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2 The Long-Term Structure of Production, Factor Demand, and Factor Productivity in U.S. Manufacturing Industries

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2.1 Introduction

The rate of future productivity growth has been a primary concern of policy makers and economic analysts in recent years. The reason for this concern lies largely in the fact that a least-squares time trend of private-sector labor productivity shows an annual rate of growth of 3.2% from 1947 to 1966 but only 2.4% from 1966 to 1973; the overall trend was 3.1% for the 1947–73 interval.

Opinion has varied widely concerning the sources of this productivity slowdown. For instance, Eckstein and Shields (1974), in a study for the National Commission on Productivity and Work Quality, conclude that cyclical factors[1] and energy constraints are behind the measured decrease in productivity growth. Alternatively, Jerome Mark (1975), assistant commissioner of BLS' Office of Productivity and Technology,

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1. Cyclical factors include (1) changes in the composition of demand of the economic aggregate under study because of sectoral differences in the short-run income and price (both measured and expected income and price) elasticities of demand, e.g., between durable and nondurable goods; and (2) changes in the utilization of labor and capital because of raw materials bottlenecks, tight money, or a general decline in aggregate demand. For more information see Fair (1969, 1971), Clark (1973), Jorgenson and Griliches (1967), Hirsch (1968), Friedman (1957), Hayek (1951), Hawtrey (1913), and Hicks (1950).

has suggested that secular forces[2] account for the post-1966 decline in productivity. Nordhaus (1972) takes a similar position. In a study covering the period 1948–71, Nordhaus asserted that cyclical factors played a small part in the reduced rate of productivity since 1965, and that most of the deceleration can be explained by changes in the composition of demand—specifically, by shifts to low-productivity from high-productivity industries rather than shifts between industries with high and low rates of productivity growth.

Most attempts to isolate and remove the cyclical influences in observed series on labor productivity consist of either mechanical least-squares trend fits or ad hoc single-equation multiple regression procedures employing a "cyclical" variable such as the unemployment rate (see, e.g., Nordhaus 1972). Such procedures give no insight into the determinants of factor productivity in general or labor productivity in particular. They tell us little as to why productivity moved the way it did or where it was going because they are not based on any meaningful representation of the decision-making behavior of the economic agents under consideration.

The purpose of this paper is to set forth a procedure which is firmly grounded in production and cost theory, and which can be used to partition the observed productivity series in individual industries into cyclical and secular components. This study predates the energy problem by analyzing data only through the fourth quarter of 1972, and it avoids the shifting-mix problem to a large extent by analyzing two-digit manufacturing sectors. This disaggregation seems appropriate in view of the evidence[3] that the productivity slowdown cannot be laid solely to changes in the composition of output among broadly defined aggregates,[4], as in the Nordhaus study, but rather is indigenous to the components of these aggregates. To eliminate seasonal changes in productivity,

2. Some of the secular forces most frequently discussed in the literature include the following: (1) secular changes in the composition of output and labor attributed to the individual industries of the economic aggregate being studied (Denison 1973; Nordhaus 1972); (2) changing age-sex composition of the labor force (Perry 1971; Denison 1974); and (3) a slowdown in the growth of the capital-labor ratio (Christensen, Cummings, and Jorgenson 1980).

3. The evidence indicates that the productivity slowdown is not confined to a few sectors but is pervasive at a detailed industry level. According to the BLS, more than two-thirds of the industries the bureau studied had lower rates of productivity gain during the 1966–73 period than in the 1948–66 period (see Mark 1975, p. 21).

4. In fact, the research of the BEA indicates that studying productivity at too high a level of aggregation can even conceal the extensiveness of the slowdown. Thus, the BEA study shows that while the productivity of aggregate nondurable manufacturing slowed very little among the individual nondurable sectors, only 20% of the output in 1970 was accounted for by industries that did not experience a slowdown (see comments by Vaccara in Nordhaus 1972, p. 541).

this study uses seasonally adjusted quarterly data for ten two-digit manufacturing studies.[5]

Basically, the model posits that cyclical and secular influences can be individually captured by a partial adjustment model. The goal of this adjustment process is the long-run or least-cost combination of inputs $X^*_i(Y;\boldsymbol{P})$ $(i = 1, \ldots, n)$ appropriate for gross output level Y, and the vector of factor prices levels, P.[6] Thus, the functions X^*_i describe the classical instantaneous adjustment expansion path which is defined in this study to be the long-run objective of entrepreneurs. When the X^*_i are imbedded in an interrelated dynamic adjustment model, a system of equations results which describes both the short-run and long-run technology of the industry in question.

Such a model provides a general equilibrium framework for analyzing both the long-run and actual expansion paths of the studied industries. The parameters for the complete system are simultaneously estimated by a generalized least-squares method. Having estimated and isolated the parameters describing the long-term of least-cost expansion path[7] we are then in a position to simulate this path and compare it to the actual expansion path. The simulations produced by this study will show a sharp contrast in overall efficiency of resource use in most of the ten industries between the relatively stable growth period between 1961 and 1966 and the unstable period between 1966 and 1972. In short, this study will show that the prolonged period of economic instability between 1966 and 1972 resulted in a general decline in the productive efficiency of the input mix in general and of production workers in particular. This condition arose because the unstable post-1966 eco-

5. The following industries are included:

SIC 20	Food and beverages	SIC 330 = (331 + 332)	Primary ferrous metals
SIC 22	Textile mill products	SIC 333 = (33 − 330)	Primary non-ferrous metals
SIC 26	Paper and allied products	SIC 35	Nonelectrical machinery
SIC 28	Chemical and allied products	SIC 371	Motor vehicles and equipment
SIC 30	Rubber and plastic products		
SIC 32	Stone, clay, and glass products		

In 1971, BEA's gross product originating (GPO) data show that these industries comprised 74% of gross output in nondurable goods manufacturing, 51% in durable goods manufacturing, and 62% in total manufacturing.

6. Since the work of Parks (1971) and Berndt and Wood (1975) suggests that a value-added approach may bias the substitution relationship between inputs, a total factor approach is taken in this study.

7. It should be understood at the outset that the end product of this study is not a smooth secular productivity path. On the contrary, the long-run path will be heavily impacted by the effects of changes in output and factor prices. In summary, the long-run expansion path indicates what factor demand and factor productivity would be if entrepreneurs could instantaneously adjust from one least-cost input combination to another as suggested by the traditional comparative static model of production.

nomic climate, in contrast to the 1961–66 period, did not allow for stable output projections and consequently provided no prolonged period of stable growth in which to bring the actual input mix into line with the least-cost mix. This kind of analysis cannot be provided by crude approaches to isolating the impact of the business cycle.

The model developed in this study is similar in some respects to the Nadiri and Rosen model but, as will be discussed, there are important differences in specification, method of estimation, and internal consistency between the two models. It will also be seen that our dynamic specification renders a significant improvement in statistical results over the Berndt and Christensen comparative static approach to modeling the structure of production and factor demand. These models, while employing a rich flexible functional form, are contaminated with serially correlated residuals—a problem which our partial adjustment approach shows considerable improvement on. Moreover, in contrast to the Berndt and Christensen and Berndt and Wood studies, we find no evidence of complementarity between inputs on the long-run expansion path, even though such relationships are found to exist in the short run. We suspect that specification and/or aggregation bias may be responsible for the complementarity findings of the above-mentioned authors.

The remainder of this paper is organized as follows: section 2.2 provides a detailed description of the model to be used in this study; section 2.3 describes the method used to transform our measures of least-cost input shares into least-cost or long-run measures of factor demand and factor productivity; section 2.4 provides a detailed discussion of the empirical results for the ten industrial sectors examined and contains the results of tests which examine the structure of production for each industry; and section 2.5 summarizes our findings and conclusions. The data, their sources, and the methodological considerations pertinent in their construction are described in a brief appendix.

2.2 Model Structure and Theory

2.2.1 Introduction

The theoretical model used in this study hypothesizes that cost minimization is the modus operandi of entrepreneurs. The structure of the model results from a melding of the duality theorem of Shepherd (1953, 1970), the translog production function of Christensen, Jorgenson, and Lau (1971, 1973) and the dynamic interrelated factor demand model of Nadiri and Rosen (1969, 1973). The model views the entrepreneurs as attempting to satisfy expected gross output (measured as shipments plus inventory change) at the lowest cost—the locus of such points describing a firm's long-run expansion path. Much of the literature on the derived demand for factors of production attempts to model this least-cost expansion path directly, i.e., by a comparative statics model employing constant returns to scale and perfect competition assumptions. This approach not only ignores adjustment costs[8] but also may be the cause of the autocorrelated disturbances usually found in such models (e.g., Berndt and Christensen 1974; Berndt and Wood 1975).[9] Thus, it may be possible for a firm or industry to accommodate output variations by adjusting the flow of services from its inputs, but it may not be possible to adjust the stock variables which embody these service flows.[10] For instance, the hours worked per employee can be adjusted more rapidly than the level of employment; the utilization rates of plant and equipment can be adjusted more rapidly than the stocks of either capital input. Apart from purely logistical reasons, some of the sluggishness in the adjustment rates of the stock variables is no doubt due to reluctance on the part of entrepreneurs to respond to economic stimuli they suspect are short-run; that is, they take a wait-and-see attitude. However, for both reasons the actual input adjustment path is going to heavily reflect the effect of short-term or interim input adjustments which differ from the optimal ones which would be made in a world where perfect certainty and perfect adjustment capabilities prevailed. Finally, when it is recognized that input adjustments are interrelated (e.g., a decision to increase the utilization rates of the capital stocks in

8. In addition, such a comparative statics model has a number of other deficiencies including the following: (1) Returns to scale may be other than linear homogeneous in particular and homothetic in general. (2) Perfect competition may not exist in the product or factor markets. (3) The form of the production function regularly used in such models (Cobb-Douglas or CES) assumes separability of inputs, and strong separability at that, since the elasticity of substitution $\sigma_{ij} = k$ for all i and j. Note that Berndt and Christensen (1974) and Berndt and Wood (1975) treat separability as a testable, not a maintained, hypothesis.

9. In their note 8, Berndt and Wood indicate that they could not reject the null hypothesis of no autocorrelation against the alternative of a nonzero diagonal autocovariance matrix. In the view of this author, the Berndt and Wood alternative hypothesis is biased toward rejection. This is not only because the R matrix of Berndt and Wood in the context of a system of share equations must be diagonal, but also all elements on the diagonal must be equal. The individual equation Durbin-Watson statistics reported by Berndt and Wood suggest that this is probably not the case, with the K and E equations manifesting positive autocorrelation and the L and M equations zero autocorrelation.

10. Flow variables in this study are loosely defined as that dimension of an input which moves most closely in tandem with the short-run variation in output. For example, the composite measure of production labor input in this study is defined as $E_t\ (HS_t + HO_t)$, where E_t, HS_t, HO_t stand for employment, straight-time hours, and overtime hours, respectively. Of these three components, HO_t has the most pronounced cyclical movement, and so only HO_t is described as a flow variable. Capacity utilization is also a flow variable, while intermediate materials inputs share elements of both flow and stock variables.

excess of their desired levels may also necessitate increasing the average number of hours worked by the labor stocks) the following stock-adjustment model can be used to decompose the short-run and long-run movements in factor demand:

$$\Delta X_t = B[X^*_t(Y;P) - X_{t-1}] + U_t \qquad (t = 1, \ldots, n) \tag{1}$$

where

$\Delta X_t =$ a $(k \times 1)$ vector of first differences in the k observed input levels where the components of ΔX_t are $X_{it} - X_{it-1}$ $(i = 1, \ldots, k)$.

$X^*(Y;P) =$ a $(k \times 1)$ vector of functions which describes the least-cost expansion path of the inputs X^*_i. The arguments of X^*, i.e., Y and P, are measures of output and input prices, respectively.

$B =$ a $(k \times k)$ matrix of partial adjustment coefficients which include both own and cross effects.

$U_t =$ a $(k \times 1)$ vector of random disturbances assumed to be distributed normally with $E(u_{it}) = 0$ for all i, and where across the whole set of observations, n, the variance-covariance matrix for U is assumed to have the following form:

$$\Sigma = E\,(UU) = \begin{bmatrix} \kappa_{11} & \kappa_{12} \cdots & \kappa_{1k} \\ \kappa_{21} & \kappa_{22} & \kappa_{2k} \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \kappa_{k1} & \kappa_{k2} & \kappa_{kk} \end{bmatrix} \times I,$$

where I is a unit matrix of order $n \times n$.

The form assumed for Σ states that the disturbance in any single equation is homoscedastic and nonautocorrelated, and that there is non-zero correlation between contemporaneous disturbances across equations. In short, equation (1) suggests that movements in observed input levels are composed of an interrelated partial adjustment factor, where the goal of the adjustment mechanism is $X^*(Y;P)$ which describes the long-run input expansion path. In what follows we will formulate and assemble the pieces of the theoretical puzzle presented as equation (1).

2.2.2 Optimization in Production

We begin our discussion with the following assumptions: (1) entrepreneurs are cost-minimizers; (2) the long-run input expansion path can be closely approximated by a translog cost function,

$$\ln C^*(Y;P) = \min_{x} \Sigma P_i x_i;$$

(3) technology is Hicks-neutral.

Assumption (1) is a weaker assumption than profit-maximization since it does not require that entrepreneurs know their demand curve and thus conforms more closely with the accuracy of the information actually available to decision makers.[11] An advantage of a cost-minimization model is that optimization is invariant to the degree of competition in the product market.

Assumption (2) is an improvement over much of the earlier literature in that it includes other model formulations (notably Cobb-Douglas and CES) as special cases and enables the researcher to easily test for input separability and the nonhomotheticity of production rather than imposing these conditions on an estimating form.

Given the output level, Y, and input prices, P, our model's comparative static expansion path can be described by a six-input translog cost function:

$$\ln C^*_t(Y_t;P_t) = \alpha_y \ln Y + \alpha_t T + \sum_{i=1}^{6} \alpha_i \ln P_i + \frac{1}{2} \sum_{i=1}^{6} \sum_{j=1}^{6} \delta_{ij} \ln P_i \ln P_j + \sum_{i=1}^{6} \beta_i \ln Y \ln P_i, \tag{2}$$

where Y_t and P_t are observed gross output and prices,[12] respectively and T is time. For (2) to be considered a "well-behaved" cost function, it must satisfy the following conditions:

i) Symmetric Hessian (Young's theorem)

In this study we treat the translog cost function as a second-order approximation to any continuous, twice differentiable cost function. As a result, the matrix of δ_{ij}'s in (2) is equivalent to the Hessian of the Taylor series expansion of the true cost function. Thus by Young's theorem this matrix must be symmetric or

11. Profit-maximization implies that firms are capable of adjusting output levels so as to satisfy the necessary condition for profit-maximization, namely, the equality between marginal revenue and marginal cost. This requires that firms have a knowledge of both their demand and cost curves. The author's position is that (1) knowledge of the cost curve is more likely to be part of the information set available to the firm; (2) output price is more likely to be administered; (3) production goals to satisfy expected current demand at that price and inventory investment (to satisfy unexpected current demand) are determined at the start of the production period from information exogenous to the cost function (e.g., the previous period's level of demand, the level of beginning inventories, and the size of the backlog of new orders).

12. The vectors of inputs are indexed as follows: X_1 = hours of production workers; X_2 = nonproduction worker employment; X_3 = equipment stock; X_4 = plant stock; X_5 = capacity utilization; X_6 = materials including energy. The prices of these inputs are indexed analogously. The construction of gross output Y, inputs $(X_i \mid i = 1, \ldots, 6)$ and input prices $(P_i \mid i = 1, \ldots, 6)$ is discussed in the Data Appendix.

$$\delta_{ij} = \delta_{ji} \qquad (i, j = 1, \ldots, 6; i \neq j).$$

ii) Linear homogenity in prices: a doubling of prices doubles cost. This implies that

$$\Sigma\alpha_i = 1, \quad \sum_i \delta_{ij} = 0, \quad \sum_j \delta_{ij} = 0, \quad \Sigma\beta_i = 0.$$

This condition follows from the logic that a proportional increase in the price of all inputs will not change the input mix for a given level of output.

iii) Monotonicity: The cost function must be an increasing function of prices such that

$$\frac{\partial \ln C^*}{\partial \ln P_i} = \alpha_i + \Sigma\delta_{ij}\ln P_j + \beta_i \ln Y > 0.$$

Since $\partial \ln C^* / \partial \ln P_i$ is the cost share of input X^*_i, (iii) will be satisfied as long as the input shares are positive.

iv) Concavity of input prices: the Hessian of second partials, H, of equation (2) must be negative semidefinite within the range of observed input prices.

Since equation (2) is linear homogenous in factor prices, the Hessian will be singular but concavity is assured if the principal minors of H alternate in sign starting with negative.

The vector of coefficients, $\boldsymbol{\beta}$, in equation (2) represents nonhomothetic output effects on factor demand. Statistical tests of their significance from zero provides a test of the homotheticity of production.[13]

According to the approach used in this study, (2) is not expected to hold instantaneously; rather, it represents the objective to which the decision maker aspires in acquiring and assembling his inputs since it represents the least-cost input combination given an output level, Y, and a vector of input prices, $\boldsymbol{P}$.

2.2.3 Derived Demand Equations

By Shephard's lemma (1953, 1970) it is known that the partial derivative of the cost function, $C^*(Y;\boldsymbol{P})$, with respect to input price P_i gives the derived demand equation for input X_i, i.e.,

$$\frac{\partial C^*}{\partial P_i} = X_i(Y;\boldsymbol{P}) \qquad (i = 1, \ldots, 6).$$

13. If the cost function, $C = F(Y;P)$, can be written as separable functions in output and factor prices $C = H(Y)G(P)$, the structure of production is homothetic. Further, if $\partial \ln C / \partial \ln Y = k$, a constant, then the structure of production is homogeneous. For further discussion of the concepts of homotheticity and homogeneity in production see Clemhout (1968), Zellner and Revankar (1969), Wolkowitz (1971), Parks (1971), and Diewert (1974).

The analogue of this for the translog function (2) gives a set of cost share equations:

$$(4) \qquad \frac{\partial \ln C^*}{\partial \ln P_i} = S_i(Y;P) = \alpha_i + \sum_{j=1}^{6} \delta_{ij} \ln P_j + \beta_i \ln Y \qquad (i = 1, \ldots, 6).$$

There are two subtle points affecting the system described by equations (2) and (4). The first point deals with the correct measure of cost for which equation (2) determines the minimum level. The second point refers to the fact that the system of cost-share equations in (4) is singular.

1) Real versus measured total factor cost (RTFC vs. MTFC). The objective of the firm is to minimize the cost of producing a given level of output subject to a production function constraint. Mathematically, the problem can be stated as

$$(5) \qquad \begin{aligned} \min \text{MTFC} = {} & X_1 P_1 + X_2 P_2 \\ & + X_3\{[q_{e,\,t-1} r_t - (q_{et} \\ & - q_{et-1}) + q_{et}\delta_e \,(1 + X_5 - \overline{X}_5)^2]\,\tau_e\} \\ & + X_4\{[q_{s,\,t-1} r_t - (q_{st} \\ & - q_{st-1}) + q_{st}\delta_s \,(1 + X_5 - \overline{X}_5)^2]\,\tau_s\} \\ & + X_6 P_6, \end{aligned}$$

subject to $\hat{Y} - f(X_1, \ldots, X_6) = 0$

where the terms within braces are shown in the data appendix to be equal to P_3 and P_4, respectively. These are modifications to Hall and Jorgenson (1967) rental prices. The first relationship in equation (5) is measured total factor cost (MTFC) and is a simple accounting relationship. However, note that MTFC is nonlinear in X_3, X_5, and X_4, X_5. Using the method of the Lagrangean multiplier, we can rewrite equation (5) as

$$(6) \qquad \min L = \text{MFTC} + \lambda[\hat{Y} - f(X_1, \ldots, X_6)].$$

The well-known first-order conditions for equation (6) are $P_i = \lambda MP_i$, $i = 1, \ldots, 6$, where P_1 through P_6 are defined in the data appendix. The set of relationships derived from equation (6) dictate that in order to minimize cost subject to the production function constraint it is necessary for the firm to use each input to the point where the marginal factor cost or shadow price of that input is equal to the product of marginal cost, λ, and the marginal product of the input, MP_i.[14] These

14. See Samuelson (1963), pp. 57–89.

first-order conditions are important to the derivation of the Allen partial elasticities of substitution (AES) since it can be shown that the AES_{ij} ($i, j, = 1, \ldots, 6$) are contingent on the following definition of cost:[15,16]

(7) $$RTFC = \sum_{i=1}^{6} P_i X_i,$$

that is, a definition based on the shadow prices of the inputs.[17] We will hereafter refer to (7) as the definition of real total factor cost (RTFC). It differs from MTFC by the term $P_5 X_5$ which is the marginal factor cost of increasing the rate of capital use. Note that throughout this study we assume that the rates of utilization of plant and equipment are the same since this is the best that available data will allow.

2) The singularity of the system of cost share equations. The set of

15. Note, in contrast to the typical textbook example, the nonlinearity of MTFC in X_3, X_5 and X_4, X_5 destroys the usual equality between MTFC and $\Sigma P_i X_i$. Thus, the transformation of (9a) into (9b) requires the use of RTFC in place of MTFC.

16. To see this consider that the Allen partials ($AES_{ij} = \sigma_{ij}$) can be defined equivalently as

(8a) $$\sigma_{ij} = \frac{\sum_{h=1}^{6} MP_H \cdot X^*_H}{X^*_i X^*_j} \frac{|F_{ij}|}{|F|},$$

where $|F|$ is the determinant of the bordered Hessian matrix and $|F_{ij}|$ is the co-factor of the ijth element of F, or equivalently as either

(8b) $$\frac{\sum_{h=1}^{6} P_H X^*_H}{X^*_i X^*_j} \frac{\partial^* x_i}{\partial_{P_j}}$$

or

(8c) $$\frac{C^* C^*_{ij}}{C^*_i C^*_j},$$

where C^* is defined by equation (2). Equation (8c) follows from equations (8a) and (8b) by Shephard's lemma,

(9a) $$\frac{\partial C(Y,P)}{\partial P_i} = C^*_i = X^*_i,$$

from which it follows that

(9b) $$\frac{\partial^2 C^*(Y,P)}{\partial P_i \partial P_j} = C^*_{ij} = \frac{\partial X_i}{\partial P_j},$$

and by the set of relationships derived from (6) which are instrumental in transforming (8a) into (8b), from which the equality $C^* = \Sigma P_H X^*_H$ follows immediately.

17. Becker and Lewis (1973) make a similar point in the context of utility theory.

cost share equations defined by (4) constitutes a singular system. To see this, note that

$$(10) \qquad \sum_{i=1}^{6} S^*_i = \frac{\sum_{i=1}^{6} P_i X^*_i}{C^*} = 1.$$

From equation (10) it follows that, given any five of the six equilibrium shares, say the first five, the sixth share is definitionally equal to

$$(11) \qquad S^*_6 = 1 - \sum_{i=1}^{5} S^*_i.$$

In this study we arbitrarily drop the long-term share equation for materials, choosing the remaining five equations to form a nonsingular system.[18]

In conclusion, letting $\ln P_i = R$, the comparative static model, with symmetry, linear homogenety in prices, and (10) imposed contains the following independent equations:[19]

$$(12) \qquad S^*_{1t} = \frac{P_{1t} X^*_{1t}}{C^*} \sum_{j=2}^{6} = \alpha_1 + \delta_{1j}[R_j - R_1] + \beta_1 \ln Y,$$

$$S^*_{2t} = \frac{P_{2t} X^*_{2t}}{C^*} \sum_{\substack{j=1 \\ j\neq 2}}^{6} = \alpha_2 + \delta_{2j}[R_j - R_2] + \beta_2 \ln Y,$$

$$S^*_{3t} = \frac{P_{3t} X^*_{3t}}{C^*} \sum_{\substack{j=1 \\ j\neq 3}}^{6} = \alpha_3 + \delta_{3j}[R_j - R_3] + \beta_3 \ln Y,$$

$$S^*_{4t} = \frac{P_{4t} X^*_{4t}}{C^*} \sum_{\substack{j=1 \\ j\neq 4}}^{6} = \alpha_4 + \delta_{4j}[R_j - R_4] + \beta_4 \ln Y,$$

$$S^*_{5t} = \frac{P_{5t} X^*_{5t}}{C^*} \sum_{\substack{j=1 \\ j\neq 5}}^{6} = \alpha_5 + \delta_{5j}[R_j - R_5] + \beta_5 \ln Y,$$

where, recall, symmetry determines that $\delta_{ij} = \delta_{ji}$

2.2.4 Disequilibrium—The Dynamics of Adjustment

Up to this point, the discussion has been presented primarily in the context of a comparative statics model. The system of equations in (2)

18. As will be discussed below, the method of estimating the parameters assures that these estimates are invariant to the equation deleted.

