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PRODUCTIVITY MEASUREMENT USING CAPITAL ASSET VALUATION TO ADJUST FOR VARIATIONS IN UTILIZATION

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Abstract

Although a great deal of empirical research on productivity measurement has taken place in the last decade, one issue remaining particularly controversial and decisive is the manner by which one adjusts the productivity residual for variations in capital and capacity utilization. In this paper we use the Marshallian framework of a short run production or cost function with certain inputs quasi-fixed to provide a theoretical basis for accounting for variations in utilization. The theoretical model implies that the value of services from stocks of quasi-fixed inputs should be altered rather than their quantity. This represents a departure from most previous procedures that have adjusted the quantity of capital services for variations in utilization. In the empirical illustration, we employ Tobin's q to measure the shadow value of capital, and find that for the U.S. manufacturing sector, we can attribute about 50% of the traditionally measured decline in productivity growth during 1973-77 to a decline in capacity utilization. Hence, adjusted for utilization, the 1973-77 productivity slowdown in U.S. manufacturing is considerably less than that measured using traditional productivity accounting techniques.

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I. Introduction

Ever since the early work of Jan Tinbergen [1942], George Stigler [1947] and Robert Solow [1957], the rate of multifactor productivity growth has typically been calculated as the difference between growth rates of output and aggregate input. The resulting productivity "residual" includes conceivably the effects of a host of only partially quantifiable phenomena. This has led Moses Abramovitz to refer to the residual as a "measure of our ignorance" [1956, p. 11].

Analysis and further understanding of factors affecting the productivity residual has been the goal of much recent empirical research. For example, improvements in the skill and quality of the labor force,[1] returns to investment in research and education,[2] changes in the composition of output and input,[3] and effects on productivity growth of increased regulation[4] have all been examined carefully. One issue which remains particularly controversial and decisive, however, is the manner by which one adjusts aggregate input and hence the productivity residual for variations in capital and capacity utilization. A brief review of the literature may help to put this controversy into proper perspective.

It has long been recognized that productivity movements tend to be procyclical.[5] In his 1957 paper, Robert Solow calculated multifactor productivity under the assumption that stocks of capital and labor inputs experienced unemployment to the same degree. Labor input was measured by Solow as manhours employed, and capital in use (as distinct from capital in place) was computed as the constant dollar capital stock multiplied by one minus the unemployment rate. Using this cyclically adjusted data, Solow concluded that over the 1909-49 time period in the U.S., about one-eighth of the total increase in output per manhour was due to increased capital per manhour, and the remaining seven-eighths to multifactor productivity growth ("technical change").

Entirely reversed findings were reported a decade later by Dale W. Jorgenson and Zvi Griliches [1967], who concluded that for the U.S. private domestic economy, 1945-65, the relative contribution of technical change was negligible:

> "After elimination of aggregation errors and correction for changes in rates of utilization of labor and capital stock, the rate of growth of input explains 96.7 per cent of the rate of growth of output; change in total factor productivity explains the rest."[6]

One critical difference in measurement procedures between Jorgenson-Griliches and Solow was that Jorgenson-Griliches permitted capital to experience unemployment to a different degree than labor. Specifically, Jorgenson-Griliches multiplied their aggregate capital stock series by an estimate of the utilization of capital, calculated as the relative utilization of electric motors in U.S. manufacturing and based on data constructed by Murray Foss [1963].[7] Since, among other things, over this time period the average number of shifts worked increased, capital in use increased more rapidly than capital in place, resulting in a larger measure of aggregate input and hence a smaller productivity residual.

The Jorgenson-Griliches findings and measurement procedures were debated vigorously in a series of articles and comments,[8] with Edward F. Denison objecting in particular to the capital utilization adjustment. Denison [1969] argued it was inappropriate to adjust all capital inputs -- equipment, structures, land and inventories in the entire U.S. economy -- by the manufacturing electric motor utilization index. A year later, Laurits R. Christensen and Dale W. Jorgenson [1970] reported results with only non-residential structures and producers' durable equipment adjusted by the electric motor utilization index. Based on this reduced role of the utilization adjustment and new annual data for U.S. gross private domestic product (excluding household capital services), the Christensen-Jorgenson estimate of the contributions of technical progress 1948-67 rose from a negligible 3% to 38%, while that of growth in input fell from 97 to 62%.[9]

In his most recent research on productivity, Jorgenson has abandoned entirely the practice of adjusting measured capital input for cyclical variations in utilization.[10] Among other noted productivity analysts, John W. Kendrick [1973, 1979] and J. Randolph Norsworthy et al. [1979] make no adjustment to measured capital input for cyclical variations in utilization. On the other hand, Denison adjusts his measure of total factor input for "fluctuations in intensity of use" [1979a, p. 176] using an index of the corporate profit share in corporate national income, a procedure which has been criticized since it is unlikely to distinguish accurately between cyclical and secular movements in profit shares.[11]

The difference between Denison and Norsworthy et al. in accounting for variations in capacity utilization has recently generated a significant new controversy. Denison [1979a] argues that the "mysterious" productivity slowdown in the U.S. began in 1973, while Norsworthy et al. date the unexplained decline as beginning much earlier, perhaps as early as 1965. The reason for this disagreement on timing, Denison acknowledges, "...is my inclusion of an estimate for the effect of fluctuations in intensity of demand as a determinant of output per unit of input." Hence the dating of the decline in productivity growth depends critically on the capital utilization adjustment.[12]

The above remarks, though admittedly not exhaustive, suggest clearly that the manner by which one adjusts the productivity residual for variations in utilization is both controversial and decisive. Notably, what has not appeared in this controversy is a discussion of how basic economic theory might clarify some of the issues. This paper represents a first step in the attempt to interpret more clearly and measure more consistently the productivity residual, adjusted for variations in the utilization rates of quasi-fixed inputs such as capital plant and equipment.

In Section II the traditional productivity measurement procedure is related to the theory of cost and production. There it is noted that the traditional method is appropriate only if the firm's output is produced at the minimum point of its short run unit or average total cost (SRUC) curve.[13] In Section III a more general framework is adopted within the Marshallian convention of a short run production function or a short run cost function where some input stocks are quasi-fixed (fixed in the short run but variable in the long run), other inputs are variable, and output might not necessarily be produced at the minimum point of the SRUC curve. In such a case, the contributions of quasi-fixed inputs should be valued at their shadow prices, not at their market prices. Adjustment of the productivity residual for variations in capacity utilization is therefore made by altering the value not the quantity of capital. An attractive feature of the proposed procedure is that it is non-parametric and does not require regression analysis or econometric estimation. In Section IV an attempt is made to implement these procedures empirically, using information from the stock market and "Tobin's q", which is interpreted as the ratio of the shadow value to the market value of quasi-fixed capital.[14] Section V provides concluding remarks. An Appendix discusses and lists the data.

II. Theoretical Foundations Underlying Traditional Productivity Measurement

The economic theory underlying traditional productivity measurement is closely related to the theory of cost and production. Let there be a constant returns to scale production function[15] with traditional neoclassical curvature properties relating the maximum possible output Y obtainable during period t from the flows of services of n inputs, X_1, X_2,...X_n, and the state of technology A:

$$Y(t) = F[X_1(t),X_2(t),\ldots,X_n(t),A(t)]. \quad (1)$$

An increase in time t is assumed to lead to improvements in the state of technology A(t) arising from disembodied technical change. A logarithmic differential of (1) can be written as

$$\frac{d\ln y(t)}{dt} = \sum_{i=1}^{n} \frac{\partial \ln Y(t)}{\partial \ln X_i(t)} \cdot \frac{d\ln X_i(t)}{dt} + \frac{\partial \ln Y(t)}{\partial \ln A(t)} \cdot \frac{d\ln A(t)}{dt} \tag{2}$$

Denoting the output elasticities $\frac{\partial \ln Y(t)}{\partial \ln X_i(t)}$ by W_i, setting $\frac{\partial \ln Y(t)}{\partial \ln A(t)} = 1$, and interpreting logarithmic derivatives as rates of growth we can write (2) as

$$\frac{\dot{Y}}{Y} = \sum_{i=1}^{n} W_i \frac{\dot{X}_i}{X_i} + \frac{\dot{A}}{A} \tag{3}$$

or

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \sum_{i}^{n} W_i \frac{\dot{X}_i}{X_i} \tag{4}$$

The <u>actual</u> (as opposed to measured) multifactor productivity growth rate A/A. is given by (4). Under the assumption of constant returns to scale $\sum W_i = 1$ and the last term in (4) can be interpreted as the elasticity-weighted aggregate input. If output elasticities and all service flows were observable, (4) would provide the correct measure of multifactor productivity growth independent of factor market and capacity utilization issues. These latter issues arise due to the different possible ways of measuring W_i and the flows of services from capital inputs; and hence $\dot{A}/A$.

