefore be used to measure the quantity of land."[34]

Capacity Utilization—To Adjust or Not to Adjust

It is a commonplace that the stock of capital in place is typically not used with a constant intensity over a period of time that exceeds a few years. That is, owing to cyclical factors excess capacity is present in the recession and earlier stages of the expansion phases of the business cycle.[35] The usual adjustment to a falling demand, unless the decline is prolonged over a number of years, is to reduce output by a cut-back in labor input with little or no reduction in the stock of fixed capital in place. For this reason, any temporal comparison of capital input to output should be based on terminal ratios relating to a similar phase of the business cycle. And for the fastidious the terminal cycles should be similar with respect to duration and amplitude of phases.

Denison and Kendrick make no specific adjustment for capital (i.e., capacity) utilization. The latter argues that, "The fullness of utilization of the capital stock is one aspect of the efficiency of private management . . . .[36] Denison has a different reason. If the statistics on the stock of capital differentiated those capital components whose "useful" life is extended by non-use from those whose "useful" life is not extended by non-use, he would correct the former. Since there are no such statistics, Denison relies solely on an approximate adjustment achieved merely by selecting years for comparison that are "of a reasonably similar degree of prosperity."[37]

I find it easier to accept Denison's conclusion than his explanation. All capital components are subject to obsolescence in some degree whether they are being used or not. Some measures indicate that the economic cost of obsolescence is far greater than the economic cost of physical wear and tear.[38] This reasoning, however, also leads to Denison's procedure in that non-use should be counted as a decline in productivity rather than a decline in capital input.

Solow's principal interest in capital input is its use in the calculation of the production function which should provide a statement of potential (capacity) output. Since only actual output is recorded, it is necessary to estimate the difference between actual and potential. For the lack of any better data, Solow

[34]*The Sources*, p. 89.

[35]Indeed, significant excess capacity has existed, on occasion, even at the cyclical peak. This can be demonstrated for the 1957 peak, at least for U.S. manufacturing industries. See D. Creamer, *op. cit.*, pp. 23–30.

[36]Kendrick, *Productivity Trends*, p. 32.

[37]Denison, *The Sources*, p. 97.

[38]See, for example, Raford Boddy and Michael Gort, "Obsolescence, Embodiment, and the Explanation of Productivity Change," Discussion Paper No. 86 (February 1970), State University of New York at Buffalo, pp. 1–12.

assumes "as an approximation, that the ratio of actual to potential output is a function of the unemployment rate." That is, the under-utilization of capital input as well as of labor input is measured by his unemployment rate.[39]

Jorgenson and his associates follow Solow in equating a change in utilization rate with a proportionate change in input. However, they reject his empirical compromise of using the unemployment rate as a measure of under-utilization of capital input.

The alternative they favor is to "estimate the relative utilization of capital from the relative utilization of power sources." More specifically, the measure consists of the relative utilization of electric motors. These data are available only for manufacturing and only for benchmark years. Jorgenson–Griliches "assume that relative utilization of capital goods in the manufacturing and non-manufacturing sectors is the same"—admittedly a strong assumption. They also note that benchmark estimates could provide an adjustment only for trend.[40] These two deficiencies are corrected in the second version of the estimates prepared by Christensen–Jorgenson. Thus, the utilization adjustment is restricted to non-residential structures and producers' durables. For all other classes of capital inputs (land, inventories, residential structures and consumers durables) actual and potential quantities are assumed to be identical. And annual estimates of the relative utilization of electric motors supplement the benchmark estimates, thereby providing cyclical as well as secular adjustment factors.[41]

TABLE 4

RELATIVE CHANGES IN POTENTIAL AND ACTUAL GROSS CAPITAL INPUT[a] ESTIMATED BY CHRISTENSEN–JORGENSON, SELECTED YEARS 1929–1967

	Gross Private Domestic Capital Input			
Year of Cycle Peak	Potential Quantity	Actual Index	Potential Per cent	Actual Change from Preceding Benchmark
	(1)	(2)	(3)	(4)
1929	70.3	58.9	—	—
1937	63.8	54.9	−9.2	−6.8
1948	75.8	80.5	18.8	46.6
1953	93.8	99.2	23.7	23.2
1957	106.0	110.3	13.0	11.2
1960	113.1	120.7	6.7	9.4
1967	144.8	167.7	28.0	38.9

Source: Christensen–Jorgenson, "The Measurement," Col. 1 from Table 6, sum of cols. 1 and 3; Col. 2 from Table 7, sum of cols. 1 and 3.