19. The coefficients for the sixth share equation are determined as follows:

$$\alpha_6 = 1 - (\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5); \ \delta_{i6} = -(\delta_{i1} + \delta_{i2} + \delta_{i3} + \delta_{i4} + \delta_{i5}) \ i = 1, \ldots, 5;$$

$$\delta_{66} = -(\delta_{16} + \delta_{26} + \delta_{36} + \delta_{46} + \delta_{56}); \ \beta_6 = -(\beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5).$$

and (4) describes the objective of the firm, and it contains the information necessary to chart the least-cost input expansion path. With this type of behavior as a maintained hypothesis, we can now address more clearly the dynamic manner in which the firm achieves long-run cost minimization. The point to be made here is that even when the firm can perfectly discriminate between cyclical and secular components in input prices and output, it still cannot move instantaneously from one long-run equilibrium point to another; rather, it follows a disequilibrium path along which all inputs are dynamically and interrelatedly adjusted to compensate for deficiencies between the desired and actual levels of the respective inputs. This is essentially the model formulated by Nadiri and Rosen (1973). Eisner and Strotz (1963) have provided a rationale for modeling adjustment costs in the context of a geometrically declining lag structure. The model estimated by Nadiri and Rosen is the analogue to (1) in log form,

$$\ln \boldsymbol{X}_t - \ln \boldsymbol{X}_{t-1} = \boldsymbol{\beta}[\ln \boldsymbol{X}^*_t(Y;\boldsymbol{P}) - \ln \boldsymbol{X}_{t-1}] + \boldsymbol{e}_t, \tag{13}$$

with the following important exceptions: first, Nadiri and Rosen (1973) assume first-order serial correlation in the individual equation disturbance term but do not allow for cross equation correlation of disturbances; this is directly opposite to the hypothesis maintained in (1);[20] second, $\boldsymbol{X}^*(Y;\boldsymbol{P})$ is based on a very restrictive Cobb-Douglas formulation of productive technology where it is assumed that inputs are strongly separable;[21] third, Nadiri and Rosen take as a maintained hypothesis that technology is Hicks-neutral but estimate a model which does not support this hypothesis.

The estimation model used in this study is the direct analogue to (1) in share form,

$$\Delta \boldsymbol{S}_t = \boldsymbol{\theta}[\boldsymbol{S}^*_t(Y;\boldsymbol{P}) - \boldsymbol{S}_{t-1}] + \boldsymbol{\epsilon}_t, \tag{14}$$

20. This difference in stochastic specification is especially important when there are cross equation parameter restrictions. This is the case in system (13) and as well as in (14) below. Nadiri and Rosen neglect to impose any cross equation equality restrictions on their parameters and then proceed to estimate the parameters for the system using a Cochrane-Orcutt single equation estimation technique, thereby causing overidentification of the parameters determining X^*_{it} in (13). To eliminate this problem (13) should have been estimated by a simultaneous estimation procedure, such as was used to estimate (15) (see section 2.4.2 below), in which the covariance matrix was taken into account. Nadiri and Rosen (1973, pp. 56–58) decide against this procedure and as a result destroy much of the meaning and consistency in their theoretical model.

21. Nadiri and Rosen's empirical results do not support a Cobb-Douglas specification since their derived estimates of both long and short-run elasticities of substitution differ measurably from one and in fact are close to zero. Nadiri and Rosen suggest that this is due to the fact that they do not constrain their model to the production frontier (Nadiri and Rosen 1973, p. 56).

where ΔS_t is a (6×1) vector of quarterly first differences in the six cost shares; $S^*_t(Y;P) - S_{t-1}$ is a (6×1) vector of first differences between the six minimum cost shares and lagged actual cost shares where the components of $S^*(Y;P)$ are as in (12) above; θ is a (6×6) matrix of own and cross partial adjustment coefficients; and ϵ_t is a (6×6) vector of disturbances assumed to have the same stochastic properties as U_t in (1) except that $\Sigma \epsilon_{it} = 0$ $(t = 1, \ldots, n)$ because of the adding-up condition discussed below.[22]

The system in (14) contains only five independent equations for reasons analogous to those for the system in (4), i.e., the adding-up condition holds for actual shares as well as for long-run or cost-minimizing shares. Thus, analogous to (10), we have

22. The system of equations set out in (14) can be written

(i) $$S_t = \theta S^*_t + \phi S_{t-1} + \epsilon_t,$$

where

$$\phi = I - \theta.$$

By process of repeated substitution into (i), it can be shown that (i) can be written

(ii) $$S_t = \phi^{K+1} S_{t-K-1} + \sum_{\lambda=0}^{K} M_\lambda S^*_{t-\lambda} + \sum_{\lambda=0}^{K} \phi^\lambda \epsilon_{t-\lambda},$$

where $M_\lambda = \phi^\lambda \theta$. Now, as K goes to infinity, (ii) reduces to

(iii) $$S_t = \sum_{\lambda=0}^{\infty} M_\lambda S^*_{t-\lambda} + \phi^\lambda \epsilon_{t-\lambda},$$

provided

$$\lim_{\lambda \to \infty} \phi^\lambda = 0.$$

Specification (iii) is known as the final form of (ii). It can be shown that (iii) is stable provided the eigenvalues of the ϕ matrix are all less than one in absolute value (Theil 1971, p. 464). If this condition is met, the following results hold for a constant level of Y_t, and P_t:

(iv) $$\sum_{\lambda=0}^{\infty} M_\lambda S^*_t = \theta[I + \phi + \phi^2 + \ldots + \phi^n] S^*_t,$$

and since $\phi = I - \theta$, we have

$$\sum_{\lambda=0}^{\infty} M_\lambda S^*_t = S^*_t,$$

and

(v) $$E(\Sigma \phi^\lambda \epsilon_{t-\lambda}) = E(\epsilon_t) + \phi E(\epsilon_{t-1}) + \phi^2 E(\epsilon_{t-2}) + \ldots + \phi^n E(\epsilon_{t-n}) = 0,$$

since we have assumed $E(\epsilon_{t-\lambda}) = 0$ for all λ. Therefore, the expected value of the set of factor cost shares in the long run is

(vi) $$E(S_t) = S^*_t.$$

(15) $$\sum_{i=1}^{6} S_{it} = \frac{\Sigma P_i X_i}{C} = 1,$$

where C_t is the cost identity computed as in (7). This implies that

$$\sum_{i=1}^{6} \epsilon_{it} = 0 \ (t = 1, \ldots, n)$$

and that $E(\epsilon_t \epsilon'_t)$ is singular for all t. However, as shown by Berndt and Savin (1975), invariant maximum-likelihood estimates of the parameters in (14) can be obtained by arbitrarily deleting any one of the six equations. As before, the materials cost share equation is arbitrarily dropped since its coefficients are contained either implicitly or explicitly in the remaining five equations.[23]

Combining equation (15) with (10), we obtain in matrix form the following system of five independent equations:

(16) $$\Delta S'_t = T[S^{*\prime}_t\,(Y;P) - S'_{t-1}] + \epsilon'_t \qquad (t = 1, \ldots, n),$$

where $\Delta S'_t$, S'_t, S'_{t-1}, and ϵ'_t are defined as in equation (15) after netting out the sixth equation, and the elements of T, namely, T_{ij} $(i, j = 1, \ldots, 5)$ are defined as the composite coefficients $\theta_{ik} - \theta_{ij}$ $(i, k = 1, \ldots, 5)$.

System (16) makes explicit the following points: first, the system of equations involving S_1, S_2, S_3, S_4, S_5, and S_6 constitutes a singular system by virtue of equation (15); second, adjustment to long-run equilibrium is interrelated[24] in all inputs X_1 through X_6, and third, the system of equations involving the long-run equilibrium paths of S^*_1, S^*_2, S^*_3, S^*_4, S^*_5, and S^*_6 also constitutes a singular system by virtue of (10).

Finally, the reader should be aware that individual own and cross adjustment coefficients, θ_{ii} and θ_{ij}, cannot be obtained from a knowledge

23. The long-run equilibrium coefficients can be separately identified by the relationships set out under equations (2) and (12) above. However, the individual adjustment coefficients can be obtained for (14) only under certain conditions, as will be explained below.

24. The reader should be aware of the importance of the cross adjustment coefficients in model (14). Disregarding the cross effects would imply, for example, that a disequilibrium in equipment stock did not involve compensating adjustments in other inputs. Brainard and Tobin (1968) have described the type of system in (17) as a "general disequilibrium" framework for the dynamics of adjustment to a "general equilibrium system." Moreover, for production theory Nadiri and Rosen (1973) observed that a system of unrelated adjustment paths implies that the firm is off its production function, i.e., is using inputs inefficiently. While from a theoretical point of view, we see no reason to constrain output to the production frontier during the adjustment process, we also do not see any virtue in ignoring the obvious interrelationships that exist between inputs in disequilibrium as well as equilibrium.

of the composite coefficients, $\theta_{ij} - \theta_{i6}$. The only constraints put on the adjustment coefficients in a singular system involving cost shares is[25]

$$\sum_{i=1}^{n} \theta_{ij} = R \qquad (j = 1, \ldots, n). \tag{17}$$

However, due to (15) we can only identify the composite effects $\theta_{ij} - \theta_{i6}$ $(i, j = 1, \ldots, 5$, and (17) assures that

$$\sum_{i=1}^{6} \theta_{ij} - \sum_{i=1}^{6} \theta_{i6} = 0 \qquad (j = 1, \ldots, 5).$$

Therefore, we can identify $\theta_{6i} - \theta_{66}$ $(j = 1, \ldots, 5)$ but we have no information to identify any of the individual elements θ_{ij}.[26] This, however, does not prevent us from reaching our goal, which is to estimate adjustment-free parameters for S^*_i $(i = 1, \ldots, 6)$.

2.2.5 An Alternative View of the Adjustment Process

It may be argued that the variables in (2) are observed prices and output, and that the firm is not likely to undertake major decisions on the makeup of its capital, materials, and employment stock inputs on the basis of current levels of these variables.[27] Rather, since the firm operates in an atmosphere of uncertainty, it views the array of observed input prices and output demand as consisting of a permanent and a

25. To see this, observe that (15) and (16) give

$$\sum_{i=1}^{6} S_{it} = \sum_{i=1}^{6} \sum_{j=1}^{6} \theta_{ij}[S_{jt} - S_{jt} - 1] - \sum_{i=1}^{6} S_{it} - 1.$$

Therefore, since

$$\sum_{i=1}^{6} S_{it} = 1$$

and

$$\sum_{i=1}^{6} S_{it} = 1,$$

it is necessary that $\Sigma\theta_{i1} = R$; $\Sigma\theta_{i2} = R$; $\Sigma\theta_{i3} = R$; $\Sigma\theta_{i4} = R$; $\Sigma\theta_{i5} = R$; $\Sigma\theta_{i6} = R$.

26. A sufficient condition for identifying the θ_{ij} $(i,j, = 1, \ldots, 6)$ when

$$\sum_{i=1}^{6} \theta_{ij} = R \qquad (j = 1, \ldots, 6)$$

is that

$$\sum_{j=1}^{6} \theta_{ji} = R_i \qquad (i = 1, \ldots, 6).$$

For a general discussion of identification of parameters in singular systems, see Berndt and Savin (1975).

27. This position has been taken by Birch and Siebert (1975).

transitory[28] component, that is, $Y_t = Y^P{}_t + Y^T{}_t$, and $P_t = P^P{}_t + P^T{}_t$. In this scenario, the entrepreneur is likely to be very reluctant to undertake input stock investments, disinvestments, or reorganizations based on the levels of variables until he feels certain that there has been a permanent change in the levels of these variables.

The firm is also likely to make short-term adjustments in its flow variables (hours and utilization) to accommodate cyclical shocks in demand but less likely to do so in the case of cyclical shocks in prices. This suggests that the long-run expansion path would be composed primarily of stock variable adjustments and the short-run expansion path primarily of flow variable adjustments. This process can be illustrated with the aid of figure 2.1. Suppose at initial time $t = 0$ the firm is in equilibrium, producing output level Y_0 at the minimum cost input combination specified by point $A(L^P{}_0, K^P{}_0)$. Now, if output demand increases in period $t = 1$ to Y_1, the firm might satisfy this demand with alternative input combinations depending on (1) its ability to adjust inputs rapidly, (2) its perception of the permanency of Y_1, and (3) the cost of making adjustments which might be wrong. Thus, if Y_1 is viewed as a permanent increase in output, the firm will aspire to move along its long-run (minimum-cost) expansion path to point $B(L^P{}_1, K^P{}_1)$. On the labor side, this expansion will largely involve increasing employment, E_t, with little change in average straight-time hours, HRS_t, and possibly a decrease or total elimination in overtime hours, HRO_t, per employee.

However, if the firm views Y_1 as only a transitory or cyclical change, then it might satisfy this demand in a short-run cost minimization sense by moving to point $C(L^P{}_1, K^P{}_0)$. That is, the firm will attempt to satisfy Y_1 by using an efficient combination of inputs, defined as any input combination on Y_1 to the left of B, but, recognizing that mistakes might be costly, it chooses not to use the long-run combination which would require an expansion of capital stock. If Y_1 turned out to be transitory and the firm increased capital to $K^P{}_1$, it would be forced to disinvest $(K^P{}_1 - K^P{}_0)$ in order to return to its long-run expansion path. In contrast to the situation where Y_1 is considered a permanent level of demand, the increase in labor input will come primarily from increasing overtime hours, with smaller increases likely in the employment and straight-time hours.[29]

28. The term *transitory* here is meant to include cyclical as well as purely random movements in P_t and Y_t.

29. The logic is symmetric with respect to a decline in aggregate demand. Thus, suppose the firm is initially in equilibrium at point B for output level Y_1, but output demand decreases to Y_0. If the firm views this decrease in output as a transitory or cyclical change in output, it will likely move from point B on Y_1 to point D on Y_0 primarily by reducing overtime hours.

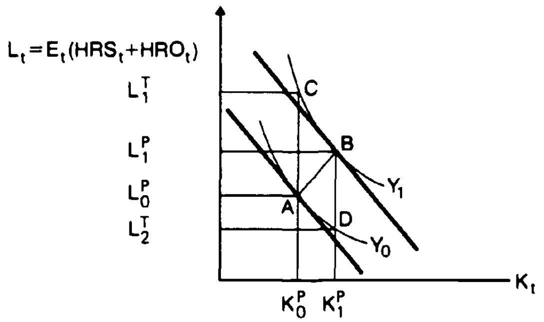

Fig. 2.1 Short- and Long-Run Expansion Paths

This expectational variable approach has an important conceptual[30] difference from the interrelated dynamic adjustment model of Nadiri and Rosen. This is because the Nadiri and Rosen model implies that the firm has static expectations concerning output and relative factor prices and thus expects the current level of output and price to continue. Accordingly, there is no need for the firm to discriminate between transitory and permanent components in the observed variables so that the movement from point *A* to point *C* in figure 2.1 represents a partial adjustment of all inputs (both stock and flow) toward a new equilibrium at point *B*, although the initial adjustment to point *C* is likely to impact most strongly on the flow variables.

30. The conceptual difference notwithstanding, mathematically there are strong similarities in form between the two approaches. It is shown in footnote 22 that equation (14) can be rewritten as an infinite distributed lag of current and past desired share levels:

$$S_t = \sum_{\lambda=0}^{K} \theta[I-\theta]^{\lambda} S^*_{t-\lambda} + [I-\theta]^{K+1} S_{t-K} + \sum_{\lambda=0}^{K} [I-\theta]^{\lambda} e_{t-\lambda}. \tag{14a}$$

Utilizing equations (4) and (14), this can be written equivalently as

$$S_t = \sum_{\lambda=0}^{K} \theta[I-\theta]^{\lambda} \begin{bmatrix} \alpha_1 & \delta_{11} & \delta_{12}\cdots\delta_{16} & \beta_1 \\ \alpha_2 & \delta_{21} & \delta_{22}\cdots\delta_{26} & \beta_2 \\ \cdots & \cdots & \cdots & \cdots \\ \alpha_6 & \delta_{61} & \delta_{62}\cdots\delta_{66} & \beta_6 \end{bmatrix} \begin{bmatrix} 1 \\ LnP_{1t-\lambda} \\ LnP_{2t-\lambda} \\ LnP_{6t-\lambda} \\ \cdots \\ LnY_{t-\lambda} \end{bmatrix} \tag{14b}$$

2.3 Decomposition of Factor Demand and Labor Productivity

In section 2.2 we set forth a model that allowed us to discriminate between long-run and short-run parameters. Up to this point the analysis was developed in the context of relative cost shares; now we proceed to measure the long-run (cost-minimizing) demand for factors of production and output per production worker hour and develop a relationship between the short-term (or cyclical) movements in the observed data and these long-run measures.

2.3.1 Long-Run Demand for Factors of Production

From equation (15), the equilibrium share for the *i*th factor of production is

$$+[I-\theta]^{K-1}S_{t-K-1}+\sum_{\lambda=0}^{K}[I-\theta]^{\lambda}\epsilon_{t-\lambda}.$$

In vector notation (14b) becomes

$$S_t=\sum_{\lambda=0}^{K}\theta[I-\theta]^{\lambda}\delta V_{t-\lambda}+[I-\theta]^{K+1}S_{t-K-1}+\sum_{\lambda=0}^{K}[I-\theta]^{\lambda}\epsilon_{t-\lambda}=\delta\sum_{\lambda=0}^{K}\theta[I-\theta]^{\lambda}V_{t-\lambda}+[I-\theta]^{K+1}S_{t-K-1}+\sum_{\lambda=0}^{K}[I-\theta]^{\lambda}\epsilon_{t-\lambda}. \tag{14c}$$

The term

$$\sum_{\lambda=0}^{K}\theta[I-\theta]^{\lambda}V_{t-\lambda}$$

represents a distributed lag of current and past output prices. This leads naturally to an expectational variable interpretation such that the expectation of V_t, say $\hat{V}_t$, is

$$\hat{V}_t=\sum_{\lambda=0}^{K}\theta[I-\theta]^{\lambda}V_{t-\lambda}.$$

From this we can write (14c) as

$$S_t=\delta\hat{V}_t+[I-\theta]^{K+1}S_{t-K-1}+\sum_{\lambda=0}^{K}[I-\theta]^{\lambda}\epsilon_{t-\lambda}. \tag{14d}$$

Thus, while the direct estimation of (14d) would require a more elaborate generalized least-squares approach than (14), since the residuals in (14d) would definitely be autocorrelated despite the fact that individual elements in $\Sigma[I-\theta]^{\lambda}\epsilon_{t-\lambda}$ were assumed independent within each equation in (14), the model to be estimated in this study does implicitly contain a special case of an expectational-variable model. Preliminary attempts by the author to replace observed output and prices in (14) with permanent output and price components based on a rational expectations approach have not proved fruitful. This may suggest that the observed variables in the context of the lagged adjustment model (14) adequately represent the proper set of decision-making arguments.

$$S^*_i = \frac{P_i X^*_i}{C^*} = \alpha_i + \sum_{j=1}^{6} \delta_{ij} R_j + \beta_i \ln Y \qquad (i = 1, \ldots, 6),$$

where C^* is defined by equation (2). It follows that the minimum-cost input of X_i is determined as

$$(18) \qquad X^*_{it} = S^*_{it} \frac{C^*_t}{P_{it}}.$$

The problem is that C^*_t is unobservable and some estimate of it must be made in order to determine X^*_{1t}.

The method used, while not perfect, is an attempt to derive an input series which eliminates most of the cyclical adjustment impact in the raw data and is therefore closer to the input set on the long-run expansion path.[31] The process consists of the following steps:

1. For each year in the sample, compute an average of quarterly inputs, factor prices, and output designated as $X^A{}_i$, $P^A{}_i$ $(i = 1, \ldots, 6)$, and Y^A, respectively.

2. Use the input and price series from point (1) to construct a proxy measure for C^*_t, namely

$$\text{RTFC}^A = \hat{C}^{*A}{}_t = \sum_{i=1}^{6} P^A{}_i X^A{}_i.$$

3. Use the parameters estimates from (14), Y^A, $P^A{}_i$, and $\hat{C}^{*A}{}_i$, to form the relationship

$$(19) \qquad \hat{Z}^* = \alpha_{At} T + \alpha_Y \ln Y^A{}_t + v_t,$$

where

$$Z_t = \ln \hat{C}^{*A}{}_t - \sum_{i=1}^{6} \hat{\alpha}_i R^A{}_{it} - \frac{1}{2} \sum_{i=1}^{6} \sum_{i=1}^{6} \hat{\delta}_{ij} R^A{}_{it} R^A{}_{jt}$$
$$= \Sigma \hat{\beta}_i R^A{}_{it} \ln Y^A{}_t$$

and $R^A{}_i = \ln P^A{}_i$. Now, (19) is an approximation to (2) and α_{At}, α_Y are measures of Hicks-neutral technical progress and homothetic returns to scale, respectively. There are two obvious reasons why $\hat{Z}^*{}_t$ is likely to contain measurement error: first, because $\hat{C}^{*A}{}_t \neq C^{*A}{}_t$, and second, because estimated values of the parameters in (14) are used in place of the actual parameters. Suppose, then, that the true value, $Z^*{}_t$, is related to the measured value as

31. One approach we rule out directly is an estimate of C^*_t based on (7) using the actual quarterly date for P_i and X_i. We exclude this method because (1) it is a maintained hypothesis of this study that these quarterly input observations are the result of an adjustment process; and (2) the model contains no constraints to keep the firm on its production function.

(20) $$\hat{Z}^*_t = Z^*_t + d_t,$$

where d_t is the measurement error in $\hat{Z}^*_t$. Further, suppose that the true relationship which we are attempting to capture by (19) is

(21) $$Z^*_t = \alpha_{At} T + \alpha_Y \ln Y^A_t + e_t,$$

where e_t is the stochastic element in Z^*_t. By substituting equation (21) into (20) we see that $v_t = d_t + e_t$ in equation (19).

As long as d_t is uncorrelated with the independent variable in (19), it can be shown that the parameter estimates for α_{At} and α_Y from equations (19) and (21) have the same expected value.[32] With the estimates of α_t and α_Y from equation (19) we are now in a position to derive quarterly estimates of C^*_t as

(22) $$\hat{C}^*_t = [\frac{1}{4}\ \hat{\alpha}_{At} T + \hat{\alpha}_Y \ln Y_t + \Sigma \hat{\alpha}_i R_{it} + \frac{1}{2} \Sigma\Sigma\ \hat{\delta}_{ij} R_{it} R_{jt} + \Sigma \beta_i R_i \ln Y_t].$$

The results of (22) are used in (18) to obtain X^*_i $(i = 1, \ldots, 6)$.

2.3.2 Cyclical Effects on Factor Demand

The difference between the observed and the least-cost inputs of the ith factor of production,

(23) $$DX_{it} = X_{it} - X^*_{it} \qquad (i = 1, \ldots, n)$$

constitutes a measure of the impact of short-run adjustments to changes in relative factor prices, and output. For each industry study we measure (23) at each quarter between three sets of peaks in the respective industry's output data.[33] The first interval is from the mid-1950s peak to the quarter with the highest output level in 1972. The second interval is between the mid-1950s peak and the mid-1960s peak. The third interval is from the mid-1960s peak to the 1972 peak. For each quarter in the sample, (23) is expressed as a percentage of the long-run factor input level for the quarter or

(24) $$\% DX_{it} = \frac{X_{it} - X^*_{it}}{X^*} \times 100.$$

32. See Rao and Miller (1971), pp. 179–84.

33. The peak quarters chosen to delineate the three intervals do not necessarily correspond to the peaks in the constant-dollar output series for each of the three periods. This is because the peak quarters chosen were made to reconcile with peaks in the utilization series. This approach to choosing the peaks was adopted because of possible errors in the construction of the gross output series.

We then sum (24) over the quarters in each of the intervals and divide by the number of quarters in each interval to obtain a measure of the average percentage deviation of short-term or cyclical adjustments from the long-run expansion path for production worker hours $(A\% DX^{p_1 - p_2})$, that is,

$$(25) \qquad A\% DX_t^{p_1 - p_2} = \frac{\sum_{t=p_1}^{p_2} \% DX_{it}}{q_{p_1 - p_2}},$$

where p_1 is the beginning peak in the interval; p_2 is the ending peak in the interval (so p_1—p_2 defines the interval); and $q_{p_1 - p_2}$ is the number of quarters in the interval from p_1 to p_2.

The differential measured by equation (23) is not a measure of cyclical influence in the sense that the deviation between the actual input level and a peak-to-peak trend level of input might be considered a measure of business cycle influence. Rather, since X^*_{it} represents the input demand resulting from an instantaneous adjustment to changes in output and price levels, its path in a period of economic instability will manifest a very cyclical character. In fact, for inputs such as plant and equipment, which have a long adjustment lag, the least-cost path is likely to show much more cyclical movement than the actual path. Nevertheless, DX_{it} does provide a measure of the extent to which changes in the economic climate affect the operating efficiency of an industry at a point in time.[34]

At any point in time, the value of DX_{it} may be the result of several influences which affect the relative speed at which a certain input can be adjusted to its least-cost level. Thus, one or more of the following factors may affect DX_{it}: (1) the underlying short-term technology in the industry;[35] (2) a change in economic conditions affecting an industry, as when a secular decline in either the growth rate or level of demand in an industry generates excess capacity which requires time to reduce; (3) the presence of institutional restraints such as labor union

34. This fact shows up very well in figs. 2.2–2.11, especially in the growth recession and absolute recession period between 1969 and 1972.

35. For example, we might expect production worker-hours and employment to adjust fairly rapidly to economic conditions. However, a basic tenet of the model described by (14) is that hours are not adjusted independently of other inputs—hours may be a short-term substitute for one input and short-term complement to another input—and the net effect of disequilibrium in the components of the input set which co-operate with production workers may in some industries substantially slow the adjustment process toward the least-cost expansion.

contracts which may prevent or at least substantially lengthen the adjustment process of actual input levels to least-cost levels; (4) the extent to which competitive pressures are strong enough to force an industry's management to adopt minimum-cost production procedures; and (5) the degree to which an industry's managers possess the skills necessary to define and organize a least-cost technology.[36]

A more long-term perspective on not only the relative ability of an industry to adjust quickly to business cycle conditions but also on the adequacy of the cost-minimization hypothesis as a characterization of the long-run behavior of an industry is provided by (25). Thus, while we would expect to see fluctuations—both positive and negative—in the value of DX_{it}, we would also expect an industry which follows a conscious policy of cost minimization to be fairly close, on the average, to the long-run expansion path. Moreover, in a sustained growth period, such as that characterized by the interval between 1961 and 1966, we would expect to find a high degree of correspondence between the actual and long-term paths with a low value for (25) relative to an unstable period such as between 1966 and 1972.

