PRODUCTIVE CAPACITY OF CAPITAL STOCK: PROBLEMS OF MEASUREMENT

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FOREWORD

This Collaborative Paper is one of a series embodying the outcome of a workshop and conference on *Economic Structural Change: Analytical Issues*, held at IIASA in July and August of 1983. The conference and workshop formed part of the continuing IIASA program on Patterns of Economic Structural Change and Industrial Adjustment.

Structural change was interpreted very broadly: the topics covered included the nature and causes of changes in different sectors of the world economy, the relationship between international markets and national economies, and issues of organization and incentives in large economic systems.

There is a general consensus that important economic structural changes are occurring in the world economy. There are, however, several alternative approaches to measuring these changes, to modeling the process, and to devising appropriate responses in terms of policy measures and institutional redesign. Other interesting questions concern the role of the international economic system in transmitting such changes, and the merits of alternative modes of economic organization in responding to structural change. All of these issues were addressed by participants in the workshop and conference, and will be the focus of the continuation of the research program's work.

Geoffrey Heal
Anatoli Smyshlyaev
Erno Zalai

PREFACE

When studying the "economic growth" of a country, one must be careful to identify it with processes that occur in real economic life. It is neither adequate nor correct to define it merely in terms of the growth of a particular statistical indicator such as real GNP or national income. But when dealing with real growing economies, one actually has only two possible courses of action, namely, to study either the growth of aggregate value -- however it is defined -- or the growth of the aggregate use value. The latter option means studying the growth of the aggregate utility of all goods and services produced during the period concerned. I believe that aggregate value has little or nothing to do with any useful definition of economic growth, whereas aggregate use value is precisely what should be kept in mind in any such studies.

Having adopted this definition of economic growth, however, the problem of measurement immediately arises. To measure the growth of aggregate utility adequately, it is necessary to measure both the growth in the quantity of goods and services produced and the improvements in their quality. My feeling is that the present state of the art in measuring the quality component of economic growth is such that almost nothing definite can be said about the actual rate of economic growth of a given country. Except one thing: it must be higher than the rate of growth of real GNP.

Therefore, this paper does not set out to examine the measurement of economic growth per se. Rather, it is concerned with the measurement of one of the factors of economic growth, namely, capital input, which is at least more or less observable. Several estimates of the rate of growth of the productive capacity of capital stock have already been published, mainly by US economists such as Robert Gordon of Northwestern University, Dale Jorgenson of Harvard, and others.

One very noticeable feature of the available estimates is that they reflect different facets of economic reality, and do not directly correspond to one another. Therefore, the first purpose of this paper is to arrange and systematize them somewhat. The second purpose is to provide a rough estimate of the growth rate of the productive capacity of capital stock for the US economy: this is chosen purely as an illustrative example.

It is clear that the problem itself is of a general, universal nature. The need to assess the contribution of increased capital stock productivity to national economic growth exists in all countries, even though perceptions of its relative importance may differ from one country to another.

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PRODUCTIVE CAPACITY OF CAPITAL STOCK: PROBLEMS OF MEASUREMENT*

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The extensive growth in the physical volume of capital goods is nowadays only one of the reasons behind increases in the productive capacity of fixed capital stock. The other major factor that can enable capital to produce an even greater final output is the rise in the quality of producers' durable equipment and structures, which increasingly embody the latest technological achievements.

This can be illustrated by the following example. Numerically controlled machine tools appear to be much more productive than those that they replace. Real value added in the US industries using machine tools grew 16% over the period 1973-1978 while the total number of machine tools fell by 14% (AM 1978). Another example: the total number of grain combines in the United States fell from 938,000 in 1961/65 to 655,000 in 1975 -- a drop of 30% -- as a result of the shift toward new, general-purpose combines; over the same period, the total planted acreage was expanded by 20% (IT 1978).