[a]Entire private sector except households and nonprofit organizations.

[39]Solow, "Technical Progress," pp. 77–78.

[40]Jorgenson and Griliches, p. 265.

[41]Christensen and Jorgenson, *The Measures*, p. 314 and 319.

The statistics in Table 4 show how the Christensen–Jorgenson adjustment for variations in capacity utilization affect the relative movement of the capital stock between cyclical peaks. In only one of the six comparisons does the relative movement in the actual capital input (adjusted for utilization rate) differ by less than 20% from that for potential capital input.[42] This limited evidence suggests that the measurement of capital input *is sensitive* even at cycle peaks to this particular measure of capacity utilization rate. This is not surprising since the measures of capacity (hence, of capacity utilization) are probably cruder than measures of capital stocks.

Equally relevant is the sensitivity of relative movements in capacity utilization rates to different methods of measurement. In addition to the Christensen–Jorgenson adaptation of Foss' measure there are two other series in the U.S. that are widely circulated. Both are issued quarterly—one by the Federal Reserve Board and the other by the Economics Research Unit, Department of Economics, Wharton School of Finance and Commerce, University of Pennsylvania. In the former the measure is an average of two capacity approximations, one of which is based on manufacturing company reports to McGraw-Hill Publishing Company and the other on capital stock estimates. Capacity in the Wharton School measure is based essentially on "trend through peak output." In Table 5 these three measures of capacity utilization rates for manufacturing are given as indexes.

It is apparent that both the Federal Reserve Board and the Wharton School indexes for manufacturing differ substantially from the Christensen–Jorgenson index, although there is evidence of convergence after 1957, particularly with the

TABLE 5

COMPARISON OF INDEXES OF CAPACITY UTILIZATION IN MANUFACTURING, SELECTED YEARS, 1948–1967

	Indexes of Capacity Utilization Rate in Manufacturing			As Per Cent of C–J Indexes	
Business Cycle Peaks	Christensen–Jorgenson[b]	Federal Reserve Board[c]	Wharton School[d]	Federal Reserve Board	Wharton School
1948	111.6	121.2	125.9	109	113
1953	109.8	127.3	125.7	116	114
1957	106.6	113.0	119.9	106	112
1960	110.1	108.9	111.6	99	101
1967[a]	125.0	115.3	126.6	92	101

[a]Last year available in C–J index but also a near peak.

[b]"The Measurement of U.S. Real Capital Input, 1929–1967", *Review of Income and Wealth*, December 1969, Table 7, col. 7.

[c]*Federal Reserve Bulletin*, July 1967, p. 1098 and release dated July 21, 1971.

[d]By telephone from Economics Research Unit, Wharton School.

[42]Christensen–Jorgenson refer to both measures as *gross* capital input. This also contributes to the confusion over what they are actually measuring. See discussion above, p. 11, and footnote 14.

Wharton School index. Even with respect to the direction of year-to-year change the FRB index and C–J index differ in two of the four comparisons. More importantly the average of the five peak-year differences from the index base, 1958, a business cycle trough, are 12.62, 17.14, and 21.94, respectively, for C–J index, FRB, and the Wharton School. It should be pointed out that the Wharton School now prepares a capacity utilization index with broad industrial coverage—mining, manufacturing, public utilities, transportation, use of space (housing, office space, and hotels) and, recently, construction. This becomes very much closer to the industry coverage of the Christensen–Jorgenson's measure of capital input and therefore would seem to be a more appropriate adjustment index, if one is to be used, than an adjustment factor based only on manufacturing activity.

In addition to the deficiencies that are specific to each measure of capacity and capacity utilization, there is a methodological limitation that applies to all current measures and imparts a bias that serves to understate excess capacity. Many economic activities occur in local or regional markets in contra-distinction to national markets. It is possible, and indeed known to have happened, that fully utilized capacity for the production of a given product for a specific regional market can concurrently co-exist with under-utilized capacity in another region. National measures make it possible for full or over-utilization in one or more regions to offset under-utilization in other regions. It is this that results in the understatement of excess capacity.

Since the measure of capacity *is sensitive* to the method used and since all current measures have inherent deficiencies, it seems to me that the estimator minimizes errors in the estimate of capital input by *not* making a formal computational adjustment for capacity utilization. In my view, the preferred procedure, given the state of the estimating art, is to restrict intertemporal comparisons of measures of capital input to output in years with about the same degree of prosperity.