2.3.3 Labor Productivity

The long-term path of labor productivity is defined as the level of output per production worker hour on the long-run expansion path:

$$P^*r_1 = Y/X^*_{1t}, \tag{26}$$

while actual labor productivity is defined as the level of output per production worker hour on the actual expansion path:

$$Pr_1 = Y/X_{1t}. \tag{27}$$

As before, the deviation between the observed and long-run levels ($DPr_1 = Pr_1 - P^*r_1$) is a measure of the short-term adjustment component in the observed series, and

36. Industry 22 offers a case where the actual and least-cost expansion paths for hours, equipment, and plant showed substantial divergence between the mid-fifties and mid-sixties peaks. A BLS profile of the industry published in 1966 bears heavily on points (2), (4), and (5) and states that

> interest in plant modernization is stronger now than at any time in the last 50 years. . . . The push for technological improvements is being stimulated by intensified efforts to meet foreign and interfiber competition, an improved financial position, and the emergence of larger companies with more professional experience.

See *Technological Trends in Major American Industries*, Bulletin no. 1474, Feb. 1966, p. 148.

$$(28) \qquad A\%DPr_1{}^{P_1-P_2} = \frac{\sum_{t=P_1}^{P_2} \%DPr_1}{q_{P_1-P_2}}$$

where $\% \ DPr_1$, defined analogously to (24), is a measure of the average percentage deviation of the cyclical adjustments from the long-run productivity expansion path. In other words, (28) is a long-term measure of the difference in the levels of output per man-hour on the actual and least-cost expansion path.

Finally, we are in a position to address the basic question of this study: What is the underlying rate of productivity growth? The hypothesis maintained is that this path is described by (26) and so the question is, What does relationship (26) for each of the ten industry sectors suggest about the growth rates of productivity from the mid fifties to the mid sixties, and from the mid sixties to the 1972 output peak? Further, how does this picture compare with the picture derived from (27)? To answer this question we divide the results from (26) and (27) for each industry into intervals determined by output peaks discussed under equation (23). For each equation we then fit a least-squares trend to each of the three intervals, taking specific note of the two shorter intervals contained within the long interval. Two points of comparison result from this process: first, we are able to contrast the levels of the rates of growth between the actual and long-run series; second, we are able to contrast changes in the rates of growth between the two short intervals for each series. Of course, the basic question is, Does the long-run path indicate a productivity slowdown?

2.3.4 Real Total Factor Cost—Actual versus Long-Run

As mentioned several times throughout this study, a primary consideration of this paper is to determine the underlying or long-term path of productivity for the purpose of discovering whether the observed slowdown in labor productivity is of cyclical or secular origin. Measuring the growth rate of labor productivity is important primarily because productivity helps to control the rise in prices. However, labor is only one of several inputs in the production process, and the rise in production costs and therefore in output prices depends on the productivity of the other co-operating inputs as well. Therefore, we calculate what may be the most important measure produced by this study, namely, the levels and rates of growth of actual and long-term real total factor cost. Actual real total factor cost, defined by (7) and repeated here, is

$$\text{RTFC} = \sum_{i=1}^{6} P_i X_i.$$

The long-run measure of RTFC is

$$\text{(29)} \qquad \text{RTFC}^* = \sum_{i=1}^{6} P_i X^*_i.$$

To compare the levels of RTFC and RTFC* we compute a measure analogous to (25) and (28), namely,

$$\text{(30)} \qquad A\%\text{RTFC}^{p_1-p_2} = \frac{\sum_{t=p_1}^{p_2} \%D\text{RTFC}_t}{q_{\bar{p}_1-p_2}},$$

where

$$\%D\text{RTFC}_t = \frac{\text{RTFC}_t - RTFC^*_t}{\text{RTFC}^*_t} \times 100.$$

The value of $A\%D\text{RTFC}^{p_1-p_2}$ indicates for the interval $p_1—p_2$ the average percentage amount by which RTFC exceeded RTFC*. Especially in industries where unit cost pricing prevails, this measure would be highly suggestive of how much lower the level of prices could have been if the industry could have followed its least-cost expansion path.

From the point of view of inflation, however, the critical question is how fast RTFC grows in comparison to RTFC*. To answer this question, we compute least-squares rates of growth for each of these cost measures for the three peak-to-peak intervals described previously.

2.4 Empirical Results

2.4.1 Introduction

In order to simplify the orderly presentation of the mass of statistical results generated by our research, the contents of this section are presented and generally discussed according to the broad categories of nondurable and durable goods manufacturing rather than for each of the ten sectors individually.[37] The reader is reminded at the outset that there are three main objectives in this research effort: first, to determine the "best" representation of the structure of production for each industry; second, to use this structure to estimate the long-term path of demand for factors of production and production worker productivity; third, to contrast these long-term paths with the paths of the measured or observed variables. The reader is provided with tables and charts to assist in evaluating the discussion on each of these aforementioned ob-

37. See note 5.

jective.[38] These tables include the following: Table 2.2 gives the F-test results for three alternative specifications of the long-term structure of production and two alternative specifications of the dynamics of adjustment. Table 2.3 gives the matrix of "best" model mean Allen partial elasticity of substitution coefficients for the years between 1957 and 1972. Table 2.4 provides the values of the "best" model Allen partials by industry for 1957, 1965, and 1972. Table 2.5 provides estimates of the "best" model Hicks-neutral technical progress and the homothetic returns to scale coefficients for each sector.[39]

Tables 2.6A–2.15A provide the contrasting measures of the least-squares rates of growth for the actual versus the long-run measures of production worker input, relative cost share, productivity, and real total factor cost. For these variables these tables also provide a measure of the average cycle effect computed according to formulas (25), (28), and (30) in each of the peak-to-peak intervals.[40] Finally, these tables also provide a measure of the average cycle effect on output for each of the peak-to-peak intervals. This effect is defined as

$$\left[\left(\sum_{t=P_1}^{P_2} \text{abs}\, \frac{Y_t - YTR_t}{YTR_t}\right) \Big/ \, q_{P_1 - P_2}\right] \times 100,$$

where YTR is equal to the mid-fifties peak-to-peak trend level of output, q, P_1, and P_2 are as defined in section 2.3.2, and "abs" stands for absolute value. Tables 2.6B–2.15B provide the contrasting measures of the least-squares rates of growth for the actual versus the long-run measures of nonproduction worker employment, equipment, plant, capacity utilization, and materials. For these five nonproduction worker inputs, these tables also provide a measure of the average cycle effect computed according to formula (25) for the three peak-to-peak intervals.[41]

38. A complete set of tables and graphs for each industry is provided in Mohr (1978). Included are the estimation results for (16) under both homothetic and nonhomothetic specifications; estimates of the Allen partial elasticities of substitution for the homothetic and nonhomothetic versions of (12); tables and graphs profiling each of the variables used in estimating (16); and a set of graphs profiling and contrasting the paths of the actual and long-run values for each of the six factors of production.

39. See discussion in section 2.3.1.

40. See discussion in section 2.3.2.

41. The method used to construct the investment price of plant helped to safeguard against unreasonable first- to fourth-quarter jumps in the level of the constructed quarterly plant investment prices. (See Data Appendix in Mohr 1978). However, it is not designed to prevent such jumps in the first difference of the constructed plant investment prices, and the first difference as well as the levels of these prices is part of the constructed rental prices of plant for each industry.

In addition to these twenty summary tables (2.6A–2.15A and 2.6B–2.15B), there are also provided for each industry four charts (parts A through D of figs. 2.2–2.11) which profile and contrast the paths of actual and long-run values for plant and equipment as well as for production worker productivity and real total factor cost.

2.4.2 Method of Estimation

The system in (16) and all variants of it discussed below were estimated on a 1956.2 to 1972.4 quarterly data set. Since we chose to interpret the translog cost function in (2) as a second-order approximation to an arbitrary twice-differential cost function, all the arguments in (16) and its variants were indexed to 1 = 1963.

Since the system of cost share equations (14) is assumed to have not only contemporaneous cross equation correlation in the vector of error terms $(e_{1t}, e_{2t}, \ldots, e_{6t})$ for all t, but also symmetry, adding-up, and homogenity restrictions,[42] all factor share models in this study were estimated using a generalized least-squares (GLS) technique known as iterative Zellner-efficient estimation (IZEF). If the regressors are independent of the disturbances in each equation and if IZEF converges, it converges to maximum-likelihood estimation (Kmenta and Gilbert 1968). Further, Pollak and Wales (1969) have shown that maximum-likelihood estimation of *any* subset of $n-1$ independent equations in a set of n equations provides maximum-likelihood estimates of the parameters of the entire set. In particular, Berndt and Savin (1975, pp. 974–50) show that all the parameters of the established nonlinear model (16) are invariant to the equation deleted.

It may be argued that the correct estimation technique for (14) is IZEF combined with two-stage least-squares (2SLS) to form iterative three-stage least squares (I3SLS). However, in view of the massive amount of data constructed here, I3SLS seemed to be an unnecessary refinement.[43]

An inspection of the quarterly constructed plant rental price series showed a large outlier in 1956.1 which was not obvious in the constructed plant investment price data. Our original simulation with the outlier in it seriously distorted the relationship between the long-run and actual paths of plant demand. As a consequence, for all industries the mid-fifties to mid-sixties average cycle effect on plant was estimated with 1956.2 as the beginning year. Also, the plot of the actual and long-run plant demand in figs. 2.2A–2.11A always begins with 1956.2.

42. See conditions (i) and (ii) under equation (2) and equations (10) and (15).

43. Berndt and Christensen (1973*b*) reported that, based on a model estimated on aggregate manufacturing data, their results from IZEF and I3SLS were very similar.

2.4.3 Testing the Structure of Production

Two sets of criteria were used in deciding upon the "best" model to represent the structure of production in each industry. The first criterion is statistical and the second is theoretical. To understand how the statistical tests were constructed, consider that the model of production (14) is composed of two structures: first, the long-term or comparative static structure (12), and second, the short-term or partial adjustment structure. Each of these structures represents areas where tests of alternative theories can be conducted. The series of tests described below amounts to the imposition of parameter restrictions on the basic model (14), and as such the validity of these restrictions can be ascertained by an F-test.[44]

The maintained long-term hypothesis embodied in (14) is (12), i.e., the long-term structure of production conforms to a nonhomothetic translog cost function. Therefore, the first series of tests we wish to construct is aimed at testing widely used alternatives to (12), namely, homothetic translog and Cobb-Douglas specifications. Note that the validity of the adjustment process is being maintained in this first series of tests. Now, when the null hypothesis to (12) is homothetic translog, this amounts to constraining the five β_i parameters in (12) and (14) to zero. Further, when the null hypothesis is not only homothetic but also Cobb-Douglas, an additional fifteen zero-parameter restrictions are being imposed on δ_{ij}'s in (12) and (14). Thus, we can construct a series of nested F-tests where each successive stage in the series is conditioned on the acceptance of the null hypothesis in the preceeding stage.[45] At each stage in the series the change in the weighted sum of squared residuals from restrictions imposed at this stage is calculated, and then divided by the sum of squared residuals at the previous stage. Of course, both the numerator and denominator of this ratio are adjusted by the appropriate degrees of freedom. Accordingly, the first F-test on the long-term structure is computed as

$$F_1 = \frac{[RSS_H - RSS_{NH}]/(50\text{–}5)}{RSS_{NH}/(335\text{–}50)},$$

where the subscripts H and NH stand for homothetic and nonhomothetic, respectively; 50 is the number of free parameters in the maintained hypothesis embodied by (12) and (14); 5 is the number of zero restrictions imposed by the null hypothesis of homothetic translog; and 335 is the number of observations in the stacked regressions for all the

44. See Theil (1971), pp. 402–3.
45. See Christensen, Jorgenson, and Lau (1973), pp. 38–45.

models estimated in each industry. Conditional on the acceptance of homothetic translog in F_1, we then test the validity of a Cobb-Douglas specification of (12) and (14) as

$$F_2 = \frac{[RSS_{CD} - RSS_H]/(45\text{–}15)}{RSS_H/(335\text{–}45)},$$

where the subscripts CD and H refer to Cobb-Douglas and homothetic translog, respectively; 45 is the number of free parameters in the homothetic translog version of (12) and (14); and 15 is the number of additional zero restrictions which are imposed on the homothetic versions of (12) and (14) when the null hypothesis is that long-term structure of production is Cobb-Douglas. F_2 is both a test of the Nadiri-Rosen model and also a test of complete global functional separability of the factors of production.[46] The overall level of significance for this first series of tests is set at .02 and is allocated among the two stages equally, i.e., at the .01 level.

The second series of tests to be constructed bears on the short-term or partial adjustment structure of (14). In effect, the null hypothesis to be tested here is that adjustment is rapid enough to be adequately captured by a direct comparative static model. In particular, we test the null hypothesis that the model is homothetic and translog without any adjustment parameters. Except for the fact that a production function instead of a cost function is embodied in (14), the null hypothesis to be tested here is a test of the Jorgenson, Christensen, and Berndt approach to modeling the structure of production.[47] As with the first series of tests, the second can be tested in two stages. The first stage is a test of the homotheticity of the long-run structure which has already been described in F_1. Conditional on the acceptance of homotheticity, the second stage amounts to testing the validity of imposing additional zero-parameter restrictions on all twenty-five of the composite adjustment parameters, $T_{ij} = \theta_{ij} - \theta_{i6}$ $(ij = 1, \ldots, 5)$, in (16). Therefore, we construct a second series of nested F-tests where the first stage has already been computed by F_1 above, and the second stage is computed as

$$F_3 = \frac{[RSS_H - RSS_{DTL}]/(45\text{–}25)}{RSS_H/(335\text{–}45)},$$

where the subscript DTL stands for direct translog and twenty-five is the number of zero restrictions which would be imposed on a homothetic translog version of (16) when the null hypothesis is that adjustment is instantaneous. As before, we set an overall level of significance at .02 and distribute it evenly between F_1 and F_3. Critical values em-

46. See Berndt and Christensen (1973*a*, *b*).

47. See Christensen, Jorgenson, and Lau (1973) and Berndt and Christensen (1973*b*, *c*). See also Berndt and Wood (1975) where a cost function is used.

ployed in our tests are given in table 2.1. The results of the F-tests for each industry are reported in table 2.2. By comparing the values of F_1, F_2, and F_3 with their respective critical values in table 2.1 we reach the following conclusions: (1) the null hypothesis of homethetic translog is accepted by F_1 at both the 1% and 2.5% significance levels in all sectors but 330 and 371; (2) the additional parameter restrictions required for the Cobb-Douglas and direct translog null hypothesis are rejected at the 1% and 2.5% levels for all sectors by F_2 and F_3, respectively.

In addition to these purely statistical criteria, two theoretical considerations were instrumental in determining the "best" structure of production for each industry. These considerations are the monotonicity and

Table 2.1 Critical Values of F (v_1, v_2)

Degrees of Freedom			Level of Significance .01	Level of Significance .025
$V_1 = 45$, $V_2 = 285$	F_1 (45,285)	$F(40, 120)$	1.76	.161
		$F(40, \infty)$	1.59	.148
$V_1 = 30$, $V_2 = 290$	F_2 (30,290)	$F(30, 120)$	1.86	1.69
		$F(30, \infty)$	1.70	1.57
$V_1 = 20$, $V_2 = 290$	F_3 (20,290)	$F(20, 120)$	2.03	1.82
		$F(20, \infty)$	1.88	1.71

Table 2.2 Computed F-Values by Industry Category

Industry	$F_1(45, 285)$	$F_2(30, 290)$	$F_3(20, 290)$
Nondurable Goods			
SIC 20	0.5300	24.7602	40.7589
SIC 22	0.7380	5.7674	19,1618
SIC 26	0.1488	15.8936	21.4285
SIC 28	0.5948	15.4192	63.4757
SIC 30	1.1098	7.9747	24.0836
Durable Goods			
SIC 32	0.1601	8.4502	26.8025
SIC 330	2.9790	17.9297	17.2086
SIC 333	1.2932	6.1363	58.3244
SIC 35	1.1501	9.6322	58.2023
SIC 371	3.6695	9.2421	29.5406

SOURCE: *Biometrika Tables for Statisticians*, vol. 1, ed. by E.S. Pearson and H.O. Hartley (Cambridge: Cambridge University Press, 1954), pp. 160–61.

concavity conditions described in section 2.2.2. The monotonicity condition was tested for both the homothetic and nonhomothetic versions of (14) for all industries. Only the homothetic version of SIC 22 failed to satisfy this condition.

As pointed out in section 2.2.2, concavity requires that H be negative semidefinite. However, it can be shown that an equivalent condition is that σ be negative semidefinite, where σ is the symmetric matrix of Allen partial elasticities of substitution (AES). When all $\sigma_{ij} < 0$ $(i \neq j)$, a necessary condition for σ to be negative semidefinite is that all of the own AES $(\sigma_{ii}) < 0$.[48]

This necessary condition for concavity was most closely met in the data for industries 330 and 371 in homothetic form. It will also be noted by studying tables 2.3 and 2.4 that the durable goods industries come much closer to satisfying this condition than the nondurable sectors. Also, the more variation existing in the output data, the more closely this condition is satisfied; SIC 20 with the least amount of output variation constitutes the major exception. (Compare the results of tables 2.3 and 2.4 with the measure of output variation in tables 2.6A–2.15A.)

While the inequality condition on σ_{ii} is not explicitly met for most of the industries, it is still possible that this condition is satisfied provided that the own substitution parameters, δ_{ii}, in (4) are not statistically different from zero since the own AES's are defined as

$$\sigma_{ii} = \frac{1}{S^{*2}_i} (\delta_{ii} + S^{*2}_i - S^*_i) \qquad (i = 1, \ldots, 6),$$

where S^*_i are the long-run cost shares defined by (4). Therefore, if $\delta_{ii} = 0$, $\sigma_{ii} = 1 - (S_i/S^{*2}_i)$, where $S^*_i/S^{*2}_i > 1$, so that $\sigma_{ii} < 0$. Now. the δ_{ii} are not computed directly, but residually, as

$$\delta_{ii} = \sum_{\substack{j=1 \\ i \neq j}}^{n} \delta_{ij} \qquad (i = 1, \ldots, 6),$$

so that δ_{ii} is a linear combination of the δ_{ij} $(i \neq j)$. Therefore, the variance of δ_{ii} can be expressed as

$$V(\delta_{ii}) = \boldsymbol{b}'V\,(\delta_{ij})\,\boldsymbol{b} \qquad (i = j; i = 1, \ldots, 6),$$

where $\boldsymbol{b}$ is a (5×1) unit vector and $V\,(\delta_{ij})$ is the (5×5) variance-covariance matrix for the five δ_{ij} used to compute δ_{ii}. Unfortunately, the software necessary to compute $V(\delta_{ij})$ was not available so no test of significance on the δ_{ii} could be calculated. However, an inspection of

48. If this condition is satisfied, it follows from (8b) that the derived demand curve for the inputs is downward-sloping since by (8b) $\sigma_{ii} > 0$ if and only if $\partial X_i/\partial P_i > 0$, i.e., if and only if the demand curve is upward-sloping.

the t-statistics indicated that, based just on the variance components of $V(\delta_{ij})$, we could often conclude that the δ_{ii} are not significant.[49]

The theoretical considerations formed the overriding criteria in deciding on the "best" long-term structure, so that, for instance, in SIC 26 where the results of F_1 supported the null hypothesis of homotheticity, the null hypothesis was rejected by the theoretical criteria.

In summary, the results of the F-test and theoretical criteria combined led to the following conclusions: first, in all cases the Cobb-Douglas and instantaneous adjustment hypotheses were overwhelmingly rejected by the results of F_2 and F_3; second, homothetic translog was accepted in all industries except 330 and 371 by the results of F_1; third, when the theoretical criteria are considered, homotheticity is accepted for all industries but 22 and 26. Finally, the reader will notice from tables 2.3 and 2.4 that all inputs are substitutes in the long-run even though the signs on the adjustment parameters (not shown here) indicated that some inputs are short-term complements.[50]

2.4.4 Estimating Hicks-Neutral and Homothetic Scale Parameters

Estimates of Hicks-neutral technical progress[51] (total factor productivity) and homothetic returns to scale[52] are OLS estimates based on a

49. Simulation analysis conducted by Wales (1976) brings out a very important point: even though the data are the result of an optimization process—utility-maximization or cost-minimization—the translog model parameters may fail to satisfy the required regularity conditions and thus fail to verify that the underlying model, which assumes such behavior, is an accurate description of the economic conduct of the agents in question (in this study, the firms in the ten selected industries). However, Wales's results show that the translog share equation generally fitted the data very well, as measured by the R^2 or by the divergence between the true and estimated price elasticity, even when the curvature conditions were violated. These two facts imply that the parameters of the estimated function are probably not far from their true values. Furthermore, since our cross Allen partial estimates were much closer to 1 than zero, Wales's results point toward improvement in raw source data and/or methods of data construction as a possible key to satisfying the curvature condition for cost-minimization, i.e., negatively signed σ_{ii}. Some candidates for data improvement are discussed in section 2.5.

50. The reader will recall from the discussion in section 2.2.4 that the adjustment parameters estimated here are composite parameters. Therefore, we are not capable of identifying with certainty either the magnitude or sign of the individual adjustment coefficients, although reasonable conjectures about the signs can be made more easily than about magnitude. A negative sign on a θ_{ij} indicates that input i is a short-term complement to input j, while a positive sign indicates i is a short-term substitute for j.

51. When interpreting the Hicks-neutral coefficient in tables 2B and 3B, the reader should bear in mind that a cost function and not a production function was used to obtain these estimates. Therefore, a negative sign on the coefficient

1956–72 annual sample (see table 2.5). The results of these latter estimations must be viewed with some caution since (19) is estimated with prior parameter restrictions, for example, those from the share equations in (14); also, the constant term is maintained to be zero in (19), and Z^* is assumed to be an adequate proxy for Z^* in (19). In the case of industry 22 one or more of these prior constraints seems to be overly restrictive as is evidenced by the fact that $R^2 = -7.36$ for the specification represented by (19). The inclusion of a constant term for this industry noticeably improved the fit but rendered the Hicks-neutral term positive and insignificant and the homothetic scale term negative and insignificant. The former result is inconsistent with the extraordinarily high rate of labor productivity growth in sector 22 (4.44% between 1956.1 and 1972.3). The latter result implied that marginal cost in SIC 22 was negative.[53]

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indicates positive technical progress, the reverse being true for a positive-signed coefficient.

52. Long-run returns to scale in an industry can be defined by the shape of the long-run average cost curve, C^*/Y. Returns to scale are increasing, constant, or decreasing, according to $\partial(C^*/Y)/ \lesseqgtr 0$. An equivalent result is obtained when $(1 - \partial \ln C^*/\partial \ln Y) \lesseqgtr 0$, where $\ln C^*$ is defined by (2). In general, the long-run cost function can be written as $C^* = H(Y)G(P;Y)$ or $\ln C^* = \ln H(Y) + \ln G(P;Y)$, where $\ln H(Y)$ describes the homothetic returns-to-scale relationship. However, in this study we use the term homothetic in a restricted sense, i.e., we have restricted $\ln H(Y)$ in (2) in such a way that $\partial \ln C^*/\partial \ln Y = \partial \ln H(Y)/\partial \ln Y = \alpha_Y$, a constant. Thus, $\ln H(Y)$ has been restricted to the class of homogeneous functions in this study, but has not been restricted to being linear homogeneous where $\alpha_Y = 1$.

53. A well-behaved cost function must exhibit positive marginal cost in the relevant range. Long-run marginal cost is defined as dC^*/dY, and from (2) it follows that

$$\frac{dC^*}{dY}\frac{C^*}{Y} = \frac{d\ln C^*}{d\ln Y} = \alpha_Y + \Sigma\beta_i \ln P_i,$$

or that

$$\frac{dC^*}{dY} = [\alpha_Y + \Sigma\beta_i \ln P_i]\, Y/C^*.$$

Therefore, for the nonhomotheic case,

$$dC/dY > 0$$

implies

$$\alpha_Y + \Sigma\beta \ln P_i > 0,$$

since Y/C^* is by definition positive for positive values of Y. Since $\Sigma\beta_i \ln P_i < 0$ in SIC 22, a negative sign on α_Y assures violation of the positivity condition. Again, if (2) is homothetic, then

$$\frac{dC^*}{dY} = \alpha_Y\, Y/C^*$$

and $dC^*/dY > 0$ if and only if $\alpha_Y > 0$.

For the remaining industries, the Durbin-Watson (DW) statistic is low, but DW is not a valid indicator of serial correlation when the constant term is excluded from the regression. When (19) was estimated using iterative Cochran-Orcutt, the parameter values were not noticeably affected, but their significance was greatly reduced. In addition, when (19) was estimated with a constant term, the uniform result was that the technical progress parameter became negative, and quite often insignificant, while all improvement over time in unit cost became the result of positive economies of scale. By contrast, the use of (19) directly gives a much more plausible result: only sectors 330, 35, and 371 show increasing returns to scale. Since these three industries experienced much lower operating rates than the other seven sectors during the 1956–72 period (see note 62), it is reasonable to suspect that the observed data pertain to operations in the increasing returns-to-scale range of the long-run average cost curve. In summary, the estimates of the homothetic scale parameters from specification (19) suggest that industries SIC 22, SIC 26, SIC 28, SIC 30, SIC 32, and SIC 333 are characterized by decreasing returns to scale, industries SIC 35, SIC 330, and SIC 371 are characterized by increasing returns to scale, while industry SIC 20 exhibits constant returns to scale. The technical progress parameters in table 2.5 also form a reasonable pattern. The industries rank in the following order: SIC 28, SIC 22, SIC 26, SIC 30, SIC 32, SIC 371, SIC 333, SIC 20, SIC 330, SIC 35. This ranking is roughly equivalent to that based on the rate of actual labor productivity growth in tables 2.6A–2.15A;[54] the major exceptions are SIC 20 and 35, which rank fourth and fifth, respectively, among the ten industries in the rate of growth of labor productivity.