However, this phenomenon cannot be easily studied using official statistics, largely due to the way in which the productive capacity of capital stock is measured. According to numerous economists, the official series for aggregate capital published in many countries mainly reflect the extensive growth of accumulated capital goods, whereas the quality of the capital goods is taken into account only partially, if at all. Thus these series present a distorted picture of the phenomenon; they record only a portion of the actual change in capital stock, and leave unobserved the other -- no less important -- component of the movement. The annual percentage rate of change of a more adequate series, which took into account both quantitative growth and qualitative improvement of capital goods, might be expected to be substantially higher than those of the various official series.

*I would like to express my appreciation to David Bradford and Joe Peck for their helpful comments on an earlier draft.

1. PROPERTIES OF TRADITIONAL SERIES

When assessing the movement of capital accumulated in a certain country one usually starts by considering the time series of gross capital stock measured in constant prices. Out of the different published series relating to fixed capital this one generally conforms best to the notion of physical volume of available capital goods. It is calculated by the perpetual inventory method according to the following formula:

$$K(t) = \sum_{m=-\infty}^{t} g(t-m)I(m) \tag{1}$$

where I(m) is the real gross capital investment in year m, g(t-m) is the fraction of the capital goods introduced during year m and still in use in the current year t, and t-m is the age of these capital goods. Thus K(t) is the cumulative physical volume of capital goods introduced during all previous years and still available in year t.

To evaluate the current value of capital investment in constant prices statistical agencies use price indexes. Any errors in the calculation of the price indexes are automatically transferred to the real capital investment and real capital stock series where they produce corresponding biases but in the opposite direction to the original errors. The Bureau of Economic Analysis of the US Department of Commerce calculates price indexes for new construction and takes wholesale price indexes for producers' durable equipment from the Bureau of Labor Statistics of the US Department of Labor. US economists have repeatedly acknowledged that both these indexes have important shortcomings.

Theoretically, such price indexes should take into account only "pure" price increases, which are mainly due to inflation. But the reliable extraction of this type of "pure" price movement out of the total price increase -- which also includes the rise in the cost of capital goods due to their improved technical level -- presents substantial difficulties. Accordingly, it is widely accepted in the United States that the dynamics of the official price indexes reflect both pure price increases and a major portion of the price increases due to the rising quality of capital goods.

According to *Business Week* (BW 1979), Robert Gordon of Northwestern University has constructed an alternative "quality adjusted" deflator for producers' durable goods that takes into account quality changes such as increased energy efficiency and increased machine output per dollar of capital cost. Gordon's index has increased by only 23% since 1947, while the official BEA deflator has moved up 286% over the same period. In other words, the official deflator has grown 12.5 times as fast as Gordon's index. Even if these estimates exaggerate the actual difference between the official and "ideal" price indexes, the very order of magnitude of the difference highlights the possibility of significant distortion in the measurement of capital growth -- a potentially substantial underestimation of the true rate of capital growth.

Although the official US gross capital stock series does reflect the changing quality of capital goods, this reflection is far from complete; and one of the main reasons for this lies with the price indexes. Because of the shortcomings inherent in these indexes, even those quality changes that are in principle measurable and ideally should be reflected in capital stock series are in practice far from fully taken into account. At the same time, it must be emphasized that the measurable quality changes of capital goods represent only part of the total increase in their quality over a given period. The magnitude of the difference between the prices (all reduced to the same base year) of interchangeable modifications of producers' durable equipment depends primarily on the difference between the costs involved in the production of these modifications. This difference is not equal to the difference between the productive capacities of the various modifications.

The buyers' preference for the newer versions of equipment obviously indicates that the equipment's utility must have increased more than its price. This means that a certain part of the total quality improvement in capital goods cannot, in principle, be reflected in the straightforward ratio of comparable prices. This component cannot be reflected in the dynamics of gross capital stock, even if the measurable part of the quality improvement is fully taken into account. For this reason it is referred to as "unmeasured" quality change.

The relation between the growth rates of an official index of capital input and the sort of index that I would regard as more comprehensive and appropriate is shown in Figure 1. The height of the lower rectangle up to the bold line corresponds to the growth rate of the officially published gross capital stock. It includes a more or less adequately measured quantitative component of capital growth as well as a relatively small fraction of the qualitative component. The height of the upper rectangle (above the bold line) corresponds to the remaining, major part of the qualitative component of the growth rate of capital input; it consists of two subcomponents, representing the "measured" and "unmeasured" parts of the quality component.