The conventional method of measuring $\dot{A}/A$ is to assume that observed inputs and outputs have been generated by firms in competitive long run equilibrium. With prices of output and inputs fixed, the firm chooses input levels so as to maximize profits. The first order conditions for profit maximization are then

$$\frac{\partial Y(t)}{\partial X_i(t)} = \frac{P_i(t)}{P(t)}, \qquad i = 1,\dots,n, \tag{5}$$

where $P(t)$ is output price and $P_i(t)$ is the market price of the i^{th} input. Now since the output elasticities can be written in terms of marginal products,

$$W_i = \frac{\partial \ln Y(t)}{\partial \ln X_i(t)} = \frac{\partial Y(t)}{\partial X_i(t)} \cdot \frac{X_i(t)}{Y(t)}, \qquad i = 1,\ldots,n, \tag{6}$$

we can substitute (5) into (6), and obtain

$$\frac{\partial \ln Y(t)}{\partial \ln X_i(t)} = \frac{P_i(t) \cdot X_i(t)}{P(t) \cdot Y(t)} \equiv S_i(t), \qquad i = 1,\ldots,n. \tag{7}$$

Under competitive conditions, profits are zero and revenue equals costs, implying that the output elasticity W_i can be measured by the cost share of the i^{th} input in total costs of production.[16] Hence

$$\sum_{i=1}^{n} S_i(t) = 1, \tag{8}$$

and $\dot{A}/A$ is measured by

$$\frac{\dot{A}_1}{A_1} = \frac{\dot{Y}}{Y} - \sum_{i=1}^{n} S_i \frac{\dot{X}_i}{X_i}. \tag{9}$$

Under the assumption of competitive long run equilibrium, all capital inputs are optimally utilized in the sense that total cost of production per unit of output is minimized. This long run optimal utilization is what we will call "full" utilization. When utilization is "full", flows from capital inputs can be assumed to be proportional to the stocks. This leads to the replacement of unobserved capital services flows in (9) by observed stocks. The rate of multifactor productivity growth is then calculated from (9) as the difference between the growth rates of output and aggregate input $\dot{X}/X$,

$$\frac{\dot{A}_1}{A_1} = \frac{\dot{Y}}{Y} - \frac{\dot{X}}{X}, \tag{10}$$

where aggregate input growth $\dot{X}/X$ is the revenue or cost share-weighted aggregate of the individual input growth rates, i.e.

$$\frac{\dot{X}}{X} = \sum_{i=1}^{n} S_i \frac{\dot{X}_i}{X_i}. \tag{11}$$

Finally, it should be noted that a well-known discrete approximation to the continuous Divisia index (9) is the Törnqvist index

$$\ln[A_1(t)/A_1(t-1)] = \ln[Y(t)/Y(t-1)] - \sum_{i=1}^{n} \bar{S}_i(t) \ln[X_i(t)/X_i(t-1)], \tag{12}$$

where

$$\bar{S}_i(t) = 1/2[S_i(t) + S_i(t-1)]. \tag{13}$$

The above measure of multifactor productivity is inappropriate whenever firms are not in long run cost-minimizing equilibrium. In order to highlight the capacity utilization issue in the following section, we will assume that a firm is not in long run equilibrium whenever output is produced at a level other than that corresponding with the minimum point on the firm's short run unit cost curve. This, of course, is the relevant condition for a perfectly competitive industry. Were the firm under observation not in a perfectly competitive industry, we would say that it is not in long run equilibrium whenever it is producing output at a level other than that corresponding to the tangency point of a short run average cost curve and the long run average cost curve. An analogous argument to that constructed in the following section could be developed for such a case.

Before proceeding to the next section, we note that the methods outlined in the introduction which have been used to adjust capital services can of course be viewed as attempts, when the firm is considered to be out of long run equilibrium, to relax the proportionality assumption used to identify capital flows from stocks. With the exception of Baily's [1981b] constant share Cobb-Douglas model these adjustments have been ad hoc and have not recognized explicitly that the long run marginal conditions used to obtain the value (cost) shares are no longer appropriate.

III. A Generalized Approach to Productivity Measurement

In the traditional long run equilibrium treatment, it is assumed that all inputs are variable and that for each input, marginal product equals P_i/P. We now relax this assumption. Let us partition the set of n inputs into two exhaustive and mutually exclusive subsets, one subset of J variable inputs, $v = \{v_1, v_2, \ldots, v_J\}$, and another subset of M quasi-fixed inputs, $f = \{f_1, f_2, \ldots, f_M\}$. The quasi-fixed inputs are fixed in the short run, and can be varied over time but only by incurring increasing marginal costs of adjustment.

Using this partition of inputs, we now specify a short run production function[17]

$$Y(t) = F[v_1(t), v_2(t)\ldots, v_J(t); f_1(t), f_2(t)\ldots, f_M(t); A(t)],$$

$$= F[v(t); f(t); A(t)]. \qquad (14)$$

In (14), Y(t) is the maximum amount of output obtainable during period t given flows of variable inputs v(t), stocks of quasi-fixed inputs f(t) and the state of technology A(t). Note that in (14) we no longer have a flow-stock identification problem since the quasi-fixed (capital) inputs are specified as stocks. The logarithmic differential of (14) can be written as

$$\frac{d\ln Y(t)}{dt} = \sum_{j=1}^{J} \frac{\partial \ln Y(t)}{\partial \ln v_j(t)} \cdot \frac{d\ln v_j(t)}{dt} + \sum_{m=1}^{M} \frac{\partial \ln Y(t)}{\partial \ln f_m(t)} \cdot \frac{d\ln f_m(t)}{dt}$$

$$+ \frac{\partial \ln Y(t)}{\partial \ln A(t)} \cdot \frac{d\ln A(t)}{dt} \tag{15}$$

Setting $\frac{\partial \ln Y(t)}{\partial \ln A(t)} = 1$, we can rewrite (15) as

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \left[\sum_{j=1}^{J} W_j \frac{\dot{v}_j}{v_j} + \sum_{m=1}^{M} W_m \frac{\dot{f}_m}{f_m} \right] . \tag{16}$$

Now suppose a firm is not in long run competitive equilibrium but instead is in short run competitive equilibrium. A firm maximizing expected short run variable profits [given f(t)] will choose levels of variable input flows so that

$$\frac{\partial Y(t)}{\partial v_j(t)} = \frac{P_j(t)}{P(t)} \tag{17}$$

which implies that

$$W_j(t) = \frac{\partial \ln Y(t)}{\partial \ln v_j(t)} = \frac{\partial Y(t)}{\partial v_j(t)} \cdot \frac{v_j(t)}{Y(t)} = \frac{P_j(t) \cdot v_j(t)}{P(t) \cdot Y(t)} = S_j(t),$$

$$j = 1,\ldots,J, \tag{18}$$

which looks just like (7), except that (18) holds only for the variable inputs, not for the quasi-fixed inputs. Expenditures on a particular variable factor in (7) and (18) are numerically equal but $\sum_{j=1}^{J} S_j(t) \neq 1$ unless there are no quasi-fixed factors.