On balance, in spite of the cautions, the consistent use of specification (19) to estimate the Hicks-neutral and returns-to-scale parameters for each industry not only has resulted in reasonable estimates for the sectors individually but also has facilitated comparisons of these parameters among the sectors. In this respect, table 2.5 brings to light an interesting dichotomy in the long-term structure of production between the nondurable and durable goods–producing industries. The former are characterized by high rates of growth in technical progress (except for SIC 20) and decreasing returns to scale (except for SIC 20). By contrast, three out of the five durable goods industries (SIC 35, 330, and 371) showed increasing returns to scale, and only SIC 32 showed

54. The industry ranking of the growth rates in actual output per actual production hour between the mid-fifties and 1972 peaks is as follows: SIC 28, SIC 22, SIC 26, SIC 20, SIC 35, SIC 371, SIC 30, SIC 32, SIC 333, SIC 330. The rank correlation coefficient between the Hicks-neutral and labor productivity rates is .61. Excluding sectors 20 and 35 from the list of sectors results in a rank correlation coefficient of .93.

decreasing returns to scale comparable to that found in the nondurable sectors. Only two durable goods–producing industries (SIC 32 and 371) showed significant rates of increase in total factor productivity growth, but in each case the growth was substantially smaller than that of any nondurable goods sectors except SIC 20.

2.4.5 Patterns in the Long-Run Structure of Production, Output, and Productivity

In this section we use the information in tables 2.3, 2.4 and 2.5 to examine patterns in the "best" model long-term structure of production.[55] Also, as a prelude to examining the contribution of the business cycle to the slowdown in productivity growth after the mid sixties, we discuss the major patterns found in the measured data on output and productivity in tables 2.6A–2.15A. Because of space limitations, the discussion will generally be in terms of the two broad classes of manufacturing—nondurable and durable goods manufacturing.[56]

Patterns in the Structure of Production

First, in the recent production-theory literature, several authors have raised questions concerning the validity of the standard value-added approach to estimating the structure of production.[57] In the light of this controversy, all models estimated in this study are based on a gross-output concept of production. This approach is superior to a value-added approach for analyzing the determinant of factor demand and factor productivity over time unless at least one of the following conditions is satisfied:[58] (1) the ratio of materials to gross output (X_6/Y) is always constant over time; (2) the ratio of the price of materials to the price of output (P_6/P_Y) is always constant over time; (3) the in-

55. As pointed out in section 2.2.4, model (14) lacks sufficient restrictions to identify the individual short-term adjustment parameters. A heuristic approach to identifying the sign and magnitude of the θ_{ij}'s in (14) from a knowledge of the T_{ij}'s in (16) is given in Mohr (1978), but no discussion of the short-term structure of production is attempted here.

56. A detailed discussion of each of the ten industries is given in Mohr (1978).

57. See, for instance, Parks (1971), Diewert (1973), and Berndt and Woods (1975).

58. Berndt and Wood (1975) employ a four-factor, gross output, translog cost function to analyze factor demand in U.S. manufacturing for the period 1947–71. The four factors include the following: labor, capital, materials, and energy. Under the assumption that the production function is linear homogenous, Berndt and Wood test to see if any of the three sufficient conditions for validating a value-added approach to production theory and factor demand are met. They state not only that none of these conditions are met by the annual data for U.S. manufacturing in the 1947–71 period, but also that "we must call into question the reliability of investment and factor demand studies for United States manufacturing based on the value added specification."

puts X_1, X_2, X_3, X_4, and X_5 are weakly separable from X_6, implying that $\sigma_{16} = \sigma_{26} = \sigma_{36} = \sigma_{46} = \sigma_{56}$; also, if condition (1) stems from the technological nonsubstitutability of X_6, then, $\sigma_{16} = \sigma_{26} = \sigma_{36} = \sigma_{46} = \sigma_{56} = \sigma_{66} = 0$. While no formal tests of the presence of any of these three conditions were undertaken, there is evidence that none of them is met in any sector for the sample period 1956.2–1972.4. First, in the process of constructing the materials measure described in the appendix, it became apparent that the ratio X_6/Y was not constant; second, the process of constructing the output and materials price deflators indicated that the ratio P_6/P_Y also was not constant; third, an inspection of "best" model Allen partials for each industry (see tables 2.3 and 2.4) suggests that the equalities set out under condition (3) are not satisfied between 1957 and 1972. Thus, exclusion of materials from the mix of simultaneously determined inputs is likely to eliminate an important source of factor substitution. For example, process-saving advances in the quality and in the degree of fabrication of the materials supplied by the chemical and plastic industries to the auto industry have enabled the latter to substitute the capital, labor, and technology of the former for their counterparts in the auto industry.

Second, an inspection of tables 2.3 and 2.4 shows that, for all ten industries, our "best" model results suggest that all inputs are long-term substitutes regardless of their short-term relationships. The sixth and twelfth columns of table 2.3 give the unweighted averages of the elasticity of substitution coefficients for the five nondurable goods sectors and for the five durable goods sectors for the period 1957 to 1972. Comparing these numbers with a 1959–71 average of the substitution coefficients in Berndt and Wood (1975, table 4, p. 264) for all manufacturing, we discover that our numbers compare very well for the capital-labor coefficients. Berndt and Wood estimate a 1959–71 average σ_{KL} of 1.01, while we estimate a 1957–72 average $\sigma^{ND}{}_{13} = 1.06$, $\sigma^{ND}{}_{14} = .98$, $\sigma^{ND}{}_{23} = 1.01$, $\sigma^{ND}{}_{24} = .98$, $\sigma^{D}{}_{13} = .99$, $\sigma^{D}{}_{14} = .95$, $\sigma^{D}{}_{23} = .89$, $\sigma^{D}{}_{24} = .96$.[59] For the elasticity of substitution between labor and materials, we estimate a $\sigma^{ND}{}_{16} = .78$, $\sigma^{ND}{}_{26} = .83$, $\sigma^{D}{}_{16} = .91$, $\sigma^{D}{}_{26} = 1.04$. Thus, Berndt and Wood's estimate of $\sigma_{LM} = .60$ corresponds much more closely to what we find on the average in nondurable manufacturing and in particular to the σ_{16} for production workers and mate-

59. $\sigma_{ij} = \text{AES}_{ij}$ in tables 2.3 and 2.4 and $\sigma^{ND}{}_{ij} =$ the unweighted average of the AES_{ij} for the five nondurable sectors shown in table 2.3, while $\sigma^{D}{}_{ij}$ is the counterpart for the five durable sectors. Also, while Berndt and Wood's model uses an aggregate capital input K (plant plus equipment) and an aggregate labor input L (production plus nonproduction worker-hours), the present study uses plant and equipment and production and nonproduction worker inputs as separate factors. Thus, the σ_{KL} of Berndt and Wood must be compared with our σ_{13}, σ_{23}, σ_{14}, and σ_{24} in both durable and nondurable emanufacturing (see note 12).

Table 2.3 **Mean Values of "Best" Model Long-Run Allen Partials for 1957 to 1972**

Own-and Cross-Allen Partials	Nondurable Goods Industries SIC 20 (1)	SIC 22 (2)	SIC 26 (3)	SIC 28 (4)	SIC 30 (5)	Unweighted Avg. of 5 Ind. (6)	Durable Goods Industries SIC 32 (7)	SIC 330 (8)	SIC 333 (9)	SIC 35 (10)	SIC 371 (11)	Unweighted Avg. of 5 Ind. (12)
AES11	−19.267	11.822	− .442	11.240	16.777	4.026	1.504	−5.272	.827	3.948	−4.922	− .783
AES12	1.010	.993	.945	1.002	.973	.985	1.003	.998	.998	1.000	.939	.987
AES13	1.142	.993	.997	1.129	1.037	1.060	1.012	1.020	.917	1.036	.973	.992
AES14	.996	.954	.992	.956	.988	.977	.940	.895	.991	.995	.950	.954
AES15	.814	.682	.844	.780	.815	.787	.753	.881	.939	.864	.929	.873
AES16	1.019	.613	.931	.817	.507	.777	.932	.977	.999	.742	.910	.912
AES22	29.018	4.566	−7.333	−.430	8.406	6.846	.044	.773	−9.046	− 5.027	1.417	−2.367
AES23	.962	.963	1.000	1.119	.989	1.007	1.032	.899	.842	.834	.856	.893
AES24	.974	.984	.973	.977	.994	.980	.987	.843	.987	.973	.993	.957
AES25	.862	1.019	.890	.847	.955	.915	.817	1.055	.958	1.039	.984	.971
AES26	.490	.986	.843	.855	.995	.834	.891	.987	1.121	1.240	.965	1.041
AES33	− 8.647	−1.097	.417	1.116	.217	−1.599	.646	−3.311	−1.920	−10.288	−5.526	−4.080
AES34	.975	.968	.976	1.023	.914	.971	1.009	.843	.969	.744	.823	.878
AES35	1.060	.960	.926	.903	.959	.962	.944	1.094	.993	1.163	1.005	1.040
AES36	.973	.916	.849	.740	.889	.873	.762	.890	.972	1.092	.950	.933
AES44	.857	5.892	.790	2.166	6.781	3.297	.147	− .863	5.470	− 4.871	−3.042	− .632
AES45	.995	.990	.993	.985	1.001	.993	.988	.965	.996	1.009	.939	.979
AES46	.997	.987	.995	.990	1.000	.994	.982	1.044	.998	1.012	.999	1.007
AES55	− 2.801	−1.182	−1.026	−.304	−1.131	−1.289	−.847	−2.368	−3.006	− 3.771	−4.250	−2.849
AES56	.891	1.031	1.008	1.043	1.094	1.014	1.061	.894	.847	.768	.828	.880
AES66	− .173	.389	− .209	1.612	.651	.454	.846	−1.493	− .624	− 2.593	− .810	− .934

Table 2.4A **"Best" Model Long-Run Allen Partials for 1957, 1965, and 1972**

A. Nondurable Goods Industries

Own-and Cross-Allen Partials	SIC 20			SIC 22			SIC 26			SIC 28			SIC 30		
	1957	1965	1972	1957	1965	1972	1957	1965	1972	1957	1965	1972	1957	1965	1972
AES11	−15.812	−19.204	−27.412	19.270	9.233	−1.812	−1.543	−1.218	0.732	7.571	6.399	20.302	16.157	12.350	17.941
AES12	1.006	1.011	1.013	0.992	0.992	0.993	1.007	1.008	1.008	1.002	1.002	1.002	0.973	0.974	0.975
AES13	1.090	1.135	1.223	1.058	1.047	1.060	0.998	0.998	0.997	1.119	1.102	1.162	1.032	1.030	1.043
AES14	0.997	0.997	0.994	1.016	1.014	1.020	0.994	0.993	0.990	0.957	0.966	0.942	0.990	0.991	0.985
AES15	0.841	0.829	0.754	0.638	0.727	0.665	0.890	0.861	0.796	0.828	0.812	0.696	0.841	0.845	0.776
AES16	1.017	1.019	1.023	0.457	0.644	0.676	0.931	0.934	0.930	0.821	0.820	0.806	0.425	0.543	0.586
AES22	61.086	16.024	20.663	5.845	4.638	3.256	−8.148	−8.091	−6.078	−1.498	−1.661	1.826	7.205	5.921	11.741
AES23	0.961	0.968	0.956	0.966	0.965	0.960	1.050	1.055	1.075	1.113	1.101	1.140	0.990	0.990	0.986
AES24	0.968	0.980	0.972	0.987	0.985	0.980	0.977	0.978	0.966	0.977	0.981	0.972	0.995	0.995	0.992
AES25	0.817	0.893	0.873	1.080	1.079	1.085	0.916	0.900	0.859	0.877	0.862	0.803	0.962	0.960	0.942
AES26	0.277	0.554	0.560	0.983	0.985	0.988	0.833	0.850	0.848	0.857	0.852	0.859	0.994	0.995	0.995
AES33	−11.808	− 8.567	− 6.338	−0.953	−1.072	−1.163	0.746	0.500	0.203	0.991	1.457	0.952	0.517	0.349	−0.113
AES34	0.979	0.974	0.974	0.965	0.968	0.972	1.036	1.040	1.036	1.021	1.023	1.022	0.913	0.905	0.921
AES35	1.046	1.064	1.073	1.021	1.022	1.023	0.922	0.930	0.931	0.886	0.910	0.912	0.958	0.960	0.960
AES36	0.981	0.975	0.966	0.939	0.925	0.894	0.888	0.864	0.815	0.753	0.789	0.685	0.918	0.903	0.847
AES44	2.001	1.857	− 1.011	13.184	7.233	1.607	1.718	2.307	−0.863	1.113	3.541	1.029	10.818	12.294	0.525
AES45	0.996	0.995	0.995	0.991	0.990	0.988	0.992	0.994	0.993	0.981	0.986	0.986	1.000	1.000	1.000
AES46	0.997	0.997	0.996	0.991	0.989	0.982	0.996	0.996	0.994	0.990	0.992	0.988	1.000	1.000	1.001
AES55	− 2.806	− 2.955	− 2.778	−1.171	−1.176	−1.208	−0.895	−1.059	−1.073	−0.087	−0.319	−0.451	−1.026	−1.147	−1.224
AES56	0.884	0.878	0.899	1.114	1.099	1.074	1.095	1.071	1.051	1.051	1.047	1.031	1.122	1.099	1.062
AES66	− 0.141	− 0.157	− 0.197	0.194	0.311	0.632	−0.307	−0.271	−0.092	1.232	1.059	2.466	0.320	0.498	1.257

Table 2.4B **"Best" Model Long-Run Allen Partials for 1957, 1965, and 1972**

B. Durable Goods Industries

Own-and Cross-Allen Partials	SIC 32			SIC 330			SIC 333			SIC 35			SIC 371		
	1957	1965	1972	1957	1965	1972	1957	1965	1972	1957	1965	1972	1957	1965	1972
AES11	0.640	1.024	1.613	−5.370	−5.317	−5.172	−0.029	−0.312	2.040	3.059	2.541	6.382	−4.906	−4.922	−4.874
AES12	1.002	1.002	1.003	0.998	0.998	0.998	0.998	0.998	0.998	1.000	1.000	0.999	1.001	1.001	1.001
AES13	1.012	1.011	1.013	1.075	1.076	1.097	0.928	0.930	0.900	1.028	1.030	1.051	0.967	0.975	0.976
AES14	1.002	1.002	1.002	0.893	0.898	0.883	0.993	0.993	0.988	0.996	0.996	0.993	1.012	1.012	1.014
AES15	0.788	0.764	0.749	0.888	0.886	0.866	0.948	0.949	0.924	0.878	0.886	0.829	0.922	0.929	0.933
AES16	0.940	0.931	0.935	1.039	1.039	1.045	0.999	0.999	0.999	0.730	0.767	0.732	0.899	0.912	0.919
AES22	−1.448	−0.657	−0.494	1.530	1.067	9.808	−9.442	−9.692	−9.391	− 5.122	− 5.005	−5.047	11.715	0.934	1.640
AES23	1.031	1.029	1.031	0.903	0.902	0.874	0.856	0.861	0.833	0.856	0.850	0.801	0.801	0.864	0.861
AES24	0.987	0.988	0.985	0.828	0.838	0.812	0.989	0.989	0.985	0.975	0.977	0.968	0.992	0.993	0.991
AES25	0.838	0.822	0.820	1.118	1.119	1.140	1.018	1.018	1.023	1.038	1.035	1.041	0.980	0.984	0.984
AES26	0.901	0.888	0.900	1.053	1.052	1.059	1.190	1.179	1.163	1.274	1.229	1.207	1.036	1.028	1.027
AES33	0.515	0.789	0.614	−3.523	−3.452	−3.068	−1.979	−1.977	−1.837	−13.395	−10.831	−7.231	−4.930	−5.834	−5.870
AES34	1.010	1.009	1.008	0.862	0.851	0.835	0.967	0.968	0.972	0.763	0.730	0.744	0.782	0.828	0.868
AES35	0.938	0.947	0.943	1.150	1.149	1.164	1.057	1.055	1.054	1.140	1.161	1.184	1.074	1.063	1.063
AES36	0.745	0.788	0.743	0.900	0.898	0.885	0.975	0.974	0.966	1.069	1.086	1.128	1.014	1.012	1.013
AES44	−0.114	0.558	−0.869	−0.985	−0.905	−0.890	9.418	7.932	1.133	− 4.290	− 4.380	−5.570	−1.002	−3.020	−5.421
AES45	0.987	0.988	0.986	0.963	0.966	0.966	0.996	0.996	0.996	1.008	1.008	1.010	1.001	1.001	1.002
AES46	0.981	0.984	0.978	1.110	1.104	1.107	0.998	0.998	0.997	1.010	1.011	1.017	0.999	0.999	0.999
AES55	−0.849	−0.848	−0.847	−2.395	−2.329	−2.317	−3.186	−3.130	−2.702	− 3.823	− 3.892	−3.431	−4.263	−4.132	−4.154
AES56	1.062	1.065	1.057	0.891	0.893	0.897	0.828	0.835	0.879	0.742	0.761	0.817	0.826	0.832	0.837
AES66	0.965	0.580	1.145	−1.500	−1.499	−1.511	−0.565	−0.587	−0.718	− 2.171	− 2.534	−3.210	−0.788	−0.802	−0.854

Table 2.5 Estimates of Hicks–Neutral and Homothetic Scale Parameters by Industry Category*

Industry	Total Factor Productivity	Homothetic Returns to Scale
	Nondurable Goods	
	− 0.0023	0.9890
SIC 20	(− 2.1746)	(910.3445)
	− 0.0623	1.3006
SIC 22	(−20.8986)	(355.2507)
	− 0.0424	1.4835
SIC 26	(−19.4785)	(559.6018)
	− 0.0746	1.7448
SIC 28	(−30.5885)	(633.2446)
	− 0.0290	1.2490
SIC 30	(−10.3674)	(342.6716)
	Durable Goods	
SIC 32	− 0.0232	1.4314
	(− 9.3291)	(454.5437)
SIC 330	0.0025	0.7501
	(1.3791)	(351.1755)
SIC 333	− 0.0033	1.0718
	(− 0.9962)	(261.5576)
SIC 35	0.0039	0.7505
	(4.0806)	(709.7000)
SIC 371	− 0.0161	0.9112
	(−10.3424)	(522.9985)

*Numbers in parentheses are T-statistics.

rials. However, with respect to the relationship between capital and materials, Berndt and Wood's estimates are substantially lower than ours, and the fact that Berndt and Wood separate energy from materials and find that energy and capital are complements does not help to explain this difference. In any event, both studies find materials and capital to be substitutes with Berndt and Wood's results giving a 1959–71 average $\sigma_{KM} = .54$ while we estimate a 1957–72 average $\sigma^{ND}{}_{36} = .87$, $\sigma^{ND}{}_{46} = .99$, $\sigma^{D}{}_{36} = .93$, $\sigma^{D}{}_{46} = 1.01$. Berndt and Wood's finding of 1959–71 average $\sigma_{KE} = -3.3$ suggests that our estimates of the relationships between capital and materials should be lower than theirs, not higher. In another context Berndt and Christensen (1974) find that nonproduction workers and capital are complements, while our results do not. We question, then, whether the complementarity found by Berndt and Wood between capital and energy and the complementarity found by Berndt and Christensen between capital and nonproduction workers is the result of misspecification bias, i.e., results from using a model which applies that adjustment is instantaneous. We earlier overwhelmingly rejected such a model in each of the ten sectors.[60]

Third, a closer look at the patterns in the elasticity of substitution coefficients in table 2.3 shows that, in both nondurable and durable goods manufacturing, equipment is more substitutable for the services of production workers than any other input. We also discover that, while they are substitutes for both labor inputs, materials and capacity utilization in both manufacturing aggregates are more complementary with the input of production workers than with the input of nonproduction workers. Also, in both manufacturing sectors, the use rate of capital is strongly substitutable for increases in the stocks of both types of capital, and materials are more substitutable for plant than for equipment.

Comparing patterns between the two aggregate manufacturing sectors, we see the following differences (see sixth and twelfth columns of table 2.3): $\sigma^{ND}_{13} > \sigma^{D}_{13}$ by 6.9%, $\sigma^{ND}_{23} > \sigma^{D}_{23}$ by 12.7%, $\sigma^{ND}_{34} > \sigma^{D}_{34}$ by 10.7%, $\sigma^{ND}_{56} > \sigma^{D}_{56}$ by 15.2%; while $\sigma^{D}_{15} > \sigma^{ND}_{15}$ by 10.9%, $\sigma^{D}_{25} > \sigma^{ND}_{25}$ by 6.1%, $\sigma^{D}_{26} > \sigma^{ND}_{26}$ by 24.8%, $\sigma^{D}_{35} > \sigma^{ND}_{35}$ by 8.1%, and $\sigma^{D}_{36} > \sigma^{ND}_{36}$ by 6.8%. In short, durable goods manufacturing shows significantly greater opportunities than nondurable goods manufacturing to substitute materials and increases in the use rate of capital for inputs of production workers and equipment, while nondurable goods manufacturing shows substantially greater ability to replace the services of both types of labor as well as plant with the services of equipment.

Fourth, tables 2.4A and 2.4B show that all inputs are not only long-run substitutes in each sector but are also relatively stable ones. On an industry-by-industry basis the following 1957–72 trends emerge from tables 2.4A and 2.4B (more detailed tables support these results):[61]

SIC 20—Nonproduction workers, equipment, and materials show an increasing degree of substitutability for production worker hours, while capacity utilization shows a decreasing ability to be substituted for hours of production workers. Utilization has become more substitutable for nonproduction workers and equipment, while materials have become more (less) substitutable for nonproduction workers (equipment).

SIC 22—Materials have become increasingly substitutable for both labor inputs and less substitutable for plant, equipment, and capacity

60. These complementarities may also be the result of aggregation bias since, in both the Berndt and Wood and Berndt and Christensen studies, aggregate manufacturing data are used, while this study uses disaggregate manufacturing data.

61. For a discussion of the forces behind these trends in each of the ten sectors, see Mohr (1978, pp. 76–299).

utilization, with the latter relationships possibly reflecting an increasing degree of complementarity between the energy component of materials and capital goods.

SIC 26—Utilization has become decreasingly substitutable for production worker hours, nonproduction workers, and materials, while nonproduction workers have become less (more) substitutable for equipment (materials).

SIC 28—Equipment has become more substitutable for production worker hours and nonproduction worker employment and less substitutable for materials; capacity utilization has become a decreasing substitute for production worker hours, nonproduction worker employment, and materials; materials have become less substitutable for production worker hours.

SIC 30—Materials are a relatively weak but increasing substitute for production workers and a relatively strong but decreasing substitute for equipment and utilization; capacity utilization is a strong but decreasing substitute for the services of production and nonproduction workers.

SIC 32—Capacity utilization has become a decreasing substitute for the services of production and nonproduction workers.

SIC 330—Equipment has become an increasing (decreasing) substitute for production worker hours (nonproduction workers); plant and equipment have become decreasing substitutes. The ability to substitute materials for plant decreased between 1957 and 1964–65 but rose from 1964 to 1972.

SIC 333—The coefficients AES13, AES15, AES23, AES24, AES25, AES36, and AES56 were all fairly constant between 1957 and 1964–65, but AES13, AES15, AES23, AES24, and AES36 decreased between 1964–65 and 1972, while AES25 and AES56 increased.

SIC 35—Equipment has become more (less) substitutable for production workers hours (nonproduction workers); materials have become more substitutable for equipment, plant, and capacity utilization; capacity utilization has become less substitutable for the hours of production workers.

SIC 371—The ability to substitute equipment plant and materials for production worker services has increased; capital use rates and equipment have become less substitutable. The level of substitutability between capital use rates and materials has increased.

The most obvious general characteristic in terms of trend for both durable and nondurable manufacturing sectors is the decreasing ability to substitute capacity utilization for production worker hour. However, upon closer inspection, a more meaningful pattern emerges: the ability to substitute increases in the use rate of capital for both types of labor inputs shows an abrupt decrease in the 1965–72 period relative to the

1957–65 period—only the textile and auto industries (SIC 22 and 371) deviate from this pattern. This result is consistent with the fact that the average operating rates in each of the ten sectors is substantially higher in the post-1965 period than in the pre-1965 period.[62] The general state of capital underutilization during the pre-1965 period relative to the post-1965 period is reflected in figures 2.2A–2.11A and 2.2B–2.11B, where it is seen that the least-cost expansion paths for the stocks of plant and equipment in most industries are often below their corresponding actual paths in the pre-1965 period. The post-1965 period shows a very different pattern. In particular, the period between 1965.1 and 1969.3, which is the last half of the long economic expansion that began in 1961, shows strong evidence of a capital shortage developing in pulp and paper, chemicals, rubber and plastics, iron and steel, and nonferrous metals—all basic materials–producing industries. In short, after 1965 the ability of the manufacturing sector as a whole to utilize more efficiently the inputs of production workers through higher operating rates rather than increases in the co-operating stocks of capital has diminished relative to the pre-1965 period.