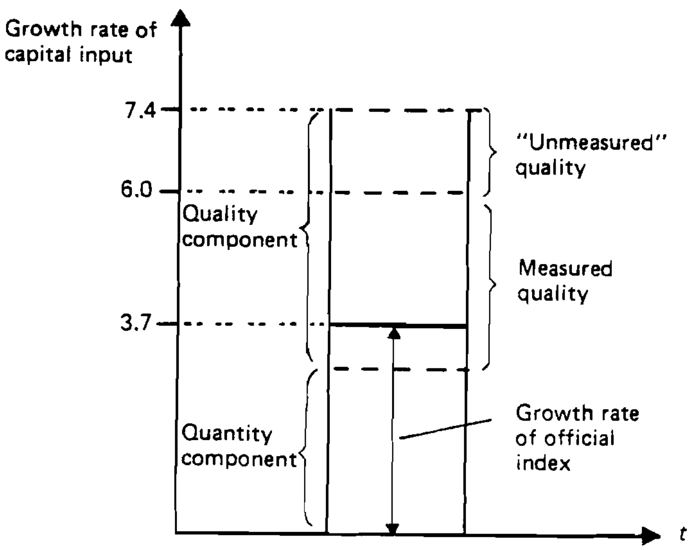

FIGURE 1 Components of the growth rate of capital input.

Previous attempts by economists to construct a series that would reflect quality changes in capital goods to a greater extent than the official series have followed three main directions: we will now briefly review each in turn.

2. USE OF THE PRODUCTION FUNCTION

Robert Solow and his collaborators concentrated on one very important aspect of quality improvement related to capital goods, namely, the growth in the productive capacity of the goods. They proceeded from the assumption that the required series can be constructed by means of econometric processing of the existing macroeconomic series of inputs and outputs of production. With that end in view, instead of the traditional index of capital stock (see eqn. 1), a new index of capital productive capacity was introduced:

$$J_{\lambda}(t) = \sum_{m=-\infty}^{t} g(t-m)(1+\lambda)^{m}I(m) \qquad (2)$$

As compared with eqn. (1), the multiplier $(1+\lambda)^{m}$ is introduced into each item of eqn. (2) to take into account the additional part of the quality improvement of capital goods that is not reflected in the official series for capital investment I(m). According to (2), fixed capital stock is represented by a vintage structure with each vintage corresponding to gross capital investments of different years less discards. As a result of technological progress, capital goods of any given vintage are assumed to be more productive than those of any previous vintage and less productive than those of any subsequent vintage.

All the quantitative estimates of λ available for the US economy (λ is referred to as the rate of embodied technical progress (ETP)) are obtained by means of indirect econometric methods within the framework of an aggregate production function, which can be written in the simplest case as

$$Y(t) = A(1+\gamma)^{t}J_{\lambda}^{\alpha}(t)L^{1-\alpha}(t) \qquad (3)$$

where Y is real GNP and L is labor input, in most cases measured as unweighted man-hours worked during a year. The elasticity of output with respect to capital α, the rate of disembodied technical progress γ, and the scale multiplier A are unknown parameters that might be estimated by the least squares method. But, to do that, one must have at least preliminary calculated series of J (t), i.e. one must know the magnitude of λ. The simplest way out of this situation is the following. Several values for λ are arbitrarily set within a sufficiently wide range, and using (2), series for $J_{\lambda}(t)$ are calculated for each λ. Then all these series are put into eqn. (3) in turn and each time the parameters α, γ, and A are estimated anew by least squares. As a result, a combination of all the parameters (including λ) is chosen that ensures that the actual data on Y(t) during the observation period are very closely approximated by the figures obtained from (3). This is the way in which most of the available estimates of λ were obtained.