It is difficult to over-emphasize the importance of the capacity utilization factor, because of the indirect role it has played in the interpretation of the extent and character of the contribution of capital input and productivity to economic growth. Denison, for example, finds that his estimates after adjustment so as to be identical in the industry coverage and time period (1950–1962) with Jorgenson–Griliches indicate an average annual rate of growth in output per unit of input (i.e. total factor productivity) of slightly more than one percent. Jorgenson–Griliches find virtually no growth in output per unit of input over this period. Economic growth, they insist in this earlier effort, has resulted only (or virtually so) from growth in inputs, both labor and capital. This finding, in their judgement, conforms with the expectation derived from the economic theory of production "if quantity of output and input are measured accurately." If empirical results differ from this, it must mean the output and input have not been correctly measured.[43] Yet the difference in empirical results between Denison and Jorgenson–Griliches is traced by Denison to the latter's use of their capital utilization adjustment,[44] which Jorgenson–Griliches have since abandoned.

[43]See "Some Major Issues," *op. cit.*, pp. 24–25 and p. 31.

[44]*Ibid.*, p. 27.

Christensen–Jorgenson revised the Jorgenson–Griliches capital utilization index in response to Denison's criticism of the grosser deficiencies in its construction. Their revised empirical results lead Christensen–Jorgenson to the following conclusion:

> "Although growth in real factor input predominates in the growth of real product, we estimate that changes in total factor productivity are substantial for 1929–1967 and for both the sub-periods we have considered (1929–1948 and 1948–1967). The conclusion of Jorgenson and Griliches that productivity growth is negligible must be revised accordingly."[45]

The authors also note that,

> "The discrepancy between our estimates... and those of Denison is accounted for almost entirely by our adjustments of the measure of capital input for quality change and relative utilization."[46]

In light of the critical position occupied by the capacity utilization adjustment in the difference in empirical results and in explanation of the sources of economic growth, this aspect of measuring capital input for factor productivity deserves further study in the hope of reaching a broader consensus than now seems to exist.

Aggregating Capital Input—The Weighting Problem

Even highly aggregative estimates of capital stock are derived by summing estimates of capital stocks in each of several broad categories of economic activities, such, for example, as residential structures; non-farm, non-residential structures; other farm structures; producers durable goods (machinery and equipment); inventories and land. Such a procedure was followed by Denison, Christensen–Jorgenson, and Kendrick. Each estimator-analyst, therefore, was obliged to determine whether the total capital stock was simply the sum of the estimates of the component sectors (unweighted) or the sum of the components after weighting. If logic requires weighting, what constitute the appropriate weights?

If the estimates of the component sectors are unweighted before aggregation, the implicit assumption is made that the unit value of the capital stock is identical regardless of whether the unit of capital is used for housing, farming, or other industry. Under conditions of perfectly competitive markets, the long term rate of return to capital in each sector would be identical and there would be no need to apply an explicit system of weights in order to aggregate by summing up sector totals. In effect each sector is self weighted by rate of return since the price of capital that enters into enterprise accounts and hence into the statistics is the present value of the sum of the expected (*ex ante*) net return over its

[45] "U.S. Real Product and Input," p. 49.

[46] *Ibid.*, p. 47. I am unable to identify that part of their estimating procedure that adjusts capital input for quality change. This is not accomplished by the capital goods price indexes used. If the adjustment is thought to reside in the weighting system, i.e., rates of return for each sub-sector (see next section) the logic eludes me. It is also worth noting that Jorgenson in the November 1971 version of his capital stock estimates omits a capacity utilization adjustment.

economic life. But in the real world of imperfect competitive markets the realized (*ex post*) rate of return is bound to differ from the expected rate, particularly in the short run, and the differences are not uniform from sector to sector or from one period to the next. This sort of reasoning requires that the sector estimates of capital be weighted before they are combined into a grand total in order to correct expected rates of return by actual rates.

This is also the conclusion of three of the estimator-analysts and this is accomplished statistically by using as weights the shares of all property income originating in the sectors. Denison and Kendrick, for example, estimate property income net of depreciation since they compare changes in net capital stocks with changes in net national output. This choice obliges the estimator to alter reported property income by the difference between depreciation in book values and replacement prices. Since in the Christensen–Jorgenson procedure an important objective is to partition capital input into physical volume and price components, they are obliged to cope with several additional estimating problems. One is the allocation of property income by asset type. This seems to be accomplished by distributing property income among asset types by the relative importance of each type of asset in total assets. The other is generating a price index for capital services which is taken to be identical with the rate of return after tax on capital stock. This leads to some refinements such as the elimination of capital gains and the resulting tax and the computation of separate effective tax rates for corporate and non-corporate enterprise. The quantitative importance of these refinements cannot be established from the Christensen–Jorgenson publications. My guess is that these refinements are peripheral in character and are quantitatively of much less importance than that part of reported net profit attributable to portfolio investment of non-financial corporations and to the financial assets in the form of cash and accounts and notes receivable. None of the estimator-analysts correct their weights for the use of financial capital in creating output.[47]