By way of contrast, table 2.4A shows that between 1957 and 1972 the ability to substitute materials for capacity utilization has been declining in the nondurable goods sectors (SIC 20 is the only exception), while table 2.4B shows that in durable goods manufacturing this ability has been increasing since 1957 (SIC 32 is the only exception).

Finally, as mentioned in section 2.4.4, four out of the five nondurable goods industries show decreasing returns to scale coupled with high rates of technical progress, while the five durable goods sectors show much lower rates of technical progress, with three of the five sectors showing increasing returns to scale (see table 2.5).

It is evident, then, that continued productivity growth in nondurable goods sectors depends greatly on developing and implementing cost-saving innovations; otherwise, sustained output growth will lead to reduced productivity growth. In durable goods manufacturing, on the other hand, the outlook for future improvement in the rate of labor productivity growth depends more on economies of scale than on technological progress—a prolonged period of sustained output growth should increase the rate of productivity growth.

Patterns in the Growth of Output and Production Worker Productivity

An inspection of the peak-to-peak output growth rates in tables 2.6A–2.15A shows that on average the nondurable goods sectors en-

62. The 1955–56 (1966–72) average operating rates by industry are as follows: SIC 20—.903 (.954); SIC 22—.853 (.942); SIC 26—.846 (.952); SIC 28—.837 (.944); SIC 30—.816 (.923); SIC 32—.925 (.921); SIC 330—.820 (.879); SIC 333—.834 (.911); SIC 35—.770 (.870); SIC 371—.800 (.849).

joyed substantially higher rates of growth than did the durable goods sectors. The unweighted average of the mid-fifties to mid-sixties growth rates of the five nondurable sectors was 4.93% versus 3.90% for the five durable goods sectors. In the mid-sixties to 1972 interval the corresponding numbers were 3.63% for nondurables and 0.40% for durables. Thus, the average rate of output growth fell by 26% in nondurables but more than triple that—89%—in durables. Much of this discrepancy in output growth rates can be explained by the greater sensitivity of the durable goods industries to business cycle conditions. As shown in tables 2.6A–2.15A, with the exception of stone, clay, and glass (SIC 32), the average absolute percentage deviation of output from its mid-fifties to 1972 peak-to-peak trend level in durable goods manufacturing is about twice that in nondurable goods manufacturing in both peak-to-peak subintervals. Finally, while each of the ten industries studied experienced a slowdown in output growth after the mid-sixties, the industries most affected were iron and steel (a 282% drop in growth rate); nonferrous metals (a 113% drop in growth rate); nonelectrical machinery (an 80% drop in growth rate); autos (a 46% drop in growth rate). Since these are all capital goods–related industries, a clear picture emerges of the extent to which business cycle conditions in the era after the mid sixties eroded incentives in the business community to expand stocks of plant and equipment.

Tables 2.6A–2.15A also show that the growth rates of production worker productivity were also generally higher in nondurable than durable goods manufacturing in each of the peak-to-peak intervals. The unweighted average of the productivity growth rates in the five nondurable goods industries was 4.26 and 3.23% in the respective peak-to-peak intervals versus 3.05 and 1.87% in the five durable goods industries. Thus, the rate of productivity growth fell by 24% in nondurables and 39% in durables. This large discrepancy in the rate of decline of productivity growth between the two broad classes of manufacturing is consistent with our earlier finding on technical progress and returns-to-scale patterns within the two manufacturing sectors. Thus, productivity in nondurable goods, with its high rates of technical progress and decreasing returns to scale, would be less affected by cyclical slowdowns than durable goods where technical progress has been occurring at a much lower rate and where returns to scale are increasing in three out of the five industries. Finally, as opposed to the pattern in output growth, where all ten industries experienced a decline after the mid-sixties output peak, only eight of the ten industries experienced a decline in the rate of growth in output per production worker hour (see tables 2.6A–2.15A). SIC 26 and 35 managed to maintain their pre–mid-sixties rate of growth. The slowdown in the productivity growth rate was most pronounced in SIC 330 (a drop of 75%) and SIC 333 (a drop of 74%).

Before proceeding to analyze the contribution of business cycle conditions on the slowdown in production worker productivity, it is important to note that a close inspection of the output paths in each of the ten sectors studied shows that the interval between the mid-fifties and mid-sixties peaks contained a long period of sustained output growth, usually between 1961 and 1966.[63] In contrast, the period following the mid-sixties peak is marked by a very depressed and erratic output pattern. In fact, the overall economy experienced a growth recession in 1967 and 1969, and an absolute recession in 1970. As will be discussed, the effects of this concentrated instability played a major role in the productivity slowdown after the mid sixties.

2.4.6 Factor Demand, Factor Productivity, and the Business Cycle

Having described the broad outlines in the productivity of the actual (measured) input of production workers, we now investigate in detail the impact of the business cycle on the efficiency of resource use in general and production worker productivity in particular. To do this we use the estimated parameters for (14) and (19) which, according to the hypothesis maintained in this study, describe the long-run structure of production. The object of our endeavors is to use this information to simulate the least-cost path of the six inputs, production worker productivity, and long-run real total factor costs. These simulations show what the factor use levels, productivity, and total factor cost would have been net of the short-term or lagged adjustment process. By comparing these simulated paths to the actual paths of the respective variables, we obtain a clearer picture of the impact of business cycle conditions, as they are manifested through the lagged adjustment process, on the efficiency of resource use. Our analysis here is based on the discussion in section 2.3 with specific reference to formulas (18), (26), and (29), which are used to simulate the long-run or least-cost path of the variables indicated above, and formulas (25), (28), and (30), which are used to compute the average cycle effects on each of these least-cost measures between the mid-fifties to mid-sixties, and the mid-sixties to 1972 output peaks. The results of our analysis for each industry are summarized in tables 2.6A–2.15A and 2.6B–2.15B.

Actual versus Long-Run Factor Demand and Factor Efficiency

An inspection of the average cycle effects on inputs in tables 2.6A–2.15A and 2.6B–2.15B provides the first bit of evidence that the productivity slowdown is due to cyclical rather than secular causes. These tables clearly show a general pattern of decline in the efficiency of resource use in the post–mid-sixties period relative to the pre–mid-

63. See Mohr (1978); especially Chart 6 for each industry.

sixties period. For example, the average percentage by which the actual levels of inputs exceed their least-cost levels shows a consistent tendency to be larger in the period following the mid-sixties output peak. The only exceptions to this pattern are in SIC 20, SIC 22, and SIC 330.[64] The explanation of the contrast in efficiency of resource use between

64. The failure of the three industries (SIC 20, 22, and 330) to follow the general pattern is due to special circumstances which affected these industries in the pre–mid-sixties period. For two of the sectors—SIC 20 and 22—these circumstances are very similar—namely, both sectors were involved in major programs to modernize, close, and replace outmoded plants and equipment during the period between the mid-fifties and mid-sixties output peaks. (See *Technological Trends in Major American Industries*, BLS Bulletin 1974, Feb. 1966, pp. 114–140, 148–154.) The obsolete state of capital in the food and textile industries is manifested by the following: in 1957 SIC 20 ranked fourth and SIC 22 ranked third among the ten sectors studied in the proportion of their plant stock which was over ten years old in 1957, while ranking second and first, respectively, in the proportion of their equipment stock more than five years old in 1957. The average cycle effects in tables 2.6 and 2.7 for SIC 20 and 22 indicate substantial discrepancies between the least-cost and actual input expansion paths during the pre–mid-sixties adjustment process. Tables 2.6 and 2.7 also indicate that in the post–mid-sixties period, with the long period of adjustment behind, the correspondence between the least-cost and actual input expansion paths has improved markedly. In short, the mid-fifties to mid-sixties average cycle effects on inputs in SIC 20 and 22 are not measures of the impact of short-term output fluctuations on the efficiency of resource use but rather are measures of the degree to which the input mixes of these industries have historically been in disequilibrium vis-à-vis a least-cost mix during this period. Since the magnitude of this disequilibrium and the period of adjustment were so extensive, they dwarf the truer measures of business cycle effects on the efficiency of resource use captured in the interval between the mid-sixties and 1972 output peaks. As a final point, SIC 20 differs from SIC 22 in the fact that, even though it shows substantial divergence on the average between the least-cost and actual levels of the individual inputs in the pre–mid-sixties period, it nevertheless was able to achieve a level of real total factor cost which was on the average close to the least-cost level (see average cycle effect on real total factor cost in tables 2.6 and 2.7). The industry was able to achieve this result because the isoquants for several pairs of inputs on the industry's long-run production surface are flat relative to those of other industries, thereby allowing for a wider range of near least-cost input combinations. For example, a comparison of the "best" model Allen partials for production workers in each industry (see tables 2.3 and 2.4) indicates that the food industry shows a higher ability to substitute nonproduction workers and equipment for production workers than any other industry. Also, it can substitute materials for production workers to a greater extent than any other sector but steel. Finally, it ranks fourth among the ten sectors in its ability to substitute plant for production workers, and ranks first among the nondurable industries in its ability to substitute equipment stocks for increases in the use rate of capital inputs. The evidence from table 2.6 is that the industry took advantage of this flexibility and heavily substituted the other inputs for production workers, with the plant-to-hours ratio showing the least rate of growth between 1956.1 and 1964.2. This flexibility also explains the food industry's ability to operate with an actual input of production-worker hours that

the two subperiods is directly linked to the 1961–66 period of stable output growth referred to in the previous section. That is, it was this prolonged period of stable growth which allowed the respective industries time to adjust their input mixes to the least-cost input combination. By inspecting figures 2.2D–2.11D, one can see that most industries experienced a considerable amount of cyclical influences in 1956, 1958, 1960, 1967, and in the period between 1969.3 and 1972.4. Thus, the decade of the 1960s is bracketed at both ends by periods of considerable instability. Figures 2.2D–2.11D show that in every industry, real total factor cost exceeded long-run real factor cost for the most of the interval spanned by each of these strong business cycle periods. In addition, figures 2.2D–2.11D also show a clear pattern of convergence between the long-run and actual cost paths beginning after the 1960 recession and continuing through 1969.3, with a major interruption being induced by the growth recession period of 1967. The impressions provided by figures 2.2D–2.11D are also supported by an inspection of the average cycle effects on real total factor cost in tables 2.6A–2.15A. In every sector but SIC 22, 26, and 330 the average percentage by which actual cost exceeded long-run cost was larger in the period after the mid-sixties output peak. In summary, the time profiles of the actual and long-run real total factor cost paths give strong evidence that not only was the overall efficiency of resource use (productivity) substantially improved by the stability of output growth between 1961 and

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averaged 12.13% less than the corresponding least-cost levels during the interval between 1956.1 and 1964.2. While the pattern of the average cycle effects in the steel industry (SIC 330) is similar to that found in SIC 20 and SIC 22, there are two very important differences: first, the size of these effects is of a much smaller order of magnitude. In fact, the steel industry operates very close on the average to a least-cost expansion path in both peak-to-peak subintervals as indicated by the size of the average cycle effects of real total factor cost in table 2.12B; secondly, the reason that the pre–mid-sixties average cycle effects on inputs exceed the post–mid-sixties effects is of a quite different origin. The primary reason is that the magnitude and frequency of output fluctuations induced by the business cycles spanning 1956.4–1959.2 and 1960.1–1961.3 as well as the strike activity of 1956 and 1959.3 and .4 were very severe relative to anything experienced by the industry in the interval between 1961.3 and 1972.4 (see fig. 2.8D). Accordingly, figs. 2.8C and D show that, in the relatively stable growth period between 1961.3 and 1965.4, the correspondence between the least-cost and measured variables is much closer on the average than correspondence which exists in the more unstable periods before and after the interval between 1961.3 and 1965.4. Thus, in contrast to sectors 20 and 22, it was business cycle–type conditions which were responsible for the pre–mid-sixties average cycle effect on inputs being larger than the post–mid-sixties average cycle effects. Furthermore, had the output fluctuations between 1956.2 and 1961.3 been less severe, the pattern of average cycle effects on input usage in SIC 330 would have followed the pattern exhibited by the other seven industrial sectors.

1969.3, but also that the period experiencing the major benefit of this stable growth was the period before the mid-sixties output peaks. By way of contrast between the efficiency of resource use in durable and nondurables, tables 2.6A–2.15A show that, except for SIC 20, the industries showing the greatest correspondence between their least-cost and actual expansion paths are all durable goods industries. Except for the interval between 1966.3 and 1972.4 in SIC 333, the average percentage deviation between actual and long-run total factor cost never exceeds 2% in any durable goods industry or in SIC 20, and only occasionally exceeds 1%. On the other hand, the average percentage deviation between the actual and long-run total factor costs in nondurables (excluding SIC 20) exceeds 2% in all but two instances—the 1966.3–1972.4 interval in SIC 26 and the 1955.4–1966.1 interval in SIC 30. Finally, in the context of a unit cost pricing policy, a direct assessment of the inflationary impact of being off the long-run or least-cost expansion path can be gained by comparing the rates at which cost increased on the long-run path to the corresponding rates on the actual path (see tables 2.6A–2.15A). The results of such an analysis indicate that in all ten sectors prices and costs on the least-cost expansion path would have risen at a slower rate than on the actual expansion path in the interval from the mid sixties to 1972. Furthermore, in sectors 22, 26, 28, 30, 330, and 333, the difference is substantial—greater than one percentage point. Conversely, during the mid-fifties to mid-sixties interval, the rate of increase of total factor cost on the long-run expansion path exceeded the rate on the actual expansion path in every industry but SIC 22 and 26. However, only in sectors 30 and 333 was the difference in rates more than one percentage point. We conclude, for the manufacturing sector as a whole, that the concentration of business cycle forces in the post–mid-sixties era caused (1) a reduction in the efficiency of resource use; (2) a higher level of prices and costs; (3) a higher rate of increase in prices and costs.

Actual versus Long-Run Production Worker Productivity

Having concluded that the productivity of the mix of co-operating inputs declined after the mid sixties because of business cycle effects, we now investigate the contribution of the business cycle to the post–mid-sixties decline in the rate of production worker productivity. As indicated earlier, this decline is observed in all sectors but SIC 26 and 35. By contrast, tables 2.6A–2.15A show that on the long-run expansion path, the rate of productivity growth declines in only two sectors—SIC 32 and SIC 371—but in both cases the decline is very small, especially in relation to the decline manifested on the actual expansion path. A more detailed chronology of the movements in production worker productivity is provided by figures 2.2C–2.11C. By comparing the movements in the actual and long-run paths in these figures, we see that, consistent with our earlier findings on the productivity of the overall mix of resources, the level of productivity per production worker hour is higher on the long-run path in both the highly cyclical periods bracketing the period between 1961 and 1969.3. SIC 20, for reasons explained earlier, is the only industry which deviates from this general pattern. Figures 2.2C–2.11C and tables 2.6A–2.15A also show that in general the correspondence between the actual and long-run levels of productivity is much greater in the period before the mid-sixties peak than in the period after, which again highlights the contribution of the 1961–66 stable growth period to least-cost production. As expected from our earlier discussion, SIC 20 and 22 do not follow this pattern. Another pattern made apparent by figures 2.2C–2.11C and generally comfirmed by tables 2.6A–2.15A is that the rate of growth of production worker productivity was generally faster on the long-run than on the actual expansion path throughout the post–mid-sixties period. The only exceptions to this pattern from tables 2.6A–2.15A are SIC 30, 35, and 371. However, figures 2.6C, 2.10C, and 2.11C for these three sectors clearly show that the long-term rate of growth exceeded the actual rate of growth for most of this period. Conversely, tables 2.6A–2.15A show that the rate of growth of productivity was higher in every industry on the actual expansion path in the period between the mid-fifties and mid-sixties output peaks. However, this phenomenon is easily explained by the fact that the level of productivity falls noticeably during a business downturn on the actual expansion path but not on the least-cost path. In fact, for those industries experiencing decreasing returns to scale there is a general tendency for the level of productivity on the least-cost path to move above the trend level. In summary, since the level of productivity on the least-cost productivity path is higher than on the actual path during the heavy business cycle period between 1956 and 1961, the least-squares growth rate of productivity is less on the long-run path during the mid-fifties to mid-sixties interval.

Of course, the reason that the levels of least-cost productivity exceed the corresponding actual levels during periods of heavy business cycle activity is that the least-cost path reflects the instantaneous-adjustment property of the long-run model (14). Thus, when the relative prices of production worker services and/or output change there is an immediate response in the labor input to the new least-cost position. Conversely, actual or observed productivity reflects the lags in adjusting labor input to the new equilibrium. The extent to which the business cycle affects the convergence of the short-run adjustment path to the long-run equilibrium path is clearly highlighted by the average cycle effects in production worker hours in tables 2.6A–2.15A. For example, except for

SIC 20, 22, and 330, the average percentage amount by which the actual level of production worker hours exceeds the desired levels is higher in all sectors in the interval between the mid-sixties and 1972 output peaks.

In summary, the input demand patterns generated by our long-term model, which filters out the effects of the lagged adjustment process to business cycle conditions, results in a dramatically different description of the underlying long-term productivity growth rate than the description obtained by fitting a least-squares trend line to the measured productivity data. For example, the averages of the least-squares growth rates from the actual data on nondurable and durable goods manufacturing in the two peak-to-peak subintervals are 4.26 and 3.23% for nondurables and 3.05 and 1.87 for durables. In strong contrast, the corresponding least-squares growth rates from the data simulated by our long-term model give 2.28 and 3.97% for nondurables, and 1.75 and 2.33% for durables. We conclude that, net of business cycle conditions after 1966, the rate of productivity growth in manufacturing would not have slowed.

2.5 Summary and Conclusions

2.5.1 Structure of Production

In this study we have attempted to model simultaneously the long-term structure and the lagged adjustment or short-term structure of production of ten manufacturing sectors to gauge the effect of cyclical fluctuations on factor demand and factor productivity, particularly production worker productivity. The models specified and tested in each industry were based on a gross output concept of production and assume that firms in these industries attempt to minimize costs in the long run.

The F test (F_3) results shown in section 2.4 strongly indicate that the short-term or interrelated partial-adjustment structure of the model significantly contributes to the explanation of variation in the input cost shares over time. This suggests that the adjustment factor embodied in the quarterly data is strong, and that the quarterly data are especially unsuitable for the comparative static approach implied by a direct modeling of the long-term cost share equations.

It also suggests that specification and/or aggregation bias might be the source of three characteristics found in several annual time series studies in manufacturing: (1) the complementarity found by Berndt and Christensen (1973*c*, 1974) between capital and white collar workers; (2) the complementarity found by Berndt and Wood (1975) and Hudson and Jorgenson (1974) between capital and energy inputs; (3) the presence of serially correlated residuals reported by Berndt and Christensen (1974) and Berndt and Wood (1975).[65] In contrast to these studies, our "best" model results for all ten industries indicate that all inputs are long-term substitutes regardless of their short-term relationships. If such a result is sustained when the materials component, X_6, is disaggregated into energy and nonenergy components, it could have profound implications for forecasting future energy needs. We also obtained substantial improvement in the Durbin-Watson statistics upon those reported in the above studies.

F test (F_2) results presented in section 2.4 also lead us to reject a Cobb-Douglas formulation of the long-term structure of production as a null hypothesis to a homothetic translog formulation. Finally, additional F tests (F_1) shown in section 4 indicated acceptance of a homothetic translog formulation of (12) and (14) as a null hypothesis to a nonhomothetic formulation in all but two sectors—SIC 330 and 371. Based on our assumption that the data in each industry are the result of long-run cost-minimization process, this purely statistical basis for choosing between the homothetic and nonhomothetic versions of (12) and (14) was conditional on the fact that the version so chosen also more closely satisfied the theoretical criteria for a well-behaved translog cost function, namely, strict positivity of the fitted share equations and concavity of the function in input prices. With these theoretical considerations forming the overriding criteria, the homothetic version of (12) and (14) was chosen as the "best" model of the structure of production in eight of the industrial sectors, with the nonhomothetic version being selected as "best" only for sectors 22 and 26.

It is disappointing that the necessary condition for the concavity of the cost function in factor prices, i.e., negatively signed own Allen partials, was not explicitly satisfied by the data in most industries. However, a detailed inspection of the significance of the β_{ij} coefficients for those inputs which have $\sigma_{ii} > 0$ in each industry suggests that the β_{ii} in these cases are not significantly different from zero, and therefore that the affected σ_{ii} are not significantly different from being less than zero. Further refinements in the data may prove fruitful in strengthening the results derived from the basic model in (14). The price deflators for new investment in plant and equipment and the quarterly earnings series for nonproduction workers deserve special consideration. New quarterly data constructed by BEA back to 1958 should significantly improve the investment and rental prices of capital series, but there was not time for these data to be incorporated in the present study.

65. Neither Berndt and Christensen (1973*c*) nor Hudson and Jorgenson (1974) report Durbin-Watson statistics. See note 9 concerning evidence of autocorrelation in the Berndt and Wood study.

The large mid-fifties to mid-sixties disparity between the long-run and actual input expansion paths in industries 20 and 22 suggests that the maintained hypothesis (that there exists a set of constant short-term adjustment coefficients) may be inappropriate for these two sectors in the interval 1956.2 to 1972.4. Available information indicates that industries 20 and 22 were making large-scale adjustments to changing technology and/or output demand during the mid fifties to mid sixties. Thus, it is quite likely that the ensuing mid-sixties to 1972 period was characterized by a substantially different short-term adjustment structure from that which characterized the earlier period. Future research should test for this possibility.

While the foregoing discussion indicates a number of areas for improvement, time and financial considerations precluded further refinement of the statistical conclusions presented in this paper. Considering the amount of constructed data (all variables except X_1, X_2, and P_1 were the product of extensive transformation of raw data sources), the quality of the empirical results generated by the basic model (14) suggests that it is a promising vehicle for the following types of research: (1) discriminating between long-run and short-run movements in factor demand and factor productivity; (2) measuring the impact of business cycle conditions on the efficiency of factor use; (3) estimating the future course of long-run factor demand and factor productivity.

2.5.2 Productivity

The evidence overwhelmingly indicates that the labor productivity slowdown in manufacturing after the mid sixties was the result of cyclical rather than secular forces. Further, had output demand after the mid sixties been less erratic and had firms been able to plan and adjust their input mixes for more stable output growth, the levels as well as the growth rates in costs and prices for manufactured goods would have been noticeably lower than their actual levels during the interval from the mid sixties to 1972.

Moreover, in the light of the dichotomy found in the measures of the rates of growth of technical progress and returns to scale obtained for nondurable and durable goods manufacturing, it is evident that continued productivity growth in nondurable goods sectors depends greatly on developing and implementing cost-saving innovations; otherwise, sustained output growth coupled with decreasing returns to scale will lead to reduced productivity growth. In durable goods manufacturing, on the other hand, the outlook for future improvement in the rate of labor productivity growth depends more on economies of scale than on technological progress; therefore, a prolonged period of sustained output growth should increase the rate of productivity growth.

2.5.3 Capital Shortages

The capital shortages problem was discussed only peripherally in this study. Our results, while tentative, are suggestive. The five sectors showing the strongest evidence of a capital shortage include paper, chemicals, rubber and plastics, iron and steel, and nonferrous metals—industries which process basic materials for the rest of the manufacturing. Bottlenecks in the supply of these materials are often considered contributory to the very high rates of inflation in 1973–1975 shown by the three major price indices—the wholesale price index, the consumer price index, and the GNP deflator.

In ascertaining whether a shortage of plant and/or equipment existed in an industry, it is generally necessary to compare the least-cost and actual paths of plant and equipment demand prior to 1969 when the rate of growth in GNP began to fall (in the fourth quarter of 1969, the level of GNP also fell). In particular, the contraction phase of the 1970 recession began in 1969.3, and the incomplete 1971–72 expansion began in 1970.4. An inspection of figures 2.2A–2.11A shows that during the 1969–72 period the actual levels of plant and equipment were above their least-cost levels, for the most part. However, when one compares the least-cost and actual paths prior to the second half of 1969, and in particular for the relatively stable growth period between 1961 and 1969.2, a clearer picture of developing capital shortages emerges.

Simulations which use 1973 data and use the "best" model structure in each industry should prove useful in discovering whether and where bottlenecks were occurring in the 1971–73 expansion. For a more contemporary assessment of capital needs, "best" model simulations based on alternative, assumed rates of output growth from 1968.4 through 1976.4 would be very useful in analyzing whether the currently available stock of capital is sufficient to support the present expansion in a least-cost manner and for measuring the dollar amount of any shortfall.

Data Appendix

Data Sources and Methods of Construction

One of the major tasks of this study was the collection and construction of a quarterly establishment-based data bank including gross output, production worker hours, nonproduction worker employment, plant, equipment, capacity utilization, materials including energy, and prices for the respective inputs and output for each industry.[66] All data are

66. Because of space constraints, the discussion here is of necessity brief. A more complete discussion is contained in the Data Appendix of Mohr (1978).

seasonally adjusted, benchmarked to 1967 prices, standardized to millions of units, e.g. dollars or hours, expressed in quarterly rates, and available from 1953.1 to 1972.4. The development and use of quarterly constant-dollar, establishment-based series for plant and equipment is a unique feature of this study. The data used in this study are generally consistent on both a 1957 and a 1967 standard industrial classification.

2.A.1 Gross Output (Y)

Gross output for each industry is defined here as ($A1$) $Y_t = S_t + \Delta I_t$, where $S_t =$ the current dollar value of shipments in period t, $\Delta I_t = I_t - I_{t-1} =$ the current dollar value of the change in the ending inventory of finished product in period t.

The monthly current dollar shipments and inventory data are from the Bureau of the Census. Quarterly levels were developed for each of these components in order to derive a quarterly output measure. Published shipments data for all industries except 330 and 333 are available beginning in 1953; for the latter sectors, unpublished census data are available from 1958 forward. From 1953.1 through 1957.4[67] the current dollar value of shipments for 330 and 333[68] was constructed according to Mohr (1978).