Table 1 presents, in chronological order, estimates published in the United States of the rates of ETP (see column 2). Corresponding estimates of the other intensive factors of economic growth are given in columns 3 and 4. Columns 5-8 contain information concerning the contribution of individual factors and groups of factors to the rate of US economic growth. Average annual rates of US economic growth itself are given in column 9.

According to Solow's estimate, the average annual rate of ETP over the period 1929-1961 was 4%. The distinctive feature of this estimate stems from an *a priori* assumption developed by Solow that ETP was the only intensive factor of economic growth. In other words, it was assumed from the very beginning that $\gamma = 0$. In addition, the index of total unweighted man-hours was taken as a labor input. But under these conditions $\lambda = 4\%$ seems to be a substantial underestimate (see Jorgenson 1966, p.1). A more realistic result, though for a slightly different interval of observation, was obtained by Jorgenson: his estimate is $\lambda = 10.1\%$.

The estimates of Intriligator, Thurow, and Szakolczai and Stahl are free of the artificial assumption made by Solow. Perhaps for this reason, the results obtained by these economists are to a great extent comparable to one another. The rate of ETP is estimated as between 4% and 5%, and the rate of disembodied technical progress plays a substantial role in all three cases, varying from 1.2% to 1.7%. The extremely low reliability of these estimates is their most important shortcoming, and this is conceded by all the authors. The fact is that the model described by eqn. (3) fits the initial statistical data almost equally well for a wide range of combinations of λ and γ. Therefore the choice of an optimal combination of these parameters can be a rather arbitrary process. The work of Berglas proceeded along very similar lines. Although Berglas' final estimates are in sharp contrast with the results obtained by Intriligator and the others, the reliability of his estimates is still very low.

In the face of these difficulties US economists have attempted to improve the statistical methods of estimating the parameters of production function (3). We will not go into the details of the new methods but will restrict ourselves to the following observation. Although Wicken's estimate of the rate of ETP is definitely nonzero (in fact, 2.2), he nevertheless writes: "we can find no evidence to support the embodiment hypothesis" (Wickens 1970, p. 192). The results obtained by You are of a more definite character. His estimate for the rate of ETP is zero. Commenting on this conclusion he writes: "However our failure to detect the embodiment effect leads us to believe that the embodiment question may, after all, be unimportant." (You 1976, p. 127).

Thus, on the one hand, the postwar period appears to have been one of rapid technical progress, which has been reflected first of all in a radical renewal of fixed capital stock. The quality of capital goods has been improved rapidly as a result of the embodiment of the latest technological achievements: and this conclusion is beyond all question. On the other hand, various econometricians, after more than twenty years of intensive efforts to obtain a quantitative estimate of the rate of ETP, have come to the conclusion that this rate is evidently equal to zero. So we face a paradox which has certainly not been clearly resolved in the economic literature. Meanwhile it is relatively easy to observe that the very methodology that underlies the approach under consideration is inherently contradictory. The authors of the estimates discussed above implemented the ETP hypothesis in a way that assumed that the capital goods

TABLE 1 Estimates of the rate of technical progress and its contribution to the rate of growth in the private business sector of the US economy.

Source	Period	Rate of embodied technical progress (%)	Rate of growth of labor quality (%)	Rate of diseab. technical progress (%)	Contributions to GNP growth rate[a] (percentage points)				Rate of potential GNP[b] growth (7)+(8)
					Embodied technical progress	Quality of labor	Intensive factors (4)+(5)+(6)	Extensive factors	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Solow (1962)	1929-61	4.0	-	-	1.7	-	2.5	0.7	3.2
Intriligator (1965)	1929-58	4.0	0.0	1.7	0.5	0.0	2.2	0.9	3.1
Berglas (1965)	1929-60	0.0	-	1.0	0.0	-	1.0	2.2	3.2
Jorgenson (1966)	1939-59	10.1	-	-	2.4	-	2.4	1.9	4.3
Thurow (1968)	1929-65	4.0	1.0	1.2	0.7	0.8	2.7	0.6	3.3
Szakolczai and Stahl (1969)	1929-58	5.0	0.0	1.4	0.6	0.0	2.0	1.1	3.1
Wickens (1970)	1900-60	2.2	-	1.7	0.5	-	2.2	1.2	3.4
You (1976)	1929-68	0.0	-	2.1	0.0	-	2.1	1.1	3.2