Since by definition the f_m are quasi-fixed in the short run, it follows that for the short run (one period) profit maximizing firm, marginal product values of the f_m are not necessarily equal to transaction prices $P_m(t)$ where P_m is now the market user cost, or one-period market rental price of the m^{th} input stock. Hence output elasticities will differ from value shares. Define the ex post realized shadow user cost of the m^{th} quasi-fixed input as Z_m:

$$Z_m(t) = \frac{P(t)\partial Y(t)}{\partial f_m(t)} ; \tag{19}$$

and the ex ante expected shadow user cost as Z_m^*:

$$Z_m^*(t) = \frac{P^*(t)\partial Y(t)}{\partial f_m(t)} \tag{20}$$

where $P^*(t)$ is the expected output price. Note that we are now considering a disequilibrium process (relative to the long run equilibrium) and non-realized expectations are possible. Implicit in our formulation is the assumption that at the beginning of the period (ex ante), the firm forms expectations about future input and output prices. Its optimal response in adjusting quasi-fixed factors is based on these expectations. Hence the expected value of the marginal product $[Z_m^*(t)]$ is the relevant shadow rental price, corresponding to the observed levels of the quasi-fixed inputs. Ex post, once actual input and output prices are known, the firm chooses the levels of its variable factors and output, conditional on the prior choice of the quasi-fixed factors.

This means that the actual value shares $[S_j(t)]$ are the correct weights for the variable factors.

$Z_m^*(t)$ represents the additional expected variable profits during period t obtained by adding one more unit of f_m for one time period. Differences between the transaction rental prices $P_m(t)$ and expected shadow rental prices $Z_m^*(t)$ are usually thought to be due to the presence of increasing marginal costs of adjustment for the quasi-fixed inputs.[18] When $Z_m^* > P_m$, the firm expects a relative shortage of f_m and has incentives to invest in additional units of f_m; when $Z_m^* < P_m$, the firm expects to find itself with relative surplus of f_m and has incentives to disinvest; finally, when $Z_m^* = P_m$, the short and long run levels of f_m coincide, implying that no incentives exist to change stocks of f_m. This suggests an important relationship among Z_m^*, P_m and capacity utilization which will be discussed later.

The output elasticity of the m^{th} quasi-fixed input can be expressed in terms of the expected shadow prices $Z_m^*(t)$ as follows:

$$W_m^*(t) = \frac{\partial \ln Y(t)}{\partial \ln f_m(t)} = \frac{\partial Y(t)}{\partial f_m(t)} \cdot \frac{f_m(t)}{Y(t)} = \frac{Z_m^*(t) \cdot f_m(t)}{P^*(t) \cdot Y(t)}, \quad m = 1,\ldots,M. \tag{21}$$

Utilizing (16), (18) and (21) we obtain a measure of multifactor productivity growth $\dot{A}_2/A_2$ consistent with short run firm equilibrium:

$$\frac{\dot{A}_2}{A_2} = \frac{\dot{Y}}{Y} - \left(\sum_{j=1}^{J} S_j \frac{\dot{v}_j}{v_j} + \sum_{m=1}^{M} W_m^* \frac{\dot{f}_m}{f_m} \right) \tag{22}$$

Notice that even though $Y = H(v, f, t)$ is homogeneous of degree one in v and f, the output elasticities S_j, W_m^* do not necessarily sum to unity. However the output elasticities S_j, W_m do sum to unity, where

$$W_m(t) = \frac{Z_m(t) \cdot f_m(t)}{P(t) \cdot Y(t)} \tag{23}$$

Equation (22) can be rewritten as

$$\frac{\dot{A}_2}{A_2} = \frac{\dot{Y}}{Y} - \frac{\dot{X}^*}{X^*} \tag{24}$$

where X* is the shadow value-weighted sum of variable and quasi-fixed inputs,

$$\frac{\dot{X}^*}{X^*} = \sum_{j=1}^{J} S_j \cdot \frac{\dot{v}_j}{v_j} + \sum_{m=1}^{M} W^*_m \cdot \frac{\dot{f}_m}{f_m} \tag{25}$$

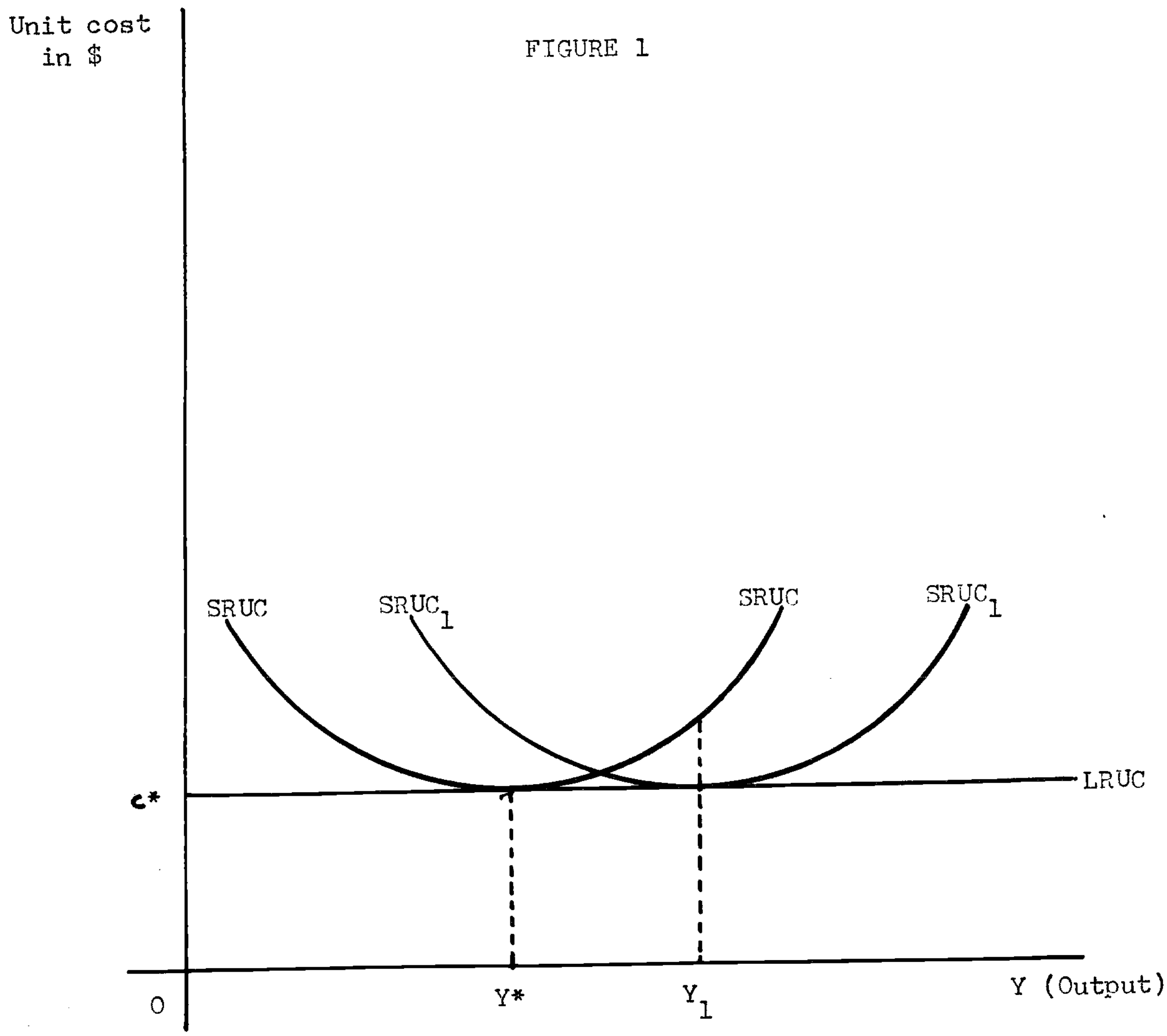
When Z^*_m decreases from $Z^*_m = P_m$ to $Z^*_m < P_m$ for all m (a relative surplus of stocks of f_m exist), f_m is valued less highly (f_m is utilized to a lesser extent), and therefore aggregate input growth $\dot{X}^*/X^*$ is less than $\dot{X}/X$, implying by (10) and (24) that $\dot{A}_2/A_2$ is greater than $\dot{A}_1/A_1$. If the firm is in long run disequilibrium because capacity has become underutilized between periods t - 1 and t, $\dot{A}_2/A_2$ is the correct measure of $\dot{A}/A$ and the traditional measure $\dot{A}_1/A_1$ understates true multifactor productivity growth. Our empirical results, presented in section IV, suggest that this is the case for U.S. manufacturing during the period 1973-77, that the reverse bias occurred during 1965-73, and hence that the productivity downturn after 1973 has not been as great as conventionally measured.