Monthly finished goods inventories are available from published census data for the period 1953 to 1972 for industry sectors 28, 30, and 32. Unpublished monthly data obtained from the Bureau of the Census were used for sectors 20, 22, 26, and 35 for the period 1958.1 to 1972.4. These monthly data were averaged to obtain a measure of average finished goods inventory levels each quarter. A combination of monthly and annual census data sources was used to construct the 1953.1–1957.4 measures of average quarterly finished goods inventory for sectors 20, 22, 26, 35, and 36, as well as the 1953.1–1972.4 measures for sectors 330, 333, and 371. The methodology is described in Mohr (1978).

2.A.2 Labor Inputs

Production Worker Hours (X_1)

The man-hours and employment used to construct total quarterly hours for production workers come from the Bureau of Labor Statistics (BLS) 790 monthly survey and are published in various issues of *Employment and Earnings.* The average weekly hours per production worker in month i (AWH_i) is equal to the sum of average weekly straight-time hours ($AWHRS_i$) plus average weekly overtime hours ($AWHO_i$) in month i. The AWH_i for each month were multiplied by

67. 1953.1 stands for the first quarter of 1953.
68. See note 5 for the definitions of sectors 330 and 333.

monthly employment (E_i) times 13 to obtain total hours paid per month at quarterly rates (TQH_i). Average employment per quarter is defined as $E_p = \sum E_i/3$. Average quarterly hours per production worker at quarterly rates is defined as $AQH = (HRS_p + HRO_p) = \sum TQH_i/3E_p$. Accordingly, the total quarterly input of production worker services is defined as (A2) $X_1 = E_p\,(HRS_p + HRO_p) = \sum_{i=1}^{3} TQH_i/3$.

Nonproduction Worker Employment (X_2)

An estimate of average quarterly employment of nonproduction workers was derived from the monthly BLS 790 data.

2.A.3 Constructing Quarterly Capital Stock (X_3 and X_4)

Nature of Problem

The theoretical model described in section 2.2 calls for a measure of the individual stocks of plant and equipment for each of the ten industries in note 5. These measures must be establishment-based in order to be consistent with the other data sources. The problem is that the only establishment-based investment series available at the level of detail required is the annual Faucett (1971) data. However, there is a detailed, company-based, quarterly investment series available from the Bureau of Economic Analysis (BEA). Our objective here is to give an outline of how the BEA data were used to move the Faucett data so as to construct constant (1958) dollar investment series for plant and for equipment, and finally to construct the constant (1958) dollar stocks of both.[69]

The Basic Steps

1. Aggregate the three-digit, historical dollar Faucett investment series for plant and for equipment to the desired level as per note 5.
2. Combine the plant and equipment series to form a total historical dollar investment series.
3. Using regression analysis, develop a correspondence between the series in (2) and the annual company-based investment series from BEA.
4. Use the parameter estimates from (3) and the quarterly BEA data to estimate quarterly Faucett total investment expenditures in historical dollars.
5. Use the ratio of plant expenditures to total investment expenditures from the annual Faucett data to separate the quarterly total expenditure estimates into quarterly plant and equipment expenditures.

69. A complete description of the methodology and its rationale along with the regression results is provided in Mohr (1978).

6. Using regression analysis, develop a correspondence between the annual Faucett plant deflator and the annual nonresidential structures deflator from BEA.

7. Use the parameter estimates from (6) and the quarterly nonresidential structures deflator to construct a quarterly Faucett deflator.

8. Construct a set of weights, appropriate to the levels of aggregation in note 5, which can be used to aggregate the Faucett deflators for equipment for the component industries within each of the ten sectors in note 5.

9. Using regression analysis, develop a correspondence between the ten equipment deflators constructed in (8) and the annual producers' durable equipment deflator from BEA.

10. Use the parameter estimates from (9) and the quarterly producers' durable equipment deflator to construct a quarterly Faucett equipment deflator.

11. For each industry, deflate the plant investment series developed in (5) by the plant deflator from (9).

12. For each industry, deflate the equipment investment series developed in (5) by the equipment deflator from (10).

13. Run the results of (11) and (12) through the Faucett STOKS[67] program to generate the quarterly stocks of plant and equipment for each industry.

Constant-Dollar Quarterly Stocks of Plant and Equipment

At this point in the discussion, we have ten quarterly constant (1958) dollar plant investment series and ten quarterly constant (1958) dollar equipment investment series. The twenty series were run through the Faucett STOKS program to develop quarterly stocks of equipment and plant for each industry. For each industry it was assumed that the limit on the service life distribution for the discard function was ±50% of the mean service life. For the decay function, beta decay[71] of .9 was assumed for plant and .5 for equipment. Thus, if a capital good has an expected life of twenty years, it will not have a 50% loss in efficiency

70. See Lineburg (1974).

71. In simple terms beta decay is a mirror image of geometric or accelerated decay patterns often assumed in the literature. (For a full discussion, see Faucett 1973, Appendix B.) It includes one-hoss shay and straight-line depreciation as limiting distributions. The capital stock estimates resulting from the β parameters assumed in the text above should conform closely to capital efficiency estimates used by Denison ("Some Major Issues in Productivity Analysis: An Examination of Estimates by Jorgenson and Griliches," *Survey of Capital Business*, pt. 2, p. 14) in which he weights gross capital stock by 3 and net capital stock based on straight-line depreciation by 1 to "obtain a series that might reasonably approximate the decline in the ability of capital goods to contribute to productivity as they grow older."

until it is between 18 and 19 years old if beta = .9, and between 13 and 14 years if beta = .5. Beta = .9 was chosen for plant on Coen's (1975) finding that structures suffer no efficiency loss over their service lives. A beta of .5 was chosen for equipment partly to offset the upward scaling of expected equipment lives that results when Faucett reconciles his historical dollars stock series to the book values of assets reported by the Bureau of the Census.[72]

2.A.4 Capacity Utilization (X_5)

The Wharton series was used for all sectors but 330 and 333. Since Wharton produces a capacity utilization measure only at the SIC 33 level, individual indices for sectors 330 and 333 had to be constructed using peak-to-peak interpolation.

2.A.5 Materials (X_6)

Because quarterly data were not available, it was necessary not only to treat materials and energy as a composite input but also to construct a quarterly series on this composite input. The raw data used in this construction came from the annual gross product originating (GPO) data supplied by BEA. The steps involved in constructing the quarterly series are described in Mohr (1978).

2.A.6 Gross Output Deflator

For each of the ten sectors a gross output deflator was constructed according to the methodology of Eckstein and Wyss (1972). The necessary formula to construct I-O sector level deflators and then SIC level deflators from raw WPI data were made available to the author by Charles Guy.[73]

2.A.7 Average Hourly Wage Rate (P_1)

The price per hour of production worker input comes from the BLS 790 establishment data. P_1 represents a weighted average of the straight-time hourly wage (W_8) and the overtime hourly wage rate, assumed by BLS to be 1.5 W_8. The weights are the proportions of overtime (HRO) and straight-time hours (HRS) in average quarterly hours paid for per production worker (AQH). Thus,

$$P_1 = [(\text{HRS}/\text{AQH})W_8 + (\text{HRO}/\text{AQH})1.5\,W_8]. \tag{A3}$$

72. See Faucett (1971), pp. 32–34, 43ff. The service lives scaled upward by Faucett fall between the Bulletin F and the 1962 IRS guidelines. Coen's results show that these prescaled lives should be close to his revealed service lives for sectors 20, 22, 26, 28, and 32, while being lower than the revealed service life in sector 30 but higher in sectors 35, 33, and 371.

73. These formulas were used by Al-Samarrie, Kraft, and Roberts (1975).

2.A.8 Average Quarterly Earnings per Nonproduction Worker (P_2)

This is another series where quarterly data are nonexistent. Annual data are available from census data. The problem we face here is the same one we faced in relation to the materials-output ration, and the procedure used to construct the quarterly earnings is similar to that detailed in points (2) and (3) under section E of the Data Appendix in Mohr (1978).

2.A.9 Capital Prices (P_3 and P_4)

The implicit rental prices of the capital stocks for each sector are computed according to a modified version of Hall and Jorgenson (1967) as follows:

$$P_{3t} = [q_{e,t-1}\, r_t - (q_{et} - q_{e,t-1}) + q_{et}\, \delta_e (1+Cu-\bar{C}u)^2] \times \left[\frac{1 - u_t Z_{et} - k_t + v_t}{1 - u_t}\right], \tag{A4}$$

$$P_{4t} = [q_{s,t-1}\, r_t - (q_{st} - q_{s,t-1}) + q_{st}\, \delta_s (1+Cu-\bar{C}u)^2] \times \left[\frac{1 - u_t Z_{st}}{1 - u_t}\right], \tag{A5}$$

where P_{3t} and P_{4t} are the implicit rental prices of equipment, e, and structures, s, respectively. Z_{et} and Z_{st} are the present values of depreciation deductions on a dollar's investment in e and s over the lifetimes, A_e and A_s, of the assets allowable for tax purposes.

Z_e and Z_s were both computed by sum-of-the-years digits. A_e was constructed as the weighted average of the ages of the sixteen equipment types purchased by each of the ten sectors. The weights used are described in Mohr (1978). The sixteen ages come from the Faucett data.

A_s was constructed directly from the two ages and two weights found in the Faucett data for each sector; u_t is the effective corporate profits tax rate; v_t is $k_t \cdot u_t \cdot Z_{et}$ for 1962–63 and zero for all other years, and is used to account for the fact that in 1962 and 1963 the investment tax credit was deducted from the value of an asset before computing depreciation; k_t is the effective rate of the investment tax credit, q_{et} and q_{st} are the constructed quarterly price deflators for new e or s (see Mohr 1978); r equals the nominal long-term market rate of interest and is assumed to be equal to Moody's AAA corporate bond rate. The terms $-(q_{et} - q_{e,t-1})$ and $-(q_{st} - q_{s,t-1})$ are measures of capital loss on the value of an asset;[70] δ_e and δ_s represent the average or expected rate

74. In a recent article Berndt (1976) tested several alternative forms for (A4) and (A5) in the context of estimating the elasticity of substitution from six alternative functional forms suggested by a CES production function. As a result of this, Berndt discovered that the Durbin-Watson statistic increased abruptly

of loss in efficiency units in e and s due to physical obsolescence and discards. An estimate of δ_e and δ_s was obtained from a regression suggested by the perpetual inventory formula, namely,

$$K_t - K_{t-1} = I_t - \delta K_{t-1}, \quad \text{(A6)}$$

where K_t = net stock in period t and I_t = gross investment in period t. For each industry and for plant and equipment separately, a regression equation corresponding to (A6) was estimated for the sample period 1950.1–1972.4. The net stock and gross investment data used were the quarterly series constructed according to the discussion in section 2.A.3. The resulting estimates for δ_e and δ_s expressed at an annual rate were used in formulas (A4) and (A5). C_u is the Wharton series for capacity utilization and C_u is the long-run or average postwar rate of utilization from 1947.1 to 1974.1.

The terms $q_e \cdot \delta_e\ (1 + C_u - C_{\bar{u}})^2$ and $q_s \cdot \delta_s\ (1 + C_u - C_{\bar{u}})^2$ define the replacement cost of capital and represent a significant modification of Hall and Jorgenson (1967). These formulas imply that entrepreneurs alter their rate of replacement expectations in a quadratic manner as the utilization rate varies around its long-run rate; that is, the marginal replacement cost is an increasing function of the utilization rate. When the actual and long-run rates of utilization are equal, the replacement cost simplifies to $q_e \cdot \delta_e$ and $q_s \cdot \delta_s$, that is, to a cost determined by the expected or average rate of replacement, δ_e and δ_s. Thus, there is an internal consistency between the definitions given to δ_e and δ_s and to the manner in which entrepreneurs are assumed to calculate the impact of intensifying the use of capital on replacement costs. Alternatively, using $q_e \cdot \delta_e \cdot C_u$ as a representation of a replacement cost function would imply that δ_e represents an upper limit on the rate of replacement which would be inconsistent with the way we have measured and previously defined δ_e.

Finally, while our interpolation method eliminated fourth to first quarter jumps in the levels of q_e and q_s, it did not eliminate such jumps in the movements of these series. Consequently, it was discovered that the inclusion of the terms $-(q_{et} - q_{et-1})$ and $-(q_{st} - q_{st-1})$ in the formulas for P_3 and P_4 contained a noticeable first to fourth quarter seasonal pattern. Therefore, a four-quarter moving average was used to smooth each of these price series before using them in the model.

2.A.10 Shadow Price of Capital Utilization (P_5)

In section 2.2.3 it was shown that the properly specified notion of total factor cost, RTFC, requires a measure of the shadow price of in-

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when real rather than nominal rates of return are employed in formulas (A4) and (A5), i.e., when the terms $(q_{et} - q_{et-1})$ and $(q_{st} - q_{st-1})$ are included.

tensifying the use rate of capital. From the logic of section 2.2.3 and the definitions of the rental prices of equipment and structures it follows that the shadow price of capital utilization is defined as

$$P_5 = 2\{X_3 - q_{e,t} \cdot \delta_e \cdot [(1 - u_t Z_{et} - K_t + v_t)/1 - u_t] + X_4 \cdot q_{s,t} \cdot \delta_s \cdot [(1 - u_t Z_{st})/1 - u_t]\} \times (1 - C_u - C_{\bar{u}}). \quad \text{(A7)}$$

2.A.11 Price of Materials (P_6)

For each of the ten sectors a composite materials deflator was constructed according to Eckstein and Wyss (1972). The formulas used here, like the formulas used to construct the gross output deflator, were provided by Charles Guy.

Tables and Charts Appendix

Table 2.6A: SIC 20 Comparison of Actual and Long-Run Production Worker Hours, Cost Shares, Productivity, and Total Real Factor Costs

Peak to Peak	Production Worker								
	Hours		Cost Shares		Productivity		Real Factor Costs		
	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Output
	Annual Rate of Change								
1956.1 1972.3	−0.45	−1.76	−1.28	−2.58	3.10	4.41	4.89	4.88	2.65
1956.1 1964.2	−1.40	−1.09	−0.71	−1.22	4.31	4.00	3.04	3.86	2.91
1964.2 1972.3	0.04	−1.63	−2.00	−3.38	2.43	4.11	7.44	7.14	2.47
	Average Cycle Effect as a Percentage of Long-Run Levels								
1956.1 1972.3	− 6.13		− 6.31		7.25		0.20		0.16
1956.1 1964.2	−12.13		−11.85		14.02		− 0.29		0.16
1964.2 1972.3	− 0.20		− 0.75		0.55		0.57		0.17

Table 2.6B: SIC 20 Other Inputs: Actual and Long-Run Comparisons

Peak to Peak	Nonproduction Worker Employment		Equipment		Plant		Capacity Utilization		Materials	
	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run
	Annual Rate of Change									
1956.1 1972.3	0.38	3.19	3.23	5.64	1.25	2.01	0.49	0.12	3.40	2.92
1956.1 1964.2	1.29	5.77	2.34	5.79	0.56	2.36	−0.19	0.72	2.87	2.99
1964.2 1972.3	−0.69	0.18	3.85	4.67	1.87	1.72	1.01	0.14	3.20	2.91
	Average Cycle Effect as a Percentage of Long-Run Levels									
1956.1 1972.3	21.13		16.64		4.96		−1.39		−3.28	
1956.1 1964.2	35.43		28.70		7.94		−3.50		−5.79	
1964.2 1972.3	6.30		4.17		1.90		0.64		−0.83	

Table 2.7A: SIC 22 Comparison of Actual and Long-Run Production Worker Hours, Cost Shares, Productivity, and Total Real Factor Costs

	Production Worker								
	Hours		Cost Shares		Productivity		Real Factor Costs		
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Output
	Annual Rate of Change								
1956.1 1972.3	0.23	2.77	−1.48	1.00	4.44	1.89	5.67	5.74	4.66
1956.1 1966.3	−0.36	4.48	−1.24	3.69	4.77	−0.06	3.76	3.66	4.42
1966.3 1972.3	−0.35	−0.50	−1.51	0.68	3.61	3.76	6.71	4.37	3.26
	Average Cycle Effect as a Percentage of Long-Run Levels								
1956.1 1972.3	15.69		11.61		−11.49		4.04		0.45
1956.1 1966.3	22.42		17.32		−16.12		4.96		0.50
1966.3 1972.3	3.59		1.59		− 3.17		2.15		0.37

Table 2.7B: SIC 22 Other Inputs: Actual and Long-Run Comparisons

	Nonproduction Worker Employment		Equipment		Plant		Capacity Utilization		Materials	
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run
	Annual Rate of Change									
1956.1 1972.3	2.45	2.14	2.56	3.26	1.43	3.44	1.23	1.35	5.63	4.49
1956.1 1966.3	1.46	0.63	0.91	2.03	−0.54	3.42	1.63	1.61	5.89	3.48
1966.3 1972.3	2.19	−0.37	3.96	2.29	3.23	1.77	−1.35	−3.43	5.16	1.46
	Average Cycle Effect as a Percentage of Long-Run Levels									
1956.1 1972.3	2.54		6.82		11.37		3.69		−0.20	
1956.1 1966.3	2.77		9.10		15.93		4.68		−1.53	
1966.3 1972.3	1.82		2.51		3.15		1.68		1.80	

Table 2.8A: SIC 26 Comparison of Actual and Long-Run Production Worker Hours, Cost Shares, Productivity, and Total Real Factor Costs

	Production Worker								
	Hours		Cost Shares		Productivity		Real Factor Costs		
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Output
	Annual Rate of Change								
1956.1 1972.4	1.17	1.13	−2.40	−2.45	3.25	3.29	7.75	7.75	4.42
1956.1 1966.3	1.19	1.40	−1.34	−1.05	3.15	2.94	6.01	5.93	4.35
1966.3 1972.4	−0.24	−1.32	−2.86	−2.55	3.17	4.25	8.78	7.40	2.93
	Average Cycle Effect as a Percentage of Long-Run Levels								
1956.1 1972.4	3.07		0.24		−2.74		2.83		0.39
1956.1 1966.3	2.85		−0.40		−2.47		3.25		0.40
1966.3 1972.4	3.09		1.26		−2.86		1.86		0.39

Table 2.8B: SIC 26 Other Inputs: Actual and Long-Run Comparisons

	Nonproduction Worker Employment		Equipment		Plant		Capacity Utilization		Materials	
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run
	Annual Rate of Change									
1956.1 1972.4	2.98	2.57	5.50	5.05	3.72	3.45	1.37	1.54	3.31	3.59
1956.1 1966.3	3.55	2.78	5.24	4.64	3.43	3.08	1.39	1.70	3.38	3.33
1966.3 1972.4	0.91	−0.33	4.63	2.43	3.43	0.94	0.26	−0.87	1.91	1.24
	Average Cycle Effect as a Percentage of Long-Run Levels									
1956.1 1972.4	0.66		0.31		0.42		3.72		4.74	
1956.1 1966.3	0.02		−0.51		0.01		4.39		6.29	
1966.3 1972.4	1.50		1.26		0.67		2.32		2.02	

Table 2.9A: SIC 28 Comparison of Actual and Long-Run Production Worker Hours, Cost Shares, Productivity, and Total Real Factor Costs

	Production Worker								
	Hours		Cost Shares		Productivity		Real Factor Costs		
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Output
	Annual Rate of Change								
1956.2 1972.4	1.46	1.61	−2.44	−2.31	4.79	4.64	7.90	7.92	6.25
1956.2 1966.1	0.93	2.93	−0.11	0.92	5.42	3.41	4.48	5.45	6.34
1966.1 1972.4	−0.06	−1.15	−3.93	−3.66	5.07	6.16	9.71	8.35	5.01
	Average Cycle Effect as a Percentage of Long-Run Levels								
1956.2 1972.4	8.94		3.67		−7.71		5.01		0.37
1956.2 1966.1	7.85		3.11		−6.67		4.48		0.40
1966.1 1972.4	10.06		4.40		−8.81		5.41		0.35

Table 2.9B: SIC 28 Other Inputs: Actual and Long-Run Comparisons

	Nonproduction Worker Employment		Equipment		Plant		Utilization Capacity		Materials	
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run
	Annual Rate of Change									
1956.2 1972.4	3.10	2.56	5.27	4.75	3.57	2.92	1.15	2.07	3.97	4.10
1956.2 1966.1	2.85	2.33	4.22	3.89	3.06	1.95	−0.67	2.98	4.17	4.77
1966.1 1972.4	1.55	0.69	5.20	3.54	3.54	1.57	0.96	−0.63	1.92	1.32
	Average Cycle Effect as a Percentage of Long-Run Levels									
1956.2 1972.4	2.57		3.11		0.50		11.41		2.83	
1956.2 1966.1	0.77		1.48		−0.85		12.83		2.95	
1966.1 1972.4	4.88		5.09		2.08		8.83		2.43	

Table 2.10A: SIC 30 Comparison of Actual and Long-Run Production Worker Hours, Cost Shares, Productivity, and Total Real Factor Costs

	Production Worker								
	Hours		Cost Shares		Productivity		Real Factor Costs		
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Output
	Annual Rate of Change								
1955.4 1972.4	3.89	4.12	−1.56	−1.33	2.41	2.19	8.70	8.70	6.31
1955.4 1966.1	3.00	5.54	−0.20	0.95	3.63	1.09	5.89	7.28	6.63
1966.1 1972.4	2.61	2.88	−2.40	−0.37	1.86	1.59	10.05	8.29	4.47
	Average Cycle Effect as a Percentage of Long-Run Levels								
1955.4 1972.4	3.96		1.81		−3.06		2.06		0.59
1955.4 1966.1	2.18		1.02		−1.25		1.02		0.58
1966.1 1972.4	6.44		3.13		−5.62		3.32		0.62

Table 2.10B: SIC 30 Other Inputs: Actual and Long-Run Comparisons

	Nonproduction Worker Employment		Equipment		Plant		Capacity Utilization		Materials	
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run
	Annual Rate of Change									
1955.4 1972.4	4.03	3.82	6.64	6.46	5.25	6.35	1.15	1.46	6.57	6.51
1955.4 1966.1	3.22	4.30	5.31	6.49	3.79	7.81	−0.24	2.54	5.82	6.26
1966.1 1972.4	3.18	0.69	7.59	4.75	7.21	2.94	−0.39	−1.72	5.90	4.42
	Average Cycle Effect as a Percentage of Long-Run Levels									
1955.4 1972.4	1.08		0.75		0.92		3.26		1.97	
1955.4 1966.1	−0.41		−0.65		0.57		2.16		1.61	
1966.1 1972.4	2.93		2.45		0.96		4.55		2.35	

Table 2.11A: SIC 32 Comparison of Actual and Long-Run Production Worker Hours, Cost Shares, Productivity, and Total Real Factor Costs

	Production Worker									
	Hours		Cost Shares		Productivity		Real Factor Costs			
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Aitual	Long-Run	Actual	Long-Run
	Annual Rate of Change									
1955.4 1972.4	0.65	0.77	−1.36	−1.20	2.38	2.26	5.97	5.93		3.02
1955.4 1966.1	0.41	1.06	−1.40	−1.02	2.91	2.25	4.93	5.20		3.31
1966.1 1972.4	0.16	0.07	−1.01	−0.35	1.95	2.05	7.47	6.71		2.11
	Average Cycle Effect as a Percentage of Long-Run Levels									
1955.4 1972.4	2.25		0.74		−1.91		1.53		0.54	
1955.4 1966.1	2.07		0.90		−1.76		1.21		0.58	
1966.1 1972.4	2.23		0.52		−1.84		1.70		0.51	

Table 2.11B: SIC 32 Other Inputs: Actual and Long-Run Comparisons

	Nonproduction Worker Employment		Equipment		Plant		Capacity Utilization		Materials	
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Aitual	Long-Run	Actual	Long-Run
	Annual Rate of Change									
1955.4 1972.4	1.88	1.49	3.78	3.16	2.74	2.03	0.05	0.35	2.94	3.38
1955.4 1966.1	2.43	1.69	4.10	2.83	3.72	2.08	0.19	1.31	2.62	4.23
1966.1 1972.4	0.73	0.61	3.03	2.52	1.42	1.03	−0.89	−1.37	3.28	1.33
	Average Cycle Effect as a Percentage of Long-Run Levels									
1955.4 1972.4	2.15		1.75		2.51		1.76		0.97	
1955.4 1966.1	1.06		0.34		1.59		2.06		1.90	
1966.1 1972.4	3.46		3.47		3.48		1.06		−0.75	

Table 2.12A: SIC 330 Comparison of Actual and Long-Run Production Worker Hours, Cost Shares, Productivity, and Total Real Factor Costs

	Production Worker								
	Hours		Cost Shares		Productivity		Real Factor Costs		
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Output
	Annual Rate of Change								
1956.2 1972.4	0.0	0.01	−1.70	−1.79	1.58	1.56	5.27	5.36	1.53
1956.2 1965.3	−0.41	−0.32	0.25	−0.02	1.47	1.38	2.44	2.78	1.06
1965.3 1972.4	−2.32	−3.43	−2.62	−2.41	0.39	1.50	6.04	4.72	−1.03
	Average Cycle Effect as a Percentage of Long-Run Levels								
1956.2 1972.4	0.34		−0.06		−0.02		0.42		1.52
1956.2 1965.3	0.83		−0.25		−0.44		1.11		1.87
1965.3 1972.4	−0.36		0.36		0.56		−0.68		1.09