[a]Approximate estimates by the author. [b]Hypothetical GNP under the assumption that the unemployment rate is 4%.

contributing to the product are of approximately invariable quality and can be adequately measured by gross capital formation in constant prices. But these same goods, forming a component of capital stock, were characterized by progressively higher levels of quality, and were therefore measured in terms of an aggregate of use values.

The most recent estimates by US economists shown in Table 1 avoid this contradiction. They indicate that the model of eqn. (3) is not self-contradictory only in the case of $\lambda = 0$. This means that even though ETP (in the sense formulated above) is one of the most important factors of real economic growth, considered as the growth of aggregate utility, it hardly has any effect on existing indexes of output such as GNP or national income (for details see Poduzov 1980, pp. 146-158). Thus, until output indexes are limited to quantitative aspects of real economic growth, any attempts to estimate the growth rate of the quality of fixed capital stock by the simple use of production functions would seem to be fruitless.*

3. USE OF ALTERNATIVE PRICE INDEXES

As pointed out earlier, certain important shortcomings in officially published price indexes lead to a significant underestimation of improvements in the quality of capital goods in the gross capital stock index. The basic method used by economists attempting to construct alternative price indexes free of these shortcomings has been known since the end of the thirties (Court 1939). However, its widespread adoption for economic research purposes began only in the sixties, mainly due to the work of Zvi Griliches and his followers. The immediate problem to be solved with the help of this method consists in calculating a hypothetical price movement for commodities (including producers' durable goods) that reflects only improvements in the quality of the commodities. The price increase caused by inflation and other factors not associated with improved quality of goods and services is calculated as the difference between the actual and hypothetical prices.

Since in any given year the great majority of commodities appear on the market in a wide variety of versions that differ from each other both in quality and in price, it is possible to examine the nature of the interdependence between price and quality characteristics for a given type of equipment without introducing further complications by stepping outside the base year. Assuming that the price difference between various versions of a given type of equipment in the base year is caused by the difference in quality of the different versions as well as by peculiarities in the marketing strategy of the firms involved, economists write down the relationship in the form of a regression equation. Statistically estimated parameters of this equation show to what extent a given improvement in the equipment

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*Note that this comment applies strictly to consideration of the entire national economy. If the approach is applied to individual sectors or industries the inherent contradiction disappears and the approach may well yield worthwhile results. This point was brought to my attention by Joe Peck.

influences its price. Having quantitative estimates of such parameters for the base year, one can then use them as a system of fixed weights for subsequent years.

The importance of these parameters lies in the fact that they allow the calculation of the hypothetical prices of capital goods with a specified level of useful properties that was absent in the base year but was achieved in subsequent years. The price change caused by a given change in the technical level of capital goods can then be calculated in this way for any subsequent year. To obtain the price index for use as a tool for deflating the current value of producers' durable equipment, the price increase associated with quality improvement is subtracted from the actual price increase of the equipment for each year. The difference thus calculated increases over time because of inflation and other factors that have nothing to do with the increasing quality of fixed capital stock.

Table 2 presents average annual percentage rates of change in real investment in producers' durable equipment calculated using both official and alternative price indexes and published by Gordon in 1980. From these estimates one can see that the magnitude of the difference between the growth rates given by the official and the alternative series is of the same order as the rate of growth of the official series itself. Gordon believes that this great discrepancy is due to a large bias inherent in the official wholesale price indexes. Besides "pure" price increases, these indexes also take into account the major part of the price increase associated with constructive improvements in equipment -- cutting operational costs, increasing efficiency, reliability, and safety, and so on. But this latter component of price increase has essentially nothing to do with price indexes: rather, it indicates that the quality of equipment is improving and, as can be seen from Table 2, when this measured quality is taken into account in the dynamics of real investment the official growth rate of investment in equipment almost doubles.