The decreased utilization of f_m when $Z^*_m < P_m$ is accounted for in (24) by adjusting <u>values</u> of stocks f_m, not their <u>quantities</u> of service flows. Recall from the introduction that previously some productivity researchers have adjusted the quantity of quasi-fixed factors (like capital) for utilization, not the value weights of these factors. Finally, it should be clear that when $P_m = Z_m^*$ for all m, $\dot{X}/X = \dot{X}^*/X^*$, and the traditional and our alternative measures of multifactor productivity coincide.

A graphical analysis may be helpful at this point. In Figure 1 below, we show the long run unit cost (hereafter, LRUC) curve as being flat, with the level of LRUC equal to c^o. The LRUC curve is flat because we have assumed that the long run production function is characterized by constant returns to scale. As seen in Figure 1, however, the short run unit cost (average total cost, hereafter, SRUC) curve is U-shaped, reflecting the fact that in the short run certain inputs are quasi-fixed. The position and shape of the SRUC curve depend on technology, Y, P_j, f_m, P_m and A.

At the level of output Y^o in Figure 1, the SRUC curve reaches a minimum point c^o. Based on a tradition dating back at least to the work of J. M. Cassels [1937], Lawrence Klein [1960, 1962] and Bert Hickman [1964], Y^o has been called the firm's capacity level of output. Notice that at Y^o, the LRUC curve is tangent to the SRUC curve.[19] It might also be noted that this short run unit cost-minimizing level of output Y^o will not necessarily coincide with the firm's short run profit maximizing level of output. For example, if the firm faced competitive markets and if suddenly the market price of Y increased to a level greater than c^o, the firm could enhance its short run profits by expanding its output beyond Y^o until short run marginal cost equalled market price.[20] Nonetheless, the capacity level of output Y^o embodies desirable economic welfare properties, in that if market prices reflected marginal social costs, Y^o would be that level of output for which society would be expending minimum unit social costs. Finally, as noted by Hickman, if the output level were sustained at Y^o, there would be no economic incentive for the firm to alter its production technology by varying quantities of its quasi-fixed inputs. In contrast, if an output level

FIGURE 1



$Y^1 > Y^0$ were sustained, the firm could reduce unit costs by adding to its net stocks of f_m, thereby eventually shifting its SRUC curve in Figure 1 to $SRUC_1$, and ultimately attaining again the minimum level of unit cost c^0 at the increased output level Y^1. With the increased stocks of f_m and the new unit cost curve $SRUC_1$, new short run capacity output would of course be equal to Y^1.

Having discussed capacity output, we now define the firm's rate of capacity utilization u as actual output Y divided by capacity output Y^0, i.e.

$$u \equiv Y/Y^0. \tag{26}$$

When $u < 1$ so that $Y < Y^0$, the firm is to the left of the minimum point on the SRUC curve; reductions in unit cost can be achieved by increasing output. On the other hand, when $u > 1$ so that $Y > Y^0$, the firm is to the right of the minimum point on the SRUC curve, where increases in output result in greater SRUC. If one defines short run returns to scale as the percentage change in output divided by the percentage change in the quantity of each variable input, all quasi-fixed input stocks fixed, then when $u < 1$ the firm enjoys short run increasing returns to scale, and when $u > 1$ it encounters short run decreasing returns to scale.[21]

As an example, consider the case of a single quasi-fixed factor (capital) and a single variable input (labor) producing output (value added). Whenever $Y > Y^0$, then not only will $u > 1$, but the expected shadow rental price of capital (Z_k^*) will be greater than the market rental price of capital (P_k). Define the ratio of Z_k^* to P_k as q_k, i.e.

$$q_k \equiv \frac{Z^*_k}{P_k} \tag{27}$$

(In the next section we relate q_k to Tobin's q in order to measure the shadow value weight W_k^*.) When the rate of capacity utilization is greater than unity, q_k will also be greater than unity. Intuitively, unit cost is rising because of diminishing returns to the increasingly utilized fixed factor capital; if the firm increased its stock of capital by renting one more unit for one period, average total costs for that period would fall. Thus the one period value of the capital to the firm -- the shadow rental price of capital, the one period reduction in unit costs -- is greater than the market rental price of capital, implying that q_k is greater than unity and that cost-reducing investment is induced; the rate of such investment depends of course on the magnitude of adjustment costs.

In a similar way, when the firm is expecting to produce output to the left of the minimum point on the SRUC curve ($u < 1$), q_k is also less than unity, and incentives for net increases in the capital stock do not exist. When the firm's expected output equals its capacity output, both u and q_k equal unity, and average cost is expected to be at a minimum.

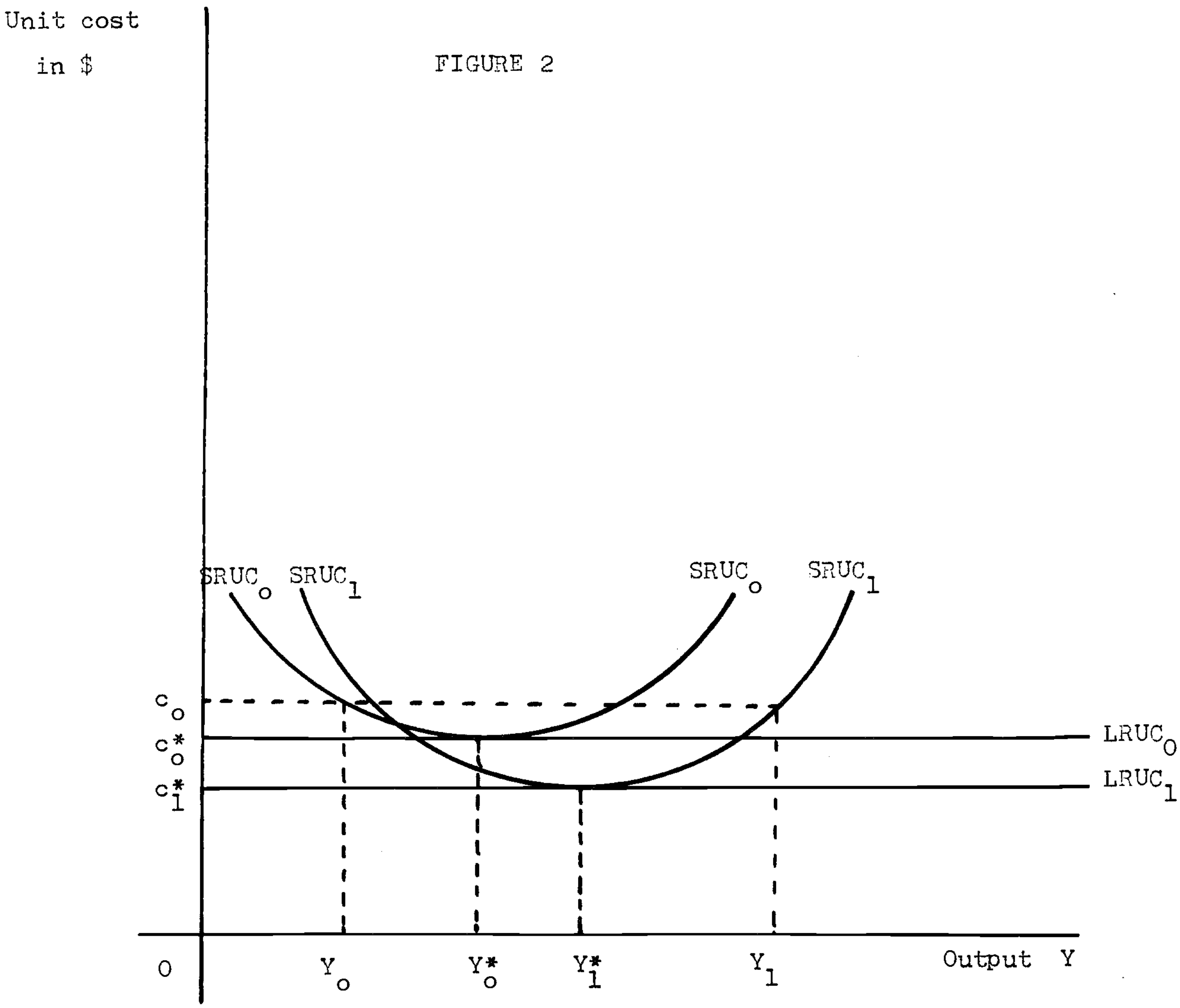
The notion of multifactor productivity growth is illustrated in Figure 2. Let the original LRUC curve be $LRUC_0$, and let the new LRUC curve reflecting an improved state of technology be $LRUC_1$. Assuming that input prices remain unchanged between periods 0 and 1, the effect of disembodied technical progress is to reduct LRUC from c^0 to c^1. Under conditions of long run competitive equilibrium, multifactor productivity growth would be calculated in Figure 2 by holding input quantities constant between time periods 0 and 1, but letting output increase. Hence total cost would remain unchanged while unit costs fell, and $\dot{A}_1/A_1$ would be indicated by the output growth BD and would be measured, using (12), as a logarithm of the ratio $0Y^1/0Y^0$.