Table 2.12B: SIC 330 Other Inputs: Actual and Long-Run Comparisons

	Nonproduction Worker Employment		Equipment		Plant		Capacity Utilization		Materials	
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run
	Annual Rate of Change									
1956.2 1972.4	0.76	0.30	3.54	2.78	−0.93	−0.98	1.38	1.46	1.69	2.69
1956.2 1965.3	−0.20	−0.19	2.30	1.45	−1.29	−0.73	1.59	1.62	0.74	2.17
1965.3 1972.4	−0.13	−2.40	3.94	0.95	−0.52	−3.03	−1.73	−2.36	−0.22	0.44
	Average Cycle Effect as a Percentage of Long-Run Levels									
1956.2 1972.4	−0.76		−1.48		−0.11		0.64		2.44	
1956.2 1965.3	−1.92		−3.05		0.23		1.30		5.90	
1965.3 1972.4	0.41		0.18		−0.99		−0.27		−2.08	

Table 2.13A: SIC 333 Comparison of Actual and Long-Run Production Worker Hours, Cost Shares, Productivity, and Total Real Factor Costs

	Production Worker								
	Hours		Cost Shares		Productivity		Real Factor Costs		
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Output
Annual Rate of Change									
1956.1 1972.4	1.49	1.77	−2.11	−1.84	2.31	2.03	7.36	7.37	3.80
1956.1 1966.3	1.30	4.10	−0.93	0.11	3.76	0.96	5.38	7.15	5.06
1966.3 1972.4	−1.62	−3.52	−3.62	−2.56	0.97	2.87	7.77	4.81	−0.65
Average Cycle Effect as a Percentage of Long-Run Levels									
1956.1 1972.4	2.17		1.59		−1.32		0.50		0.80
1956.1 1966.3	0.71		1.40		0.28		−0.84		0.67
1966.3 1972.4	4.26		1.99		−3.67		2.34		1.08

Table 2.13B: SIC 333 Other Inputs: Actual and Long-Run Comparisons

	Nonproduction Worker Employment		Equipment		Plant		Capacity Utilization		Materials	
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run
Annual Rate of Change										
1956.1 1972.4	1.86	2.25	4.69	4.94	3.86	4.32	1.25	1.53	4.93	4.59
1956.1 1966.3	0.78	4.11	2.91	5.59	3.52	6.35	1.22	3.82	4.92	5.60
1966.3 1972.4	0.23	−2.84	6.50	0.89	4.39	−1.23	−0.26	−4.28	1.23	0.14
Average Cycle Effect as a Percentage of Long-Run Levels										
1956.1 1972.4	0.71		−1.52		−2.37		0.94		1.35	
1956.1 1966.3	−0.55		−2.22		−3.37		0.17		−0.68	
1966.3 1972.4	2.17		−1.20		−1.60		1.74		4.64	

Table 2.14A: SIC 35 Comparison of Actual and Long-Run Production Worker Hours, Cost Shares, Productivity, and Total Real Factor Costs

	Production Worker								
	Hours		Cost Shares		Productivity		Real Factor Costs		
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Output
Annual Rate of Change									
1956.4 1972.4	2.14	2.18	−2.35	−2.30	2.99	2.95	8.41	8.40	5.14
1956.4 1966.4	2.75	4.19	−0.67	0.22	3.07	1.62	6.62	7.17	5.81
1966.4 1972.4	−3.00	−2.78	−3.15	−2.76	3.16	2.94	5.87	5.69	0.16
Average Cycle Effect as a Percentage of Long-Run Levels									
1956.4 1972.4	1.77		1.98		−1.45		−0.26		0.86
1956.4 1966.4	0.32		1.16		0.04		−0.91		0.84
1966.4 1972.4	4.12		3.35		−3.86		0.73		0.94

Table 2.14B: SIC 35 Other Inputs: Actual and Long-Run Comparisons

	Nonproduction Worker Employment		Equipment		Plant		Capacity Utilization		Materials	
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run
Annual Rate of Change										
1956.4 1972.4	3.40	3.29	6.57	6.48	4.01	3.65	1.56	1.69	5.61	5.61
1956.4 1966.4	2.75	3.58	4.57	6.09	3.31	3.30	2.17	2.80	6.26	5.88
1966.4 1972.4	1.14	3.12	7.06	9.24	3.96	5.05	−3.61	−5.37	0.13	−1.49
Average Cycle Effect as a Percentage of Long-Run Levels										
1956.4 1972.4	0.99		1.66		−0.99		0.17		−1.78	
1956.4 1966.4	9.89		−0.87		−2.78		0.38		−1.04	
1966.4 1972.4	4.29		6.26		2.14		−0.54		−3.28	

Table 2.15A: SIC 371 Comparison of Actual and Long-Run Production Worker Hours, Cost Shares, Productivity, and Total Real Factor Costs

	Production Worker								
	Hours		Cost Shares		Productivity		Real Factor Costs		
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Output
	Annual Rate of Change								
1955.2 1972.4	1.25	1.46	0.14	0.48	2.96	2.74	5.52	5.39	4.21
1955.2 1965.4	0.24	1.73	−0.33	1.03	4.04	2.55	4.41	4.54	4.28
1965.4 1972.4	−0.56	0.06	0.45	1.16	2.89	2.27	5.40	5.30	2.33
	Average Cycle Effect as a Percentage of Long-Run Levels								
1955.2 1972.4	1.79		0.99		−1.30		0.79		1.27
1955.2 1965.4	0.93		0.94		−0.45		0.01		1.49
1965.4 1972.4	2.77		0.95		−2.27		1.75		1.01

Table 2.15B: SIC 371 Other Inputs: Actual and Long-Run Comparisons

	Nonproduction Worker Employment		Equipment		Plant		Capacity Utilization		Materials	
Peak to Peak	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run	Actual	Long-Run
	Annual Rate of Change									
1955.2 1972.4	1.39	1.25	1.97	1.13	2.94	2.26	1.20	1.04	3.06	3.16
1955.2 1965.4	0.38	1.51	0.93	0.55	2.08	2.29	1.95	2.05	3.15	3.11
1965.4 1972.4	0.33	0.21	1.35	0.14	1.87	1.07	−1.58	−0.65	1.18	1.06
	Average Cycle Effect as a Percentage of Long-Run Levels									
1955.2 1972.4	1.09		−0.70		0.77		0.52		1.21	
1955.2 1965.4	−1.06		−4.12		−2.03		−0.80		1.81	
1965.4 1972.4	3.85		3.92		4.49		2.23		0.32	

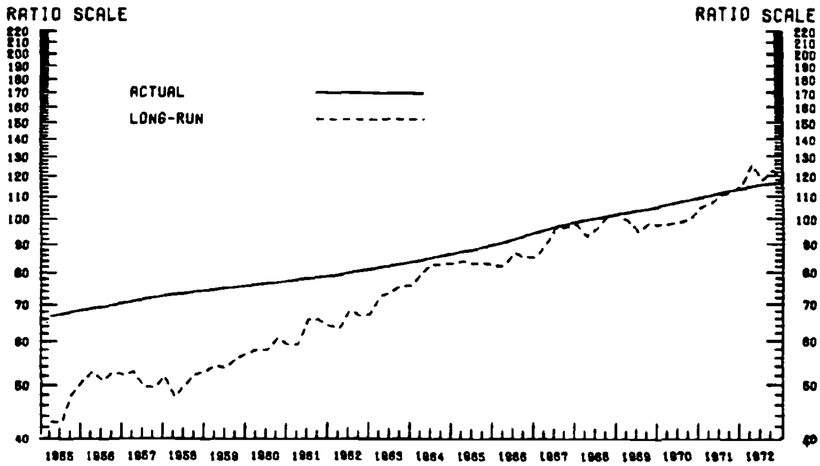

Fig. 2.2A Equipment (hundreds of millions of dollars), Actual versus Long-Run: SIC 20

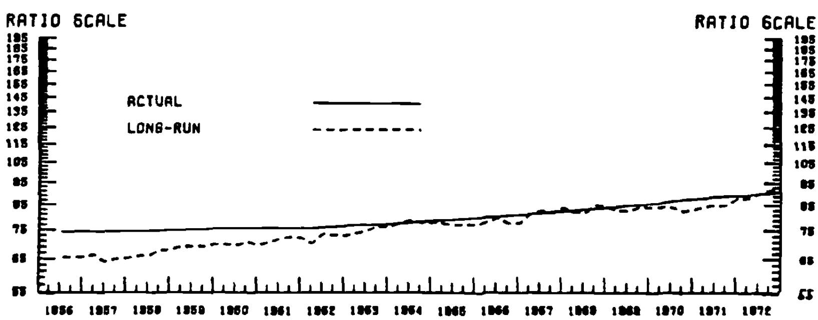

Fig. 2.2B Plant (hundreds of millions of dollars), Actual versus Long-Run: SIC 20

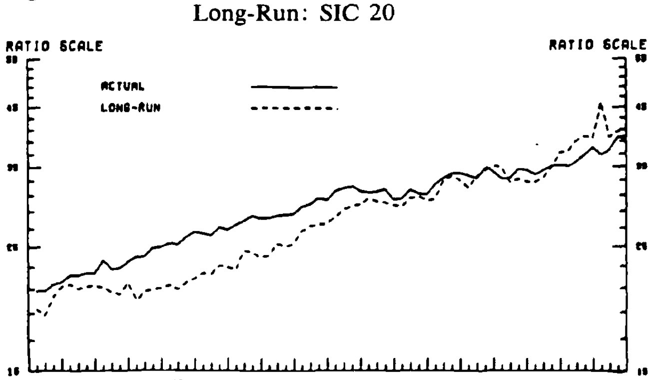

Fig. 2.2C Average Product per Production Worker Hour, Actual versus Long-Run: SIC 20

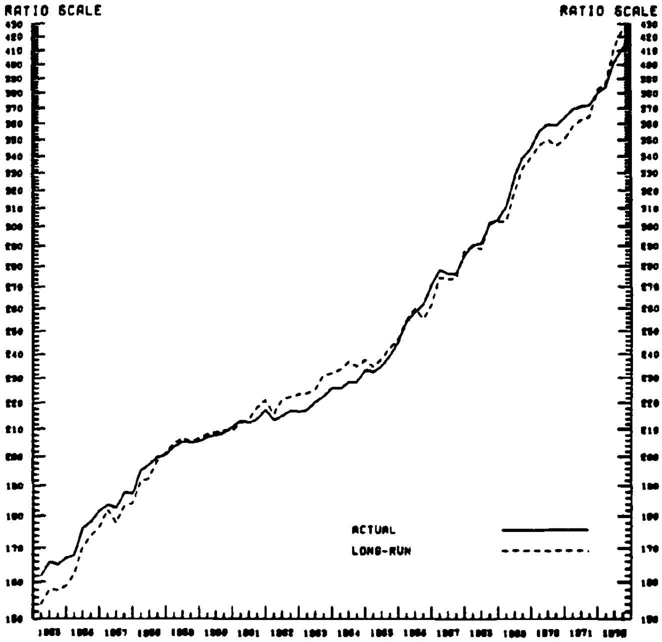

Fig. 2.2D Real Total Factor Cost (hundreds of millions of dollars), Actual versus Long-Run: SIC 20

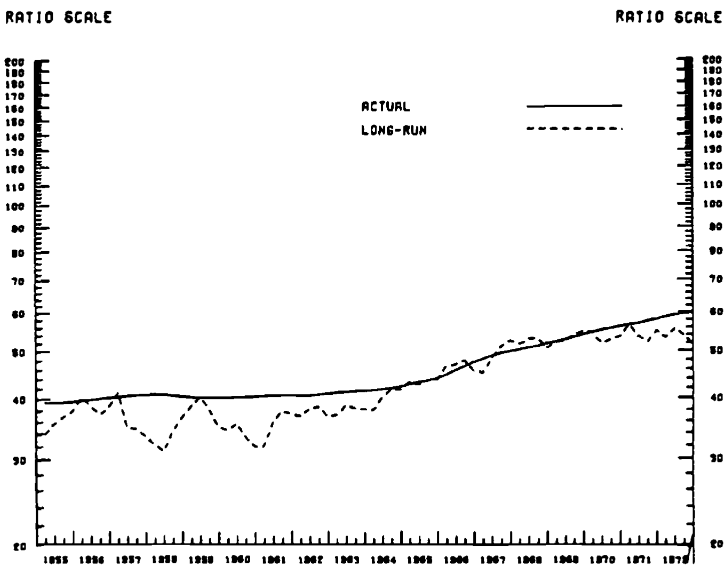

Fig. 2.3A Equipment (hundreds of millions of dollars), Actual versus Long-Run: SIC 22

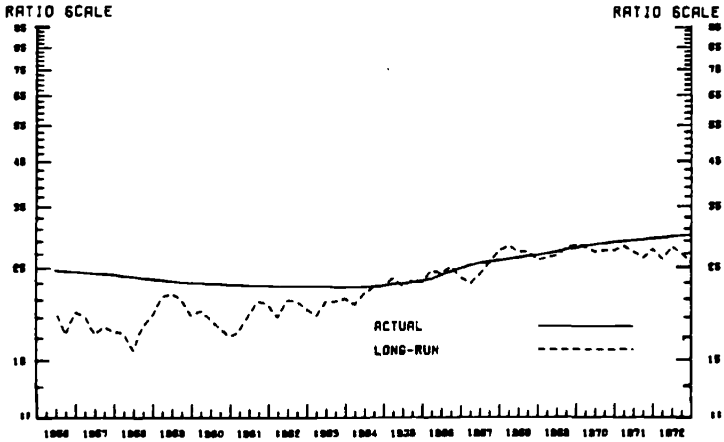

Fig. 2.3B Plant (hundreds of millions of dollars), Actual versus Long-Run: SIC 22

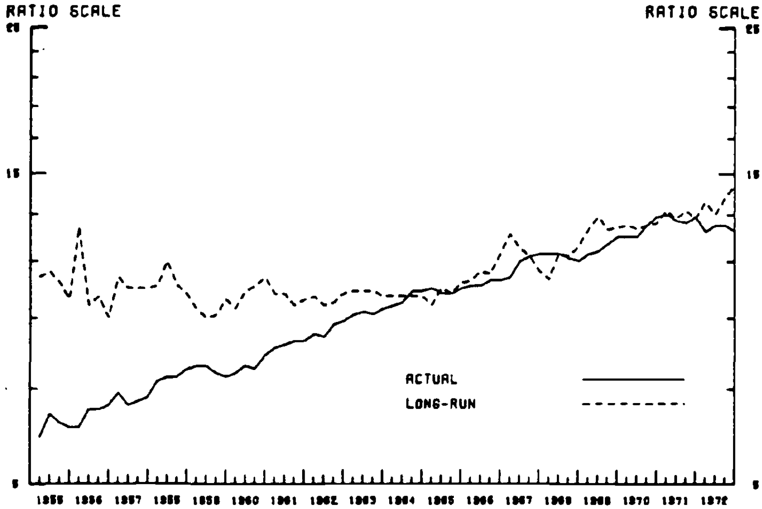

Fig. 2.3C Average Product per Production Worker Hour, Actual versus Long-Run: SIC 22

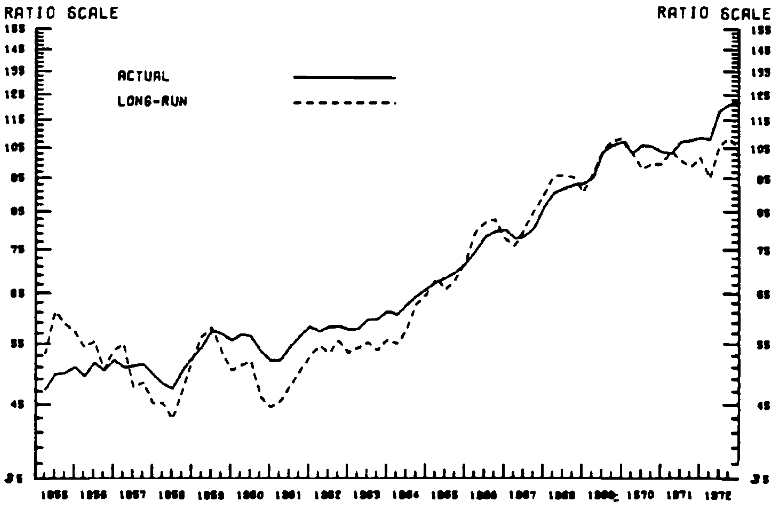

Fig. 2.3D Real Total Factor Cost (hundreds of millions of dollars), Actual versus Long-Run: SIC 22

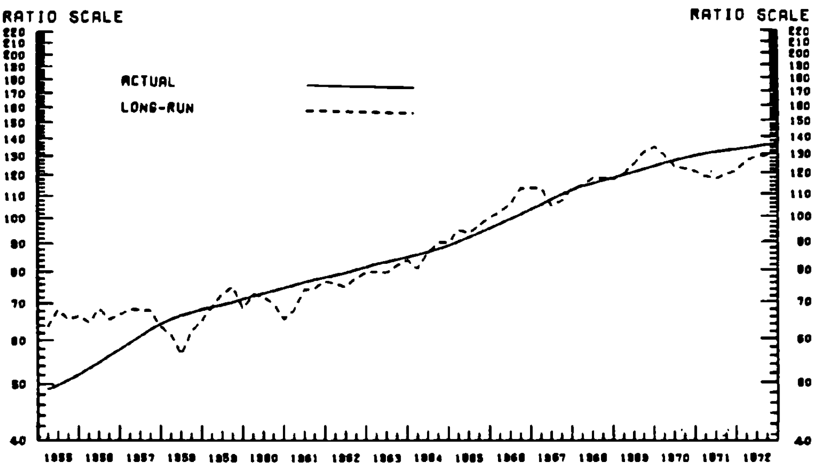

Fig. 2.4A Equipment (hundreds of millions of dollars), Actual versus Long-Run: SIC 26

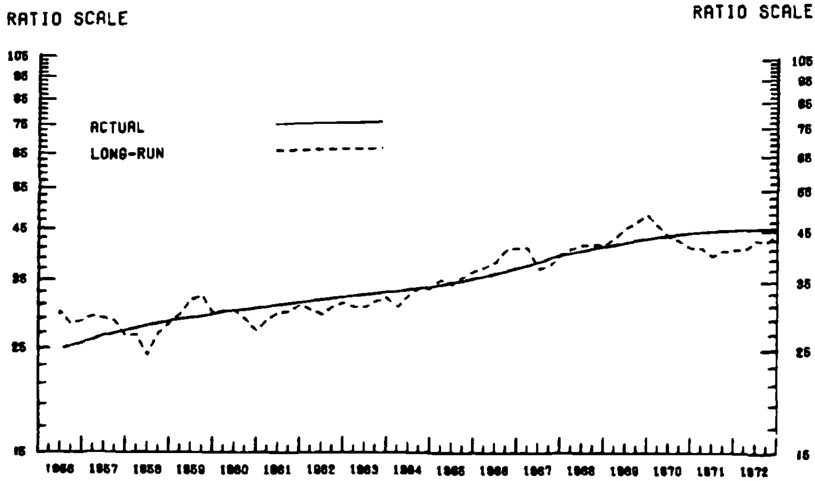

Fig. 2.4B Plant (hundreds of millions of dollars), Actual versus Long-Run: SIC 26

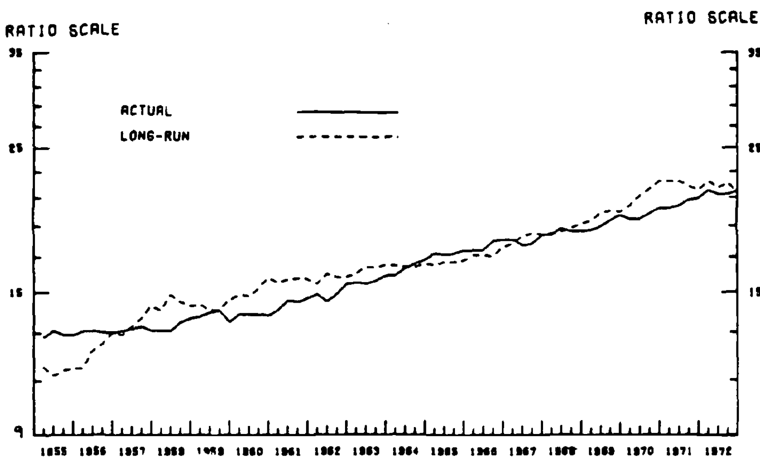

Fig. 2.4C Average Product per Production Worker Hour, Actual versus Long-Run: SIC 26

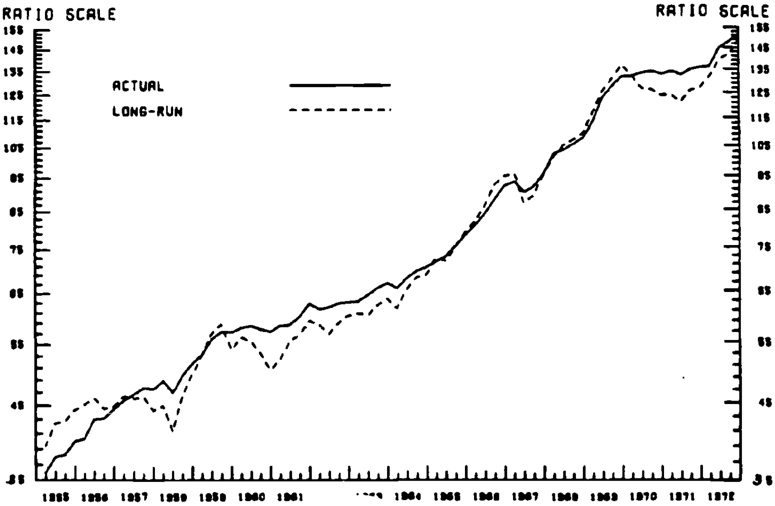

Fig. 2.4D Real Total Factor Cost (hundreds of millions of dollars), Actual versus Long-Run: SIC 26

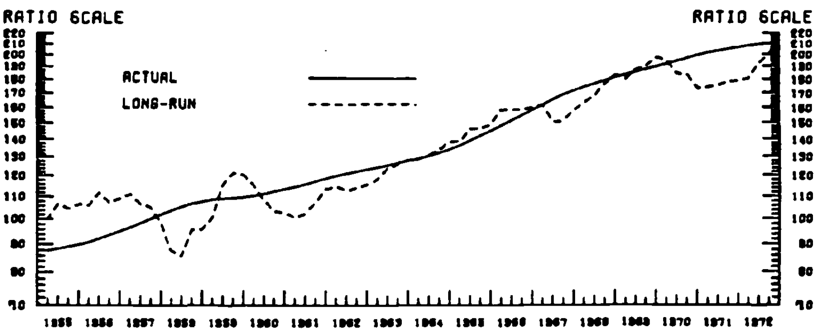

Fig. 2.5A Equipment (hundreds of millions of dollars), Actual versus Long-Run: SIC 28

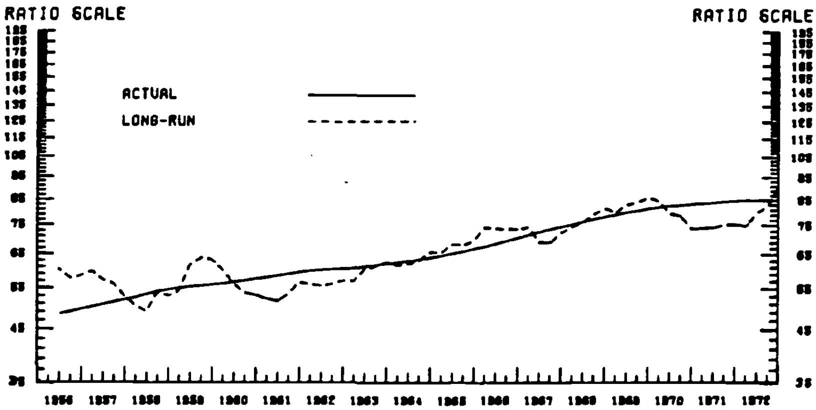

Fig. 2.5B Plant (hundreds of millions of dollars), Actual versus Long-Run: SIC 28

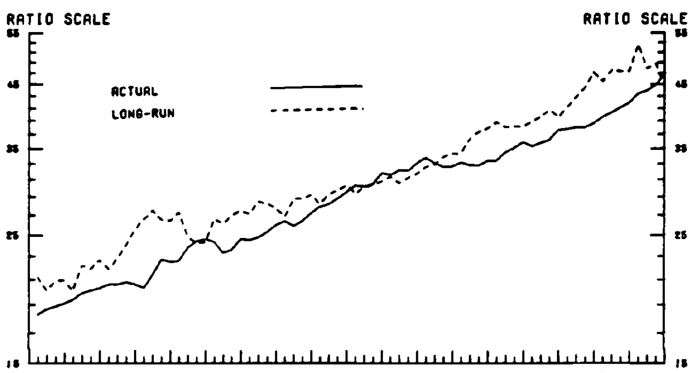

Fig. 2.5C Average Product per Production Worker Hour, Actual versus Long-Run: SIC 28