The official index of US capital investment, including both producers' durable equipment and structures, grew at an average annual rate of 3.6% over the period 1947-1970. Even if one makes the unrealistic assumption that the technical level of structures introduced during that period did not change, this figure must be increased to 5.8% to take into account just the quality improvements in producers' equipment. In other words, accumulated capital stock in the United States grew over the period 1947-1970 at an average annual rate of no less than 6%, when the measured quality of capital goods is taken into account.

TABLE 2 Annual percentage rates of change of real investment in producers' durable equipment: private business sector of the US economy, 1947-1970.

Series	1947-57	1957-70	1947-70
Official NIA	2.9	4.6	3.9
New alternative	6.7	7.7	7.2
New - official	3.8	3.1	3.3

SOURCE: Usher (1980, p.159).

When surveying the results obtained by Gordon and others we should not ignore the fact that the method employed for calculating the alternative price indexes is itself not entirely free of drawbacks. First of all, the method is purely empirical: its users make no claim that it is adequately founded in economics (Terleckyi 1975). Next, the method does not produce stable, reproducible results. It often happens that final estimates differ substantially from one investigation to another. Finally, by comparison with the methods generally used in US government statistical agencies, the alternative method requires much more information about the prices of different versions of commodities, and this information is highly expensive to collect and process.

4. USE OF CAPITAL SERVICES

Gordon's estimates given in Table 2 do not completely reflect the rising quality of US producers' durable equipment. They take into account only the measured part pf the quality improvement, i.e. the quality change reflected in the difference in prices of successive versions of capital goods. They do not, however, take into account the so-called "unmeasured" quality change that occurs over and above the simple price difference. The US economists Jorgenson, Christensen, and others believe that a relatively complete reflection of the quality changes (both measured and unmeasured) of capital goods can be achieved if these goods are widely rented and if the corresponding rental payments are incorporated into the measurement system. In other words, they propose to construct a new index of the amount of current productive services provided by all accumulated capital goods.

This approach has both supporters and opponents among economists. The well-known US economist Edward Denison is one of its most consistent opponents. His position (SCB 1982, pp. 96, 97) is as follows. Weighting the capital goods according to their relative rental values would mean that unmeasured quality differences between the goods would be taken into account. But the very term "unmeasured" means that such an approach cannot be implemented. The major difficulty is that, although leasing has become an established practice in the United States, especially during the postwar period, rented capital as a fraction of total capital stock is still insignificant. Even if appropriate statistical data were collected, its amount would still be insufficient to undertake the necessary calculations.

Denison believes, then, that an aggregate index of capital goods weighted in proportion to rental values should not be calculated at all, even if all the necessary data were available. Such a weighting system would cause the index of capital to rise more over time than the present procedure, and would represent any gains achieved by the improved design of capital goods not as advances in knowledge but simply as capital. This would nullify the concept of a rise in the efficiency of capital and would make it impossible to analyze advances in knowledge as a separate cause of growth (SCB 1982, p. 97).

In contrast, Dale Jorgenson and others who are opposed to the ideas of Denison believe that the calculation of an aggregate index of capital services would substantially expand the potentialities of economic analysis. These economists regard the quality changes that Denison describes as "unmeasurable" not only as measurable but as changes that positively need to be measured for a better understanding of the phenomenon (SCB 1982, p. 111). According to Jorgenson, the present practice of using the officially published gross stock of fixed capital as an aggregate index of capital goods introduces unjustifiable asymmetry into the treatment of capital and labor as factors of production. In his opinion, an index of capital input should be constructed in the same way as an index of labor input. Just as a quality-adjusted index of labor input is constructed from the quantities of each labor service, using as weights the relative shares of the income of each labor service in the total income of all labor services, the quality-adjusted index of capital input should be constructed from the quantities of each type of capital service, using as weights the relative shares of the rental value of each capital service in the total rental value of all capital services (SCB 1982, p. 84).