This traditional measure of multifactor productivity growth is based on the assumption that in both time periods actual output equals capacity output, i.e., $u = 1$.[22] In terms of Figure 2, it is traditionally assumed that all observed points correspond to economic capacity output levels and minimum unit costs such as (c^0, Y^0) and (c^1, Y^1). We now provide a graphical interpretation of multifactor productivity measurement when rates of capacity utilization differ from unity.

In Figure 2, let the original level of output be Y_0^s rather than Y^0 and for simplicity assume <u>ex ante</u> expectations are realized. Since $Y_0^s < Y^0$, the original rate of capacity utilization u_0 is less than unity. Let the output level at time period 1 be Y^1. This implies that while $u_0 < 1$, $u_1 = 1$.[23] Assume that input prices do not change between time periods 0 and 1. Now if only the two data points (c^0, Y_s^0) and (c^1, Y^1) were observed, if it were incorrectly assumed that both points represented long run equilibria (where $u = 1$), and if multifactor productivity growth were then measured using (12), true multifactor productivity growth would be overstated, since the horizontal distance $Y^1 - Y^s$ is larger than $Y^1 - Y^0$. By incorrectly assuming that (c^0, Y_0^s) represented a long run equilibrium, the researcher would be attributing to improvements in the state of technology A(t) increases in output due partly to increases in the rate of capacity utilization. Although improvements in the state of technology would be reflected in output increases from Y^0 to Y^1, the additional increase in output from Y_0^s to Y^0 would have nothing to do with multifactor productivity growth, but instead solely reflect gains due to exploitation of short run increases in capacity utilization from $u_0 < 1$ to $u_1 = 1$.[24]

Let us now summarize the discussion to this point. Traditional multifactor productivity growth measures are appropriate only if the observed data points coincide with long run equilibrium conditions where output is produced at the point of tangency between short run and long run average (unit) cost curves. At this point, shadow rental prices Z_m^* and market rental

FIGURE 2


Unit cost
in $
SRUC$_o$
SRUC$_1$
SRUC$_o$
SRUC$_1$
c$_o$
c$_o^*$
c$_1^*$
LRUC$_O$
LRUC$_1$
O
Y$_o$
Y$_o^*$
Y$_1^*$
Y$_1$
Output Y

prices P_m coincide. When $Z_m^* \neq P_m$, capacity utilization $u \neq 1$; multifactor productivity growth should be measured using (22) which incorporates expected shadow value shares of the quasi-fixed inputs, not actual market rental shares. There does not appear to be any theorteical justification for the commonly used methods of adjusting quantities of the quasi-fixed inputs when $u \neq 1$.[25] In the case of a single quasi-fixed input (capital, K) when $u > 1$ the ratio $q_k = \frac{Z_k^*}{P_k}$ is also greater than unity. Finally, note that if q_k were observed or could be estimated, then one could solve for Z_k^* as $Z_k^* = q_k \cdot P_k$, substitute into (22), and thereby obtain a measure of multifactor productivity growth that properly accounted for variations in the rate of capacity utilization. This is the approach taken in the next section.

IV. Empirical Illustration Employing Tobin's q

In this section we present an empirical implementation of multifactor productivity measurement that attempts to incorporate variations in capacity utilization in a theoretically consistent manner. Although the general empirical applicability of the utilization-adjusted multifactor productivity growth measure (22) may be circumscribed due to difficulties in obtaining reliable data on the expected shadow values of quasi-fixed inputs, here we consider one case of special empirical interest for which an estimate of shadow values is available.

Assume the short run production function has J variable inputs $v_1, v_2, \ldots, v_J$ and only one quasi-fixed input, physical capital K. A discrete approximation to the productivity growth measure $\dot{A}_2/A_2$ in (22) can be written as[26]

$$\ln[A_2(t)/A_2(t-1)] = \ln[Y(t)/Y(t-1)] - \sum_{j=1}^{J} \bar{S}_j(t) \ln[v_j(t)/v_j(t-1)] - \bar{W}_K^*(t) \ln[K(t)/K(t-1)]. \quad (28)$$

where

$$\bar{S}_j(t) = 1/2[S_j(t) + S_j(t-1)], \; \bar{W}_k^*(t) = 1/2[W_k^* + W_k^*(t-1)]. \tag{29}$$

Recall from (21) that $W_k^*(t)$ employs the expected shadow rental value of capital $Z_k^*(t)$ rather than the ex post market rental value $P_k(t)$. Also, by way of comparison, note that the traditional multifactor productivity formula (12) for $\dot{A}_1/A_1$ assumes that capital is a variable input and that production always takes place at the minimum point on the short run unit cost curve.

In order to implement empirically measurement of $\dot{A}_2/A_2$ using (22), it is necessary to obtain data on the expected shadow rental price of capital, Z_k^*. Our approach here is to utilize a notion of James Tobin, called Tobin's q, and defined by him simply as the market value of the firm (the value of the firm's securities - debt plus equity - in the securities market) divided by the replacement cost of its physical capital stock.[27]

Tobin's q was originally presented in the context of a financial portfolio model, where a firm faced the choice of buying claims to a firm's assets or investing in the new plant and equipment directly. Whenever marginal q is greater than unity, the firm maximizing its net worth will invest in plant and equipment directly, rather than purchase financial claims to these assets, for in such a way net worth is increased by the difference between the market valuation and the costs of investing in the capital goods.[28] A slight variant of q with more "real" than "financial" structure was developed initially by Andrew Abel [1978, Essay IV], discussed also by John Ciccolo and Gary Fromm [1979], and extended by Hiroshi Yoshikawa [1980] and Fumio Hayashi [1982]. In its amended form, q is defined as the shadow price of installed capital goods divided by the tax-adjusted price of uninstalled capital goods.

The numerator represents the marginal benefits of investment, while the denominator represents the marginal costs. Using a dynamic optimization framework, Abel showed that investment is an increasing function of the shadow price of this q. E. R. Berndt [1980b] has implemented empirically Abel's notion of q, incorporating also internal costs of adjustment.

As noted by Hayashi [1982], Tobin's q incorporates information on expectations held by investors with respect to future market conditions; hence expectations regarding input and output prices are implicit in the stock market valuation process. This implies that Tobin's q is linked not to the _ex post actual_ shadow price $Z_k(t)$ but to the _ex ante expected_ shadow price $Z_k^*(t)$, as we require. It is this powerful informational content of Tobin's q which allows us to avoid explicit specification of an expectations hypothesis in our empirical analysis. Note also that regression techniques are not necessary.

From the equations of motion of the cost of adjustment model, it can be shown that the expected shadow rental price Z_k^* can be obtained by replacing the capital stock transactions price a(t) by q.a(t) in the standard Jorgenson neoclassical user cost of capital formula.[29] As long as the capital gains term is ignored, Z_k^* can be obtained equivalently as

$$Z_k^* = q \cdot P_k \tag{30}$$

where the measure of P_k is the traditional Hall-Jorgenson rental price of capital formula that includes tax variables, but that uses as the interest rate a weighted average of the debt and equity borrowing costs of capital.[30]

Jorgenson's measure has typically been an _ex post_ internal rate of return, and therefore use of that measure yields Z_k rather than P_k. Note as well that Jorgenson's measure does not yield Z_k^* unless expectations are realized. We consider this issue in more detail below.