There still remains the question whether the weights should be fixed or changing. For reasons that are familiar to all those that have developed or studied index numbers, the preferred methodology is changing weights when long term comparisons are at issue. All estimates under review use changing weights—Denison every five years, and Kendrick at each key sub-period. Christensen–Jorgenson and, presumably, Solow use Divisia indexes which are averages of growth rates with frequent changes in weights. I share the views of Kendrick[48] and Denison[49] that capital input is *not* significantly sensitive to alternative weighting systems whether changing or fixed. The negligible effect of using fixed weights or changing weights every five years on the measurement of capital input is shown by Table 6 adapted from Denison's Table 12 in *The Source*.

[47]A crude measure of the relative importance of these two items is the percent cash and accounts receivable represent of reproducible capital (structures, equipment and inventories) and land for the corporate sector of the U.S. economy. Based on balance sheets for the year-end 1967 reported to the Internal Revenue Service, this percentage was 69 per cent. Although this greatly overstates their importance since the denominator is expressed in book value and the numerator in current prices, in constant prices the percent would be about 30 at a minimum.

[48]*Production Trends*, p. 56.

[49]*Op. cit.*, "Some Major Issues," p. 3.

TABLE 6

INDEXES OF CAPITAL INPUT, 1929–1957 (1929 = 100)

	All Reproducible Capital	
Year	Weights Changed Each 5 Years	Fixed Weights
1929	100.0	100.0
1937	100.9	100.4
1948	122.1	121.5
1953	146.8	145.6
1957	168.3	164.9

Source: Denison, *The Source, etc.*, p. 100.

A Miscellany

A final comment relates to capital input in the private sector and the handling of capital components that are owned by the government but privately operated. Their inclusion in the private sector depends, in my view, on whether the output from these facilities is counted as originating in the private sector. As a legal matter, the private enterprise never has had title (ownership) of the output. For example, private enterprise is engaged as contractor-operator by the Atomic Energy Commission (AEC) for its atomic energy installations. The AEC covers all costs, variable and fixed, and pays a management fee to the private firm. That is, the private firm has no receipts from sales because it never owned the output. If this fact is reflected in the records used in the national accounts, consistency requires that the capital stock of such operations should not be included in the private sector.

Summary

The foregoing comments suggest the following guidelines for measuring capital input in a market-oriented economy for use in total factor productivity:

1. Analysis of disaggregative estimates give promise of yielding more insights than analyses of highly aggregative estimates.
2. A disaggregative approach also accommodates the inclusion of circulating (working) capital into the measure of capital input. A fully realistic understanding of entrepreneurial behavior in a market economy requires its inclusion.
3. With respect to depreciable capital, the concept of the stock of capital net of depreciation is to be preferred to the stock of capital gross of depreciation.
4. Whether the choice is the net or gross concept, it should be measured in real terms in such a manner that the capital series include only the growth of capital inputs to the productive process and exclude the contribution of technological progress.

5. In view of the considerable deficiencies in the current measures of capacity utilization, the preferred handling of this factor is to restrict intertemporal comparisons of the relationship of real stocks of capital inputs to real output to years with the same degree of prosperity.
6. Preferred weights for combining sub-sector estimates into an aggregate are the respective shares of total property received (earned) by each sub-sector.
7. In terms of the statistical series available in U.S., relative movements of real capital input over longer periods of time are *not sensitive* to the particular choice of
    (a) assumption on discards of capital components, at least as between one-horse-shay and Winfrey distribution about the average expected life of capital components.
    (b) depreciation formula that an analyst would consider seriously.[50]
    (c) price indexes used for deflating capital components.
    (d) fixed or changing weight base in aggregating the sub-sector estimates.
8. The relative movements of real capital input *are sensitive* to the choice of
    (a) capital, net or gross of depreciation.
    (b) measure of capacity utilization and measures of capacity utilization, in turn, are sensitive to method of measurement.

[50]This excludes, of course, any depreciation allowance that is essentially a form of subsidy or is designed to stimulate investment.