The major obstacle faced by Jorgenson and others when constructing quality-adjusted indexes of capital input was the lack of statistical data on rental values for leased capital goods. As already mentioned, leasing for production purposes is not a widespread practice in the United States (Hamel 1968). The major part of all capital goods are owned by their users: as far as these goods are concerned, rental values are clearly meaningless. The only possible way out of this situation is to calculate the implicit rental value of each type of capital service, i.e. the value that would be received by the owners of the capital stock if it were regularly rented. This was the procedure followed by Jorgenson (Jorgenson and Griliches 1967, Christensen and Jorgenson 1969).

The most recent of Jorgenson's estimates covers the US private domestic economy for the period 1948-1976. Total capital stock is separated into 46 industrial sectors. Within each sector capital stock is disaggregated by four legal forms of organization -- corporate business, noncorporate business, private households, and nonprofit institutions -- and by six types of asset -- producers' durable equipment, consumers' durables, tenant-occupied residential and nonresidential structures, owner-occupied residential structures, inventories, and land. The resulting estimates are shown in Table 3.

The aggregate index of the productive services of accumulated capital goods is presented in column 2. In contrast to the traditional index, which assesses items of capital stock in relative prices (see column 1), this index is based on the assessment of capital goods according to their implicit rental values. This "capital services" index increases annually by half as much again as the traditional index and that is the main result of Jorgenson's calculations. The fact that the growth rate of the capital services index is much higher than that of the physical volume of capital goods can only be due to that part of the total quality change which is unmeasured in the physical volume index but which appears to be measured in the capital services index. This is in fact the interpretation given by Jorgenson (see column 3 of Table 3).

It must be emphasized that the growth rates of "unmeasured" quality change of capital goods presented in Table 3 do not merely duplicate Gordon's estimates of measured quality change. Rather, Jorgenson's and Gordon's estimates complement one

TABLE 3 Average annual percentage rates of change of real capital stock and real capital services in the United States, 1948-1976.

Period	Capital stock (1)	Capital services (2)	"Unmeasured" capital quality (3)
1948-1976	2.7	4.0	1.3
1948-1953	3.0	5.1	2.1
1953-1957	2.6	3.9	1.3
1957-1960	1.9	2.7	0.8
1960-1966	2.6	3.8	1.2
1966-1969	3.3	5.0	1.7
1969-1973	2.9	4.0	1.1
1973-1976	2.4	3.1	0.7

Source: Furstenberg (1980).

another. Jorgenson proceeded from the assumption that the amount of productive services obtained from a certain type of capital goods is strictly proportional to the accumulated physical stock of these goods. This means that his index of productive services for any more or less narrow type of asset taken as homogenous does not reflect any quality changes other than those already reflected in the official index. Thus, the growth rates of capital quality presented in Table 3 reflect only shifts in the composition of capital stock. They show that over the postwar period a noticeable shift took place in the composition of US capital stock in favor of those types of assets for which implicit rental values per dollar of (comparable base-year) price are relatively higher. In particular, the shift in the technological structure of capital stock in favor of producers' durable equipment was apparently of considerable importance.

The shortcomings inherent in Jorgenson's estimates are the following. First, in spite of the fact that calculations are based on a rather detailed decomposition of capital stock by industries and by legal forms of organization, the overall degree of disaggregation does not appear to be very high. If the nonproductive sphere is excluded from the analysis, then within each of the remaining industries Jorgenson differentiates between only four types of assets -- producers' durable equipment, nonresidential structures, inventories, and land -- each of which is itself considered homogenous. Further decomposition within the types of assets would probably give still higher estimates for the "unmeasured" quality of capital stock.

Second, Jorgenson's procedure of weighting the elements of capital stock by rental values is based on neoclassical investment theory, which proceeds from a number of highly artificial assumptions. In particular it is assumed that the competition among firms is perfect, that all markets are in a state of equilibrium, that firms are able to foresee the expected demand for and price of their output with accuracy, and so on. This theory does not give any helpful answer to the question of whether the weighting procedure takes "unmeasured" quality change into account fully or only partially. References to the necessity of calculating the index for capital input in the same way as that for labor, which is based on the assessment and measurement of each type of labor according to its wages and salaries, are not fully convincing because in the case of labor input the idea is to take account of measured quality change, i.e. quality reflected in the price of a specific commodity -- labor.