Empirical estimates of q for the U.S. nonfinancial corporate sector on an annual basis are published regularly in the U. S. Economic Report of the President.[31] Measurement issues have been discussed by, among others, Daniel M. Holland and Stewart C. Myers [1979, 1980], who work from the notion that "...q reflects the expected profitability of corporate investment relative to the opportunity cost of capital" [1979. p. 117]. Holland-Myers note that alternative estimates of q can be obtained from the same underlying data base, due to alternative assumptions about depreciation and service lives, historical book value versus current replacement cost accounting, and "narrow" (structures, equipment, and inventories) versus "augmented" (structures, equipment, inventories, land and working capital) measures of capital stock.[32]

In Table 1 below we present four estimates of q, three for the total U.S. nonfinancial corporate sector and one for the U.S. manufacturing sector.[33] Columns 1 and 2 are estimates constructed by Holland-Myers. Their "standard q" estimates in column 1 tend to be slightly larger than their "augmented q" estimates in column 2, primarily because the former include in the denominator of q only structures, equipment and inventories, while the latter add to the denominator estimates of land and working capital. The cyclical behavior of both measures is quite similar, however, each reaching a trough in 1949 and a peak in 1965.

In column 3 we list estimates of q as published in the 1981 Economic Report of the President. These estimates are smaller than the Holland-Myers augmented q estimates in all years except 1958 and 1970; the difference, however, is rather small except for 1974. Unfortunately, the Economic Report of the President does not provide details on how the estimate of q was constructed, but merely defines it as equity plus interest-bearing debt divided by current replacement cost of net assets. In column 4 we present Holland-Myers estimates of q (based on the "standard" rather than "augmented"

TABLE 1

Empirical Estimates of Tobin's q

	U. S. Nonfinancial Corporate Sector			U. S. Manufacturing		
	Holland-Myers "Standard q"	Holland-Myers "Augmented q"	1981 Economic Report of the President	Holland-Myers "Standard q"	CU Wharton	CU FRB
1947	1.00	0.87		0.96		
1948	0.87	0.74		0.80		82.5
1949	0.71	0.60		0.60		74.2
1950	0.79	0.68		0.74		82.8
1951	0.72	0.64		0.62		85.8
1952	0.72	0.66		0.60		85.4
1953	0.71	0.65		0.62		89.2
1954	0.77	0.68		0.69	88.1	80.3
1955	0.97	0.86	0.855	0.98	90.5	87.1
1956	0.98	0.89	0.837	0.97	87.9	86.4
1957	0.92	0.82	0.775	0.92	84.0	83.7
1958	0.91	0.79	0.810	0.83	74.2	75.2
1959	1.15	1.01	0.977	1.19	78.9	81.9
1960	1.10	0.97	0.954	1.15	76.9	80.2
1961	1.29	1.13	1.055	1.33	73.7	77.4
1962	1.24	1.09	0.998	1.31	76.5	81.6
1963	1.39	1.22	1.096	1.48	77.7	83.5
1964	1.49	1.28	1.174	1.73	79.5	85.6
1965	1.57	1.37	1.247	1.98	84.2	89.6
1966	1.43	1.23	1.126	1.66	88.2	91.1
1967	1.41	1.22	1.138	1.57	86.9	86.9
1968	1.38	1.19	1.174	1.68	89.2	87.1
1969	1.31	1.13	1.053	1.50	90.1	86.2
1970	0.97	0.84	0.861	1.01	84.0	79.3
1971	1.12	0.98	0.939	1.21	82.6	78.4
1972	1.20	1.03	1.011	1.29	87.7	83.5
1973	1.16	1.00	0.932	1.10	92.9	87.6
1974	0.92	0.93	0.666	0.54	90.2	83.8
1975	0.79	0.72	0.658	0.65	79.4	72.9
1976	0.88	0.79	0.743	0.68	85.5	79.5
1977	0.79		0.656	0.68	88.1	81.9
1978	0.71		0.606	0.56	90.9	84.4
1979			0.561		92.6	85.7

SOURCES:

Column 1: Holland-Myers [1980], Table 2, p. 322.

Column 2: Holland-Myers [1979], Table 2, p. 114.

Column 3: 1981 U. S. Economic Report of the President, Table B-86, p. 331.

Column 4: Holland-Myers [1980], Table 2, p. 322.

Column 5 and

Column 6: 1981 U. S. Economic Report of the President, Table B-43, p. 281.

assumption) for the U.S. manufacturing sector. These sector-specific estimates are more volatile than those for the entire nonfinancial corporate sector. The manufacturing estimates vary, for example, from 1.98 in 1965 to 0.56 in 1978, whereas the corresponding high and low nonfinancial corporate sector estimates are 1.57 and 0.71.

Finally, since in our theoretical development we relate q to an economic notion of capacity utilization, in the final two columns of Table 1 we list Wharton and Federal Reserve Board (FRB) estimates of capacity utilization (CU) for the U.S. manufacturing sector. It should be noted here that these published measures of CU are constructed in a rather mechanical way and have only a limited relationship with the economic measure of CU defined earlier as the ratio of actual output to the output at which short and long run average cost curves are tangent.[34] The Wharton measure of CU is lowest in 1961, is surprisingly high in the 1974-79 time period, and hits its peak in 1973; by contrast, the Holland-Myers estimate of q is lowest in 1974 and highest in 1965. Hence there appears to be considerable differences between q and the Wharton measure of CU. Trends in the FRB measure of CU, however, move more closely with q. As seen in the last column of Table 1, the FRB is lowest in 1975 (when q is also very low), and is highest in 1966 (when q is also very high).[35] Hence there appears to be considerable agreement between movements in q and in the FRB measure of CU.[36]

Having discussed alternative measures of q, we now incorporate q into the measurement of multifactor productivity. While the q theory allows computation of Z_k^*, we cannot compute W_k^* exactly since P*(t) is unknown. Instead, we estimate W_k^* by $\hat{W}_k^*$ where

$$\hat{W}_k^* = \frac{Z_k^*(t) \cdot K(t)}{P(t) \cdot Y(t)} = W_k^*(t) \cdot \left[\frac{P^*(t)}{P(t)}\right] \qquad (31)$$

In essence, we replace the unobserved expected output price with the observed actual output price. This substitution may affect the measurement of productivity. However, if output price expectations are realized, it has no effect. Also, if expectations errors are small and random, the effect should be minimal. A third distinct possibility is that investors systematically underestimate cyclical variations. In that case $P(t) < P^*(t)$ when $u < 1$ and $P(t) > P^*(t)$ when $u > 1$. It follows that $\hat{W}_k^* \gtrless W_k^*$ when $u \lessgtr 1$. In this case our empirical results would underestimate the contribution of capacity utilization effects to variations in traditionally measured multifactor productivity growth.

We now calculate both $\dot{A}_1/A_1$ and $\dot{A}_2/A_2$. Recall that the former assumes all inputs are variable, whereas the latter allows capital to be quasi-fixed in the short run and permits production to be at output levels other than at the minimum point on the firm's short run unit cost curve, i.e., $\dot{A}_2/A_2$ incorporates variations over time in capacity utilization. Our results for $\dot{A}_1/A_1$ and $\dot{A}_2/A_2$ are presented in columns 1 and 3 of Table 2. These results utilize annual data provided by J. Randolph Norsworthy and Michael J. Harper of the U.S. Bureau of Labor Statistics on capital (K), labor (L), energy (E), non-energy intermediate materials (M), and gross output (Y) for the U.S. manufacturing sector 1958-77. These data are listed and discussed in greater detail in the Data Appendix.

The market rental price of capital P_k used in our measure of $Z_k^* = q \cdot P_k$ employs as the cost of capital r a borrowing rate from the securities market. This procedure differs from that of Jorgenson and his associates, who typically assume q = 1 but use as their estimate of r in P_k the *ex post* internal rate of return earned on the beginning-of-year capital stock. The rental price of capital using such an *ex post* internal rate of return is just Z_k, the actual *ex post* shadow price. Hence Jorgenson's procedure can be

Table 2

Traditional and Utilization-Adjusted Measures of Productivity:

Average Annual Growth Rates, U.S. Manufacturing, 1958-77

	$\dot{A}_1/A_1$ (Traditional Measure)	Growth Rate Using Ex Post Shadow Price Z_m (Jorgenson Measure)	$\dot{A}_2/A_2$ (Preferable Measure)
1958-77	0.829	0.832	0.749
1958-65	1.360	1.382	1.278
1965-73	0.671	0.628	0.518
1973-77	0.212	0.285	0.286

interpreted as adjusting the productivity formula for capacity utilization by employing the weight $W_k(t)$ rather than the correct weight, $W_k^*(t)$ or its proxy $\hat{W}_k^*(t)$. For comparison purposes we present in column 2 of Table 2 measures of average annual productivity growth using $W_k(t)$ as weights.

We first compare columns 1 and 2, the traditional and Jorgenson measures. Over the entire 1958-77 time period, the two average annual growth rates are virtually identical - 0.829 and 0.832 percent per year. Moreover, these two measures differ only very slightly over the 1958-65 sub-period. Beginning in 1965, however, the measures show slightly greater differences: $\dot{A}_1/A_1$ drops 0.459% per year from 1965-73 to 1973-77 (.671 to .212) whereas the Jorgenson <u>ex post</u> shadow price measure drops 0.343% per year (.628 to .285). This implies that 25% of the traditionally measured decline in productivity growth from 1965-73 to 1973-77 in the U.S. manufacturing would be captured by declines in capacity utilization using the <u>ex post</u> measure.

Now comparing $\dot{A}_1/A_1$ with the correct $\dot{A}_2/A_2$ measure, we first note that our utilization-adjusted measure of the growth rate over the 1958-77 period is somewhat less than that of the traditional measure. This reflects the fact that, on average, economic capacity utilization has been growing and been greater than full utilization, thereby inducing positive net capital accumulation. The two measures differ in all periods and the differences are substantial after 1965. In particular, from 1965-73 to 1973-77 our measure declines only 0.232% per year (compared with 0.459% for $\dot{A}_1/A_1$). Hence our analysis attributes 50% of the traditionally measured decline in total factor productivity growth after 1973 to declines in capacity utilization. This suggests that when properly measured, the productivity growth slowdown in U.S. manufacturing since 1973 is less than typically measured.

We conclude with two observations. First, although incorporation of capacity utilization into productivity calculations substantially reduces the differences in growth rates among sub-periods, some considerable differences still remain to be explained. The contribution of the $\dot{A}_2/A_2$ residual to "explaining" growth in output is 24% in 1958-65, 14% in 1965-73, and jumps to 28% in 1973-77.[37] Second, our results indicate that the major decline in long run productivity growth occurred about 1965 - not 1973. This presents a challenge to simple energy crisis explanations of the productivity growth slowdown.

V. Concluding Remarks

Although a great deal of empirical research on productivity measurement has taken place in the last decade, one issue remaining particularly controversial and decisive is the manner by which one adjusts the productivity residual for variations in capital and capacity utilization. In this paper we have used the Marshallian framework of a short run production or cost function with certain inputs quasi-fixed, and have provided a theoretical basis for accounting for variations in utilization by altering the value of services from stocks of quasi-fixed inputs, rather than their quantity. This represents somewhat of a departure from previous procedures that adjusted the quantity of capital services for variations in utilization. An attractive feature of our approach is that it is non-parametric and therefore does not require regression analysis. In the empirical illustration, we have employed Tobin's q to measure the shadow value of capital, and have found that for the U.S. manufacturing sector, we can attribute 50% of the traditionally measured decline in productivity growth, from 1965-73 to 1973-77, to a decline in capacity utilization.

Our discussion has focussed on multifactor productivity measurement, but our results also have implications for the interpretation of labor productivity growth. Of course the measure of labor productivity growth, $\dot{Y}/Y - \dot{L}/L$, is unaffected by variations in the utilization of non-labor inputs.

However, since labor productivity growth can be rewritten in terms of multifactor productivity growth,

$$\frac{\dot{Y}}{Y} - \frac{\dot{L}}{L} = \frac{\dot{A}_2}{A_2} + \sum_{\substack{j=1 \\ j \neq L}}^{J} S_j\left(\frac{\dot{v}_j}{v_j} - \frac{\dot{L}}{L}\right) + \sum_{m=1}^{M} W_m^*\left(\frac{\dot{f}_m}{f_m} - \frac{\dot{L}}{L}\right) \tag{32}$$

it is clear that the role of the properly measured utilization-adjusted $\dot{A}_2/A_2$ in "explaining" growth in labor productivity is affected by variations in capacity utilization.

In this paper differences between shadow values and market values of capital have been posited to be due to costs of adjustment. This suggests that costs of adjustments could be included explicitly into the short run production or cost function, and productivity could then be represented as the time shift in this function.[38] Capacity output could be redefined in terms of costs inclusive of adjustment costs. Alternative expectations assumptions could also be incorporated. An empirical disadvantage of such an approach, however, is that data on adjustment costs are not easily obtained, and thus empirical implementation might be difficult.

Finally, it is well known that average and marginal values of q are likely to differ, particularly when the characteristics of the capital stock in place vary considerably from those emobdied in new plant and equipment. For example, the energy efficiency of certain equipment manufactured and sold in the U.S. during the late 1960's and early 1970's may be lower than that sold in the 1950's or being produced today. As a consequence, the market value of capital in place may be considerably less than the market value of new equipment, and average q may be much smaller than marginal q.[39] Such vintage effects need to be examined more carefully, both theoretically and empirically, and their implications for productivity measurement assessed.[40]

We conclude that in order to understand better recent trends in productivity growth, particular account must be taken of the utilization and characteristics of the capital stock. This paper represents a first step in that direction.

DATA APPENDIX

Annual data on input prices and quantities for capital (K), labor (L), energy (E) and non-energy intermediate materials (M), as well as gross output (Y,OUTPUT) are listed in Table A-1. These data were generously provided by J. Randolph Norsworthy and Michael J. Harper of the U.S. Bureau of Labor Statistics. Capital is a Divisia aggregate index of producers' durable equipment, nonresidential structures, land and inventories; the capital rental price accounts for tax factors, depreciation, and uses for the rate of interest the Moody AA bond yield. Labor quantity measures incorporate variations over time in the composition and educational attainment of the labor force, as well as inter-industry shifts. The energy data represent purchases of various energy types for heat, light and motive power, while M data are based on establishment surveys and censuses, and include sales between establishments within the manufacturing and nonmanufacturing firms. The gross output measure represents deflated sales plus changes in inventories.

TABLE A-1

U. S. Manufacturing Data

Year	Y Output	YK	YL	YE	YM	PK	PL	PE	PM
1958	417.994	35.0208	167.833	6.41904	258.356	0.593870	0.526730	0.789370	0.766360
1959	459.357	35.2927	179.079	7.06733	282.570	0.645686	0.546300	0.784540	0.766310
1960	465.127	35.6455	179.779	7.35588	287.907	0.660405	0.564970	0.783740	0.761370
1961	466.437	35.9480	174.066	7.48975	288.196	0.656801	0.584790	0.777770	0.766000
1962	500.407	36.6950	182.048	8.01462	307.813	0.647969	0.604450	0.771590	0.762350
1963	528.008	37.5115	183.189	8.19349	319.685	0.650125	0.625120	0.777410	0.774500
1964	558.914	38.9687	186.903	8.71417	335.635	0.652809	0.651830	0.769620	0.780070
1965	604.454	41.3696	197.393	8.96773	361.126	0.663109	0.667010	0.777610	0.797890
1966	642.833	44.9868	211.189	9.32003	382.044	0.722147	0.694080	0.790330	0.822350
1967	654.857	48.1886	211.095	9.56001	393.754	0.752025	0.727800	0.804570	0.828830
1968	692.123	50.2491	214.934	10.4758	414.592	0.801882	0.779740	0.789640	0.849180
1969	711.421	52.3665	218.342	11.0503	426.081	0.922456	0.831380	0.791960	0.886380
1970	675.218	53.5490	206.552	10.9708	406.159	1.03148	0.888880	0.859090	0.916570
1971	694.313	53.9775	198.570	11.3427	418.607	0.997819	0.945990	0.920460	0.955500
1972	756.631	55.2884	206.225	11.7717	456.030	1.00000	1.00000	1.00000	1.00000
1973	816.286	57.4521	218.005	12.0997	490.171	1.06148	1.06967	1.12537	1.10422
1974	801.219	60.6695	214.267	12.5502	498.303	1.28810	1.17862	1.54845	1.32821
1975	735.505	61.5229	194.815	11.8640	446.630	1.43007	1.31118	1.95865	1.49253
1976	802.468	63.3889	203.834	12.7559	486.894	1.47087	1.42454	2.16268	1.54770
1977	850.459	65.6778	212.118	13.0155	511.691	1.52379	1.54735	2.51709	1.64782