Third, Jorgenson's estimates cannot be of very high reliability. Even if the procedure of weighting each type of capital according to its rental value allows us to take full account of "unmeasured" quality change (which is doubtful), the estimates presented in Table 3 are far from perfect. One of the main reasons for this is the following. Because leasing is not a widespread practice in the United States and there is a lack of direct statistical data on actual rental payments, the estimates were obtained by indirect, roundabout methods requiring sizeable preliminary calculations of implicit rental values for each type of asset.

Strictly speaking, Gordon's and Jorgenson's estimates are not comparable because of the difference in their scope. Gordon limited himself to producers' durable equipment, which is only a part -- although certainly the most important part -- of US capital stock. As for Jorgenson, he actually studied the dynamics of total national wealth, whose composition is substantially wider than that of capital stock alone. Under these conditions, any judgments about the magnitude of the postwar rise in the technical level of US capital stock must inevitably be approximate. As pointed out earlier, Gordon's estimates suggest that US capital stock, after measured quality improvements in capital goods are taken into account, grew over the period 1947-1970 at an average annual rate of no less than 6% (it was assumed that the quality of nonresidential structures did not improve over this period). Assuming further that Jorgenson's estimates for the "unmeasured" quality change in total national wealth remain valid when applied to capital stock alone, one concludes that over approximately the same period, 1948-1969, the average annual rate of "unmeasured" quality change of capital stock was about 1.4%. This means that for an approximate but fairly realistic estimate of the lower limit of US capital input growth rate one should add 1.4% to 6%. The resulting 7.4% is twice as high as the 3.7% annual growth rate in the officially published gross capital stock index over the period under consideration. (The author's rough estimate of the total quality improvement in US capital stock over the period 1947-1973 is 5% per year, and for capital input 8.5% per year: see Poduzov 1980, p. 156.)

5. CONCLUSIONS

Three main conclusions may now be drawn.

First, officially published indexes of the physical volume of capital stock do not give a complete picture of the actual rise in the potential of accumulated capital goods to contribute to the production of final output and national economic growth. Although they adequately reflect the process of quantitative, extensive growth of capital stock, they ignore for the most part changes in its quality, i.e. the growth in its productive capacity. These traditional indexes would have been fairly adequate indicators of capital input during the era preceding the industrial revolution, i.e. at a time when capital stock grew on the whole in terms of quantity, whilst quality improvements, if any, occurred relatively slowly. However, the usefulness of such indexes is diminishing greatly nowadays as the quality and efficiency of capital goods become increasingly decisive factors.

Second, economists have developed two complementary approaches to constructing indexes of capital input. One is concerned with the improvement of the official indexes of capital stock by taking more account of the so-called "measured" quality change, i.e. that change which theoretically should be accounted for but nevertheless is not reflected in the indexes because of important shortcomings inherent in the price deflators used in the calculations. The other approach is concerned with the measurement of the so-called "unmeasured" quality change, i.e. that part of the total increase in technical level of capital stock which is not in principle reflected in the relative prices of capital goods but which leads to a reduction in the price per unit of productive capacity.

Third, approximate estimates of the "measured" and "unmeasured" components of total quality change in US capital stock obtained by US economists indicate that the role of the increasing technical quality of capital goods -- associated with constructive improvements in equipment, cutting of operational costs, increasing efficiency, reliability, safety, and so on -- is comparable in importance with that of the extensive growth of capital stock. One can see from these estimates that, over the period 1947-1970, the average annual rate of growth of capital taken as an aggregate of use values is likely to have been at least twice as great as the 3.7% annual growth rate in the officially published index of gross fixed capital stock. Even an index that took into account only one aspect of the total quality change of capital goods, namely the growth in their productive capability, would also be expected to have grown much faster than the official index.

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