Footnotes

1. See, for example, Frank Gollop and Dale Jorgenson [1980] and Kent Kunze [1979].
2. See Zvi Griliches [1980a,b] and John W. Kendrick [1979].
3. For example, see M. Ishaq Nadiri [1980], Ernst R. Berndt [1980b], and Dale W. Jorgenson and Barbara Fraumeni [1981].
4. See Robert Crandall [1980] and the references cited therein. For a general survey to 1970, see M. Ishaq Nadiri [1970].
5. The literature on this topic is extensive; see Robert Solow [1957], Edwin Kuh [1960) and Thor Hultgren [1960], as well as the earlier references cited therein.
6. Dale W. Jorgenson and Zvi Griliches [1967], p. 272.
7. For more recent data, see Murray Foss [1981].
8. See Edward F. Denison [1969, 1972] and Dale W. Jorgenson and Zvi Griliches [1972].
9. Laurits R. Christensen and Dale W. Jorgenson [1970], Table 12, p. 47.
10. See for example Frank M. Gollop and Dale W. Jorgenson [1979, 1980], who estimate that over the 1948-1973 time period in the aggregate U.S. private economy, growth in inputs contributed 67.5% to growth of value added output, while technical progress was responsible for the remaining 32.5% [1979, 9.5, p. 9-25]. It should be noted that in the Gollop-Jorgenson disaggregated sectoral analysis, the output measure used is gross output rather than value added, and intermediate inputs such as energy are included. The incorporation of energy inputs into total factor input measures indirectly takes account of variations in capital utilization, but measured capital input is still unaffected by fluctuations in utilization. See E.R. Berndt [1980a] for additional details.

11. Further details are provided in Appendix I in Denison [1979a] and the "Discussion" on page 444 following the "Comment" by Denison [1979b] on J. Randolph Norsworthy, Michael J. Harper and Kent Kunze [1979].

12. Denison [1979b], p. 437.

13. A more complete discussion of the dual cost-price relationship in productivity measurement is found in Berndt-Fuss [1981].

14. A related approach has recently been taken by Martin Baily [1981b]. He also develops a theoretical model in which capital asset valuation and Tobin's q play important roles in the utilization adjustment. However his model leads to an adjustment of the quantity of capital. As Baily notes, the production function must be of the Cobb-Douglas functional form for his utilization adjustment procedure to be valid. Our method is more general and in particular is applicable to any neoclassical production function.

15. The constant returns to scale assumption is not crucial to the development of this section, although it does simplify the exposition. For a similar analysis in the case of non-constant returns to scale, see Michael Denny, Melvyn Fuss and Leonard Waverman [1981].

16. This result can also be obtained by assuming the firm is a cost minimizer subject to exogenous output requirements. See Denny, Fuss and Waverman [1981] for the derivation under this assumption which does not assume perfect competition in output markets.

17. The notion of a short run profit or production function was discussed in a rigorous manner by Paul A. Samuelson [1953-1954].

18. Adjustment costs have been discussed in a rigorous manner by Robert E. Lucas, Jr. [1967] and have been implemented empirically by Berndt, Fuss and Waverman [1979] and Catherine J. Morrison and Ernst R. Berndt [1981].

19. As noted earlier, this tangency relationship is the general criterion, valid in non-competitive environments.

20. However Y^o would correspond to the firm's long run profit maximizing output in a competitive industry with easy entry and exit.

21. For further elaboration see Morrison and Berndt [1981].

22. See Berndt-Fuss [1981] for a discussion of the corresponding productivity measurement based on the dual.

23. We could have assumed $x_1 = 1$ without any conceptual change, but with some unnecessary additional complication to Figure 2.

24. Using the above analysis, we can decompose the traditional measure of multifactor productivity growth; since $\dot{A}_1/A_1 = \dot{Y}/Y - \dot{X}/X = (\dot{Y}/Y - \dot{X}^*/X^*) + (\dot{X}^*/X^* - \dot{X}/X) = \dot{A}_2/A_2 + (\dot{X}^*/X^* - \dot{X}/X)$ where $(\dot{X}^*/X^* - \dot{X}/X)$ is the capacity utilization effect. A similar decomposition exists for the dual measures analysed below.

25. However one could find f_m^* such that $P^*(\partial Y/\partial f_m^*) = P_m$, and use f_m, P_m in the productivity formulae. This would be equivalent to adjusting the quasi-fixed factors for capacity utilization effects.

26. Denny and Fuss [1982] have shown that the approximation (28) can be obtained as the difference between two second order logarithmic expansions of (14) around the exogenous variables evaluated at t and t - 1 respectively. Equation (28) is exact if (14) is quadratic in logarithms (i.e. a translog function).

27. See James Tobin [1969].

28. For further discussion, see James Tobin and William C. Brainard [1976]. Empirical studies of investment behavior based on q include those of John Ciccolo and Gary Fromm [1979], George M. von Furstenberg et al. [1980], William Fellner [1980], and Michael A. Salinger and Lawrence H. Summers [1981].

29. See for example equation (9) in Hayashi [1982] which can be rearranged to yield $\pi_K = P^*(t) \frac{\partial f}{\partial K} = \frac{\lambda}{1 - u} [r + \delta - \dot{\lambda}/\lambda]$ where λ, the tax adjusted expected value of capital, = q . a(t). This assumes the cost of adjustment function depends only on investment so that $\psi_K = 0$.

30. Discussion of this formula is found in, among other places, Ernst R. Berndt [1976].

31. See, for example, the 1982 Economic Report of the President, Table B-88, p. 333; for 1981, Table B-86, p. 331; and for 1980, Table B-85, p. 303.

32. One could interpret q as the market value of the firm's intangible plus tangible capital divided by the replacement value of its tangible capital. Holland-Myers [1979, p. 150] find, however, that the intangible assets, growth opportunities and monopoly rents "counted for very little when NFC's [nonfinancial corporations] are examined in aggregate".

33. For two-digit manufacturing estimates, see George M. von Furstenberg et al. [1980].

34. See Ernst R. Berndt and Catherine J. Morrison [1981] and the references cited therein for further discussion of data construction procedures for CU.

35. Note also that q measures are based on end of year securities' values, while CU measures are averaged over the four quarters of the year.

36. For the manufacturing sector 1958-77, the simple correlation between the Wharton measure of CU and q is only .012; between FRB and q, 0.675; and between Wharton and FRB, 0.621.

37. Average annual growth in gross output (not value added) was 5.41% [1958-65], 3.83%[1965-73], 1.03% [1973-77] and 4.65% [1958-77].

38. See Catherine J. Morrison [1982].

39. Hayashi [1982] has proposed a method for calculating marginal q from average q. However his method depends, among other things, on the

assumption that the cost of adjustment function depends on the stock of capital as well as on its rate of change. In this case the shadow user cost is not observable from observations on average q, for Hayashi's equation (9) contains the unknown parameter ψ_K.

40. See Robert M. Solow [1960], J.B. Shoven and A.P. Slepian [1978], Baily [1981b], and Martin Feldstein [1981].

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