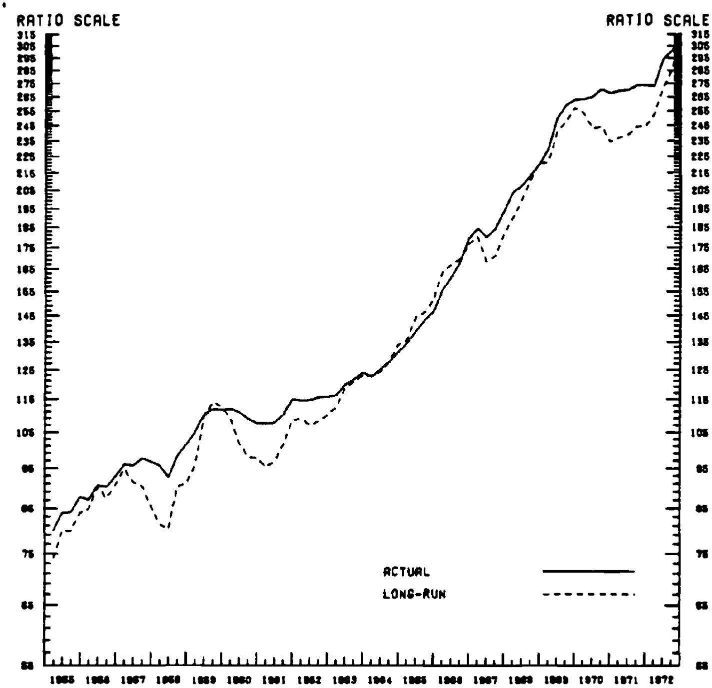

Fig. 2.5D Real Total Factor Cost (hundreds of millions of dollars), Actual versus Long-Run: SIC 28

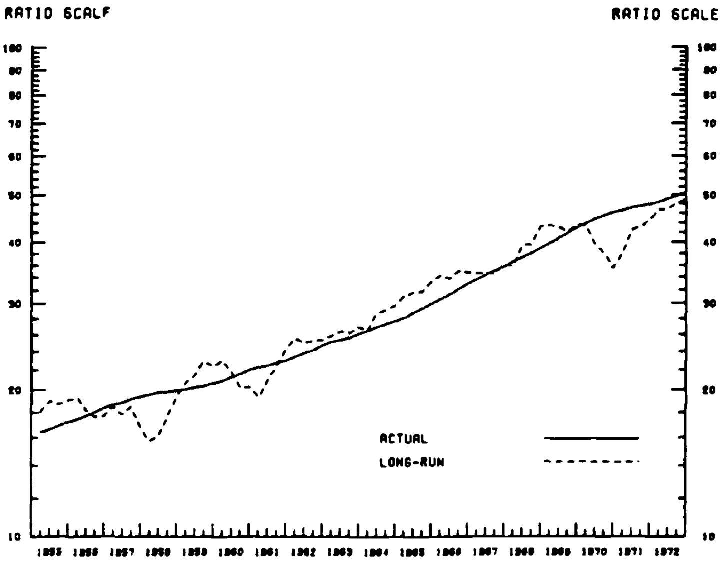

Fig. 2.6A Equipment (hundreds of millions of dollars), Actual versus Long-Run: SIC 30

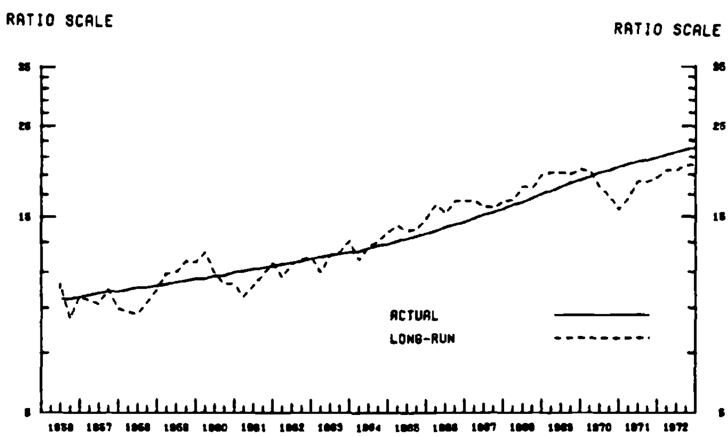

Fig. 2.6B Plant (hundreds of millions of dollars), Actual versus Long-Run: SIC 30

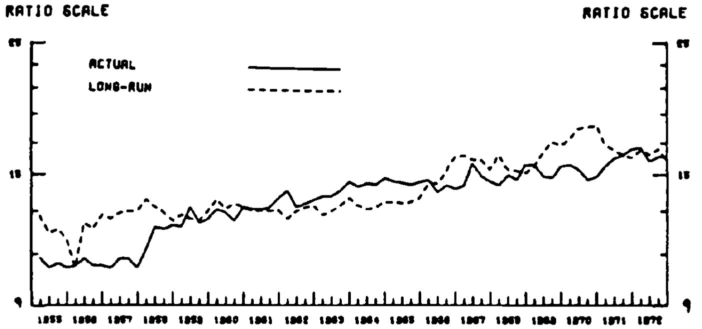

Fig. 2.6C Average Product per Production Worker Hour, Actual versus Long-Run: SIC 30

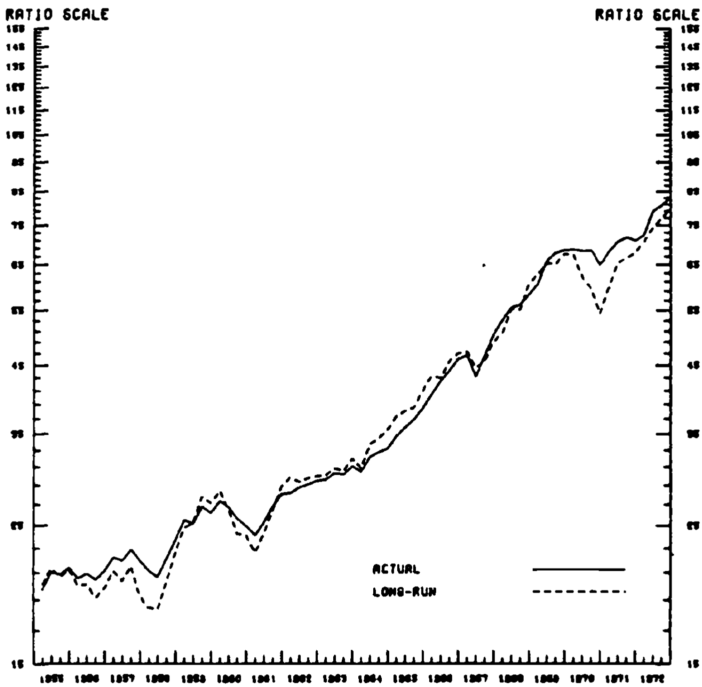

Fig. 2.6D Real Total Factor Cost (hundreds of millions of dollars), Actual versus Long-Run: SIC 30

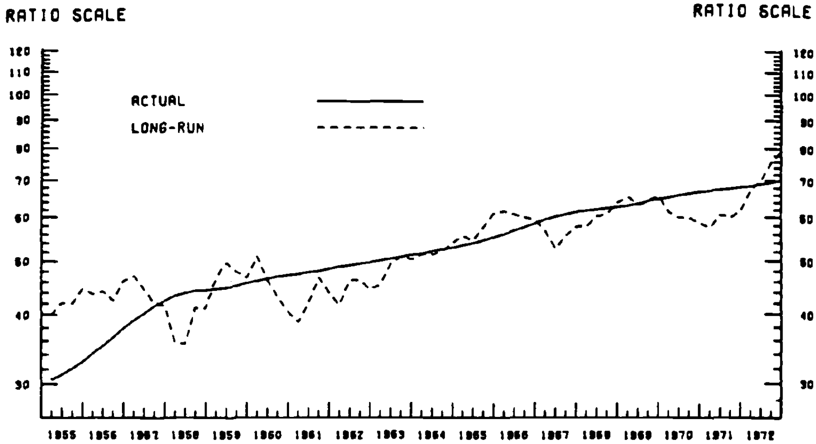

Fig. 2.7A Equipment (hundreds of millions of dollars), Actual versus Long-Run: SIC 22

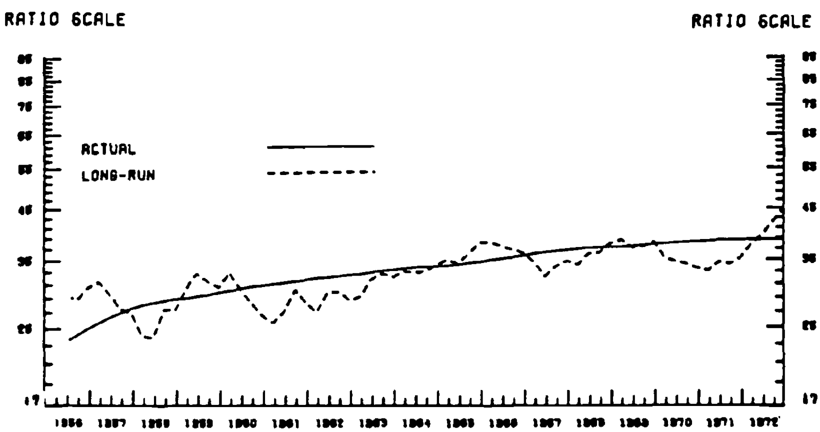

Fig. 2.7B Plant (hundreds of millions of dollars), Actual versus Long-Run: SIC 32

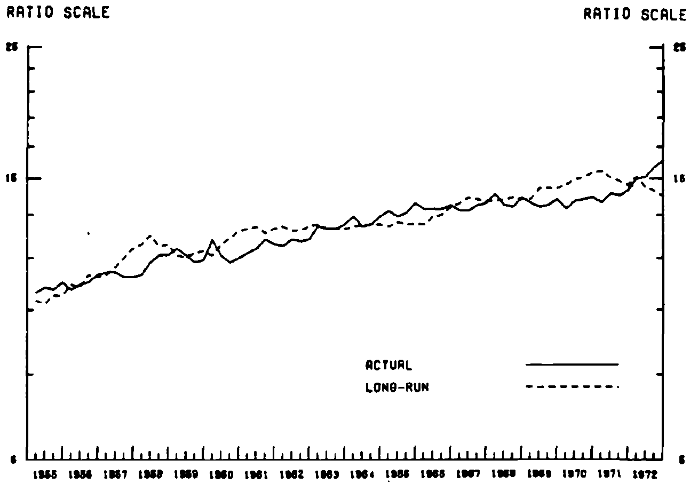

Fig. 2.7C Average Product per Production Worker Hour, Actual versus Long-Run: SIC 32

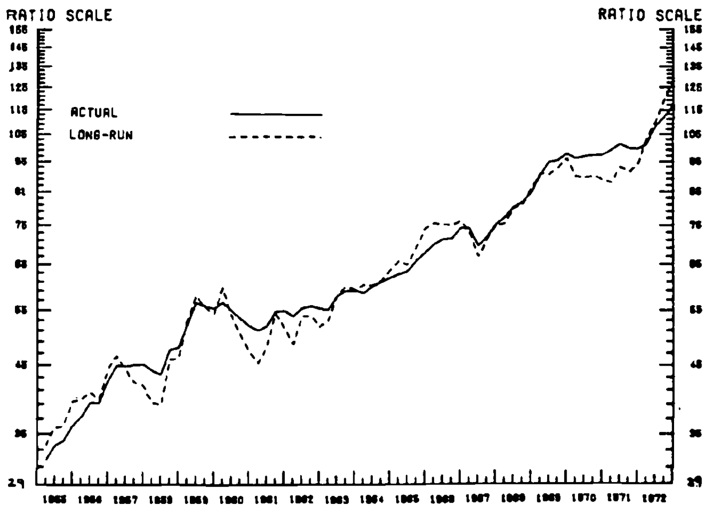

Fig. 2.7D Real Total Factor Cost (hundreds of millions of dollars), Actual versus Long-Run: SIC 32

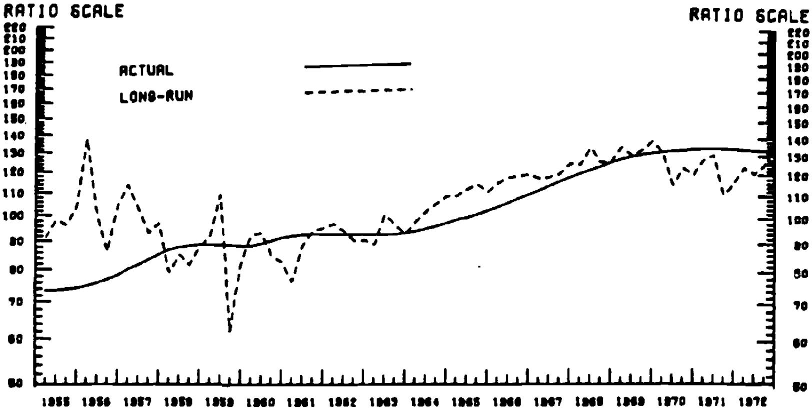

Fig. 2.8A Equipment (hundreds of millions of dollars), Actual versus Long-Run: SIC 330

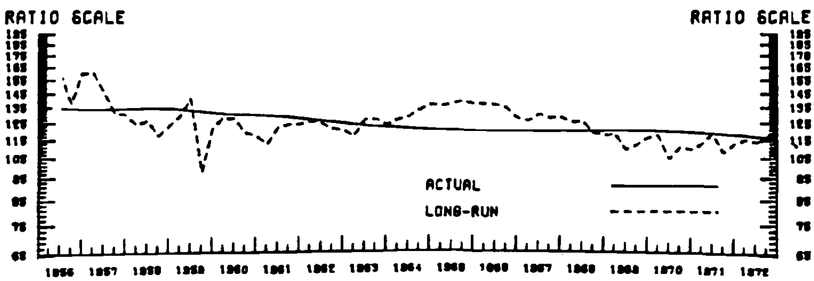

Fig. 2.8B Plant (hundreds of millions of dollars), Actual versus Long-Run: SIC 330

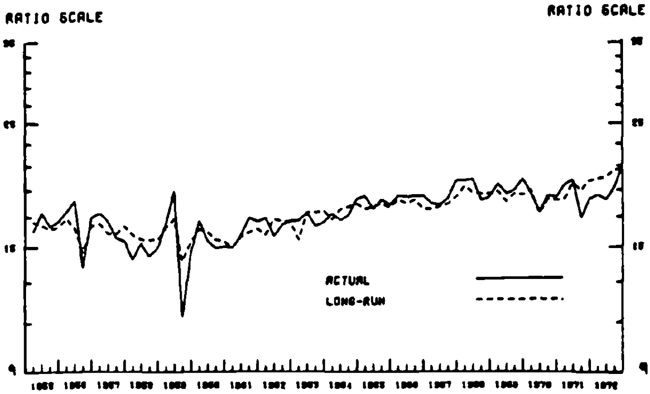

Fig. 2.8C Average Product per Production Worker Hour, Actual versus Long-Run: SIC 330

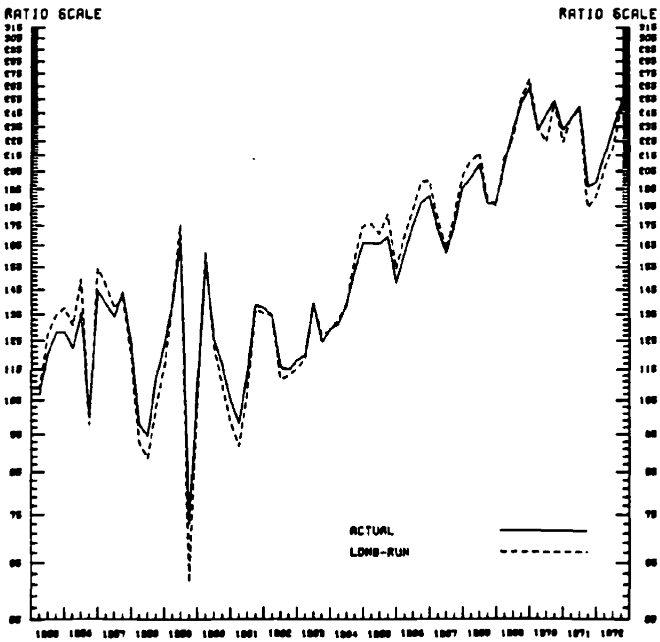

Fig. 2.8D Real Total Factor Cost (hundreds of millions of dollars), Actual versus Long-Run: SIC 330

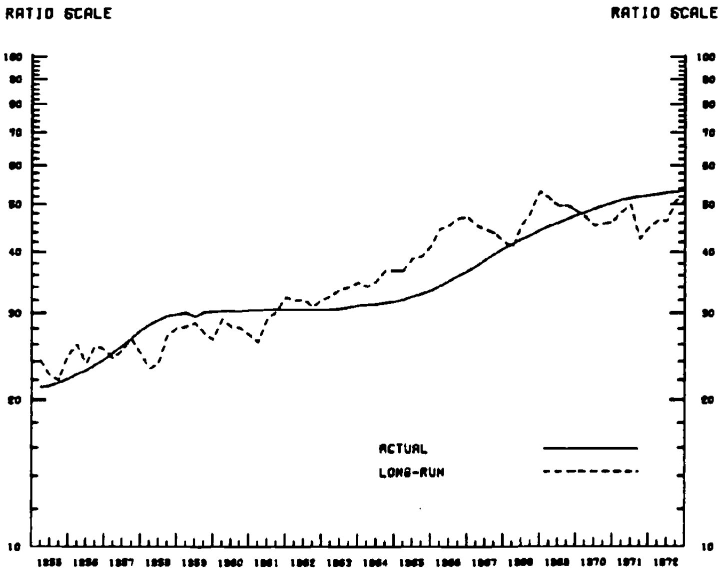

Fig. 2.9A Equipment (hundreds of millions of dollars), Actual versus Long-Run: SIC 333

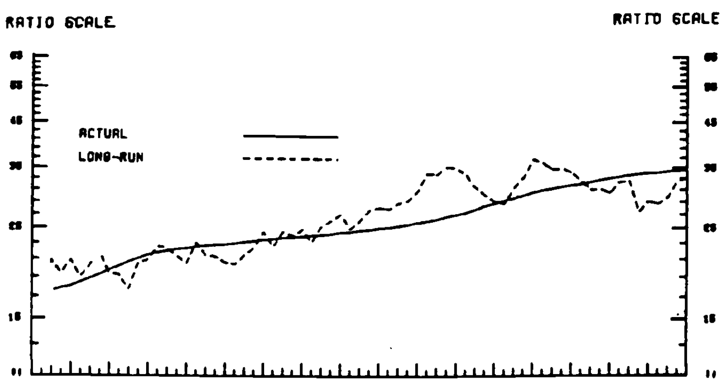

Fig. 2.9B Plant (hundreds of millions of dollars), Actual versus Long-Run: SIC 333

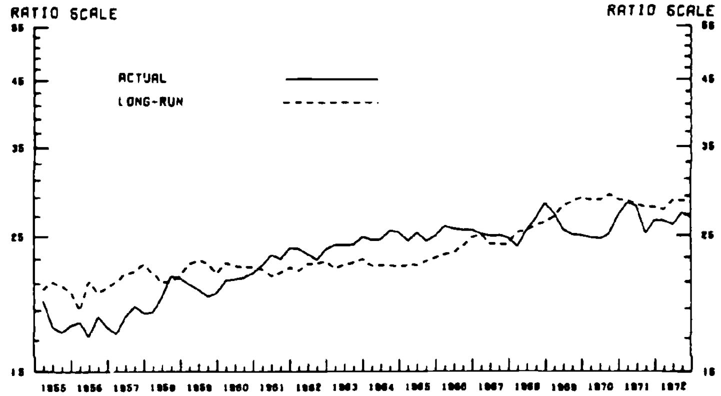

Fig. 2.9C Average Product per Production Worker Hour, Actual versus Long-Run: SIC 333

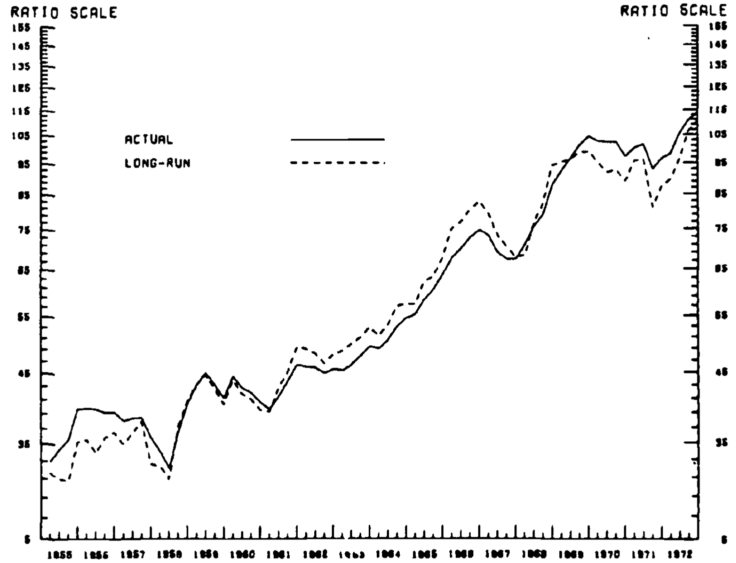

Fig. 2.9D Real Total Factor Cost (hundreds of millions of dollars). Actual versus Long-Run: SIC 333

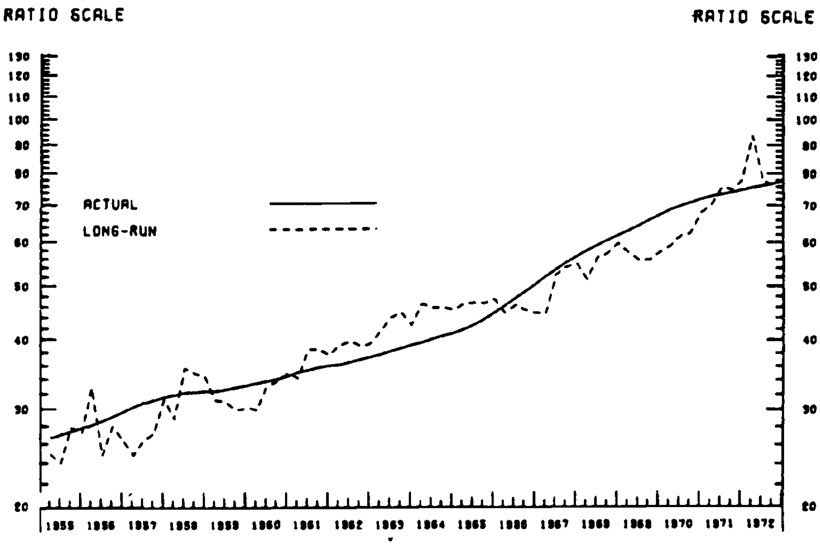

Fig. 2.10A Equipment (hundreds of millions of dollars), Actual versus Long-Run: SIC 35

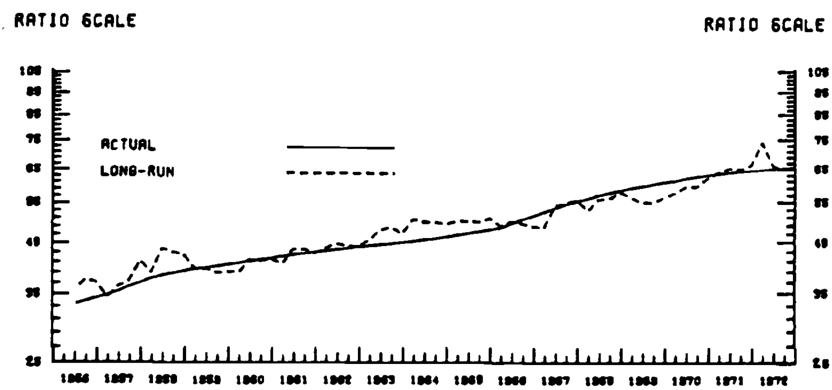

Fig. 2.10B Plant (hundreds of millions of dollars), Actual versus Long-Run: SIC 35

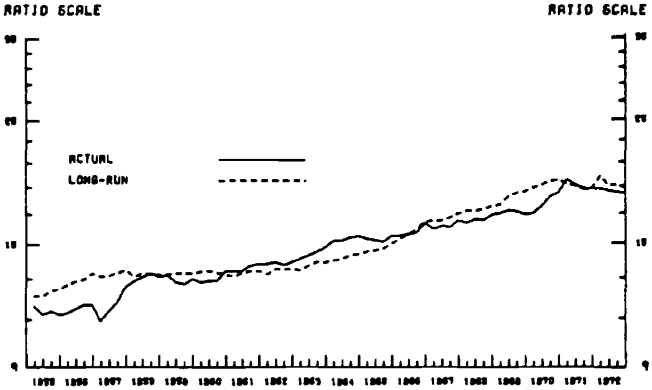

Fig. 2.10C Average Product per Production Worker Hour, Actual versus Long-Run: SIC 35

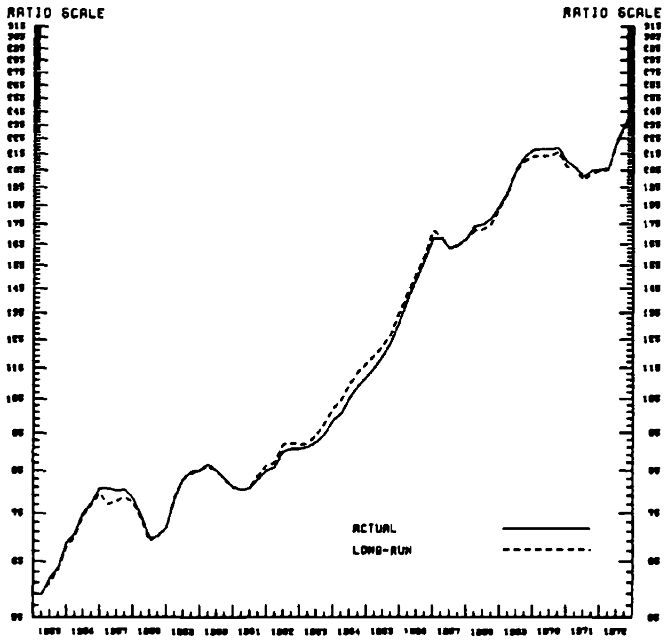

Fig. 2.10D Real Total Factor Cost (hundreds of millions of dollars), Actual versus Long-Run: SIC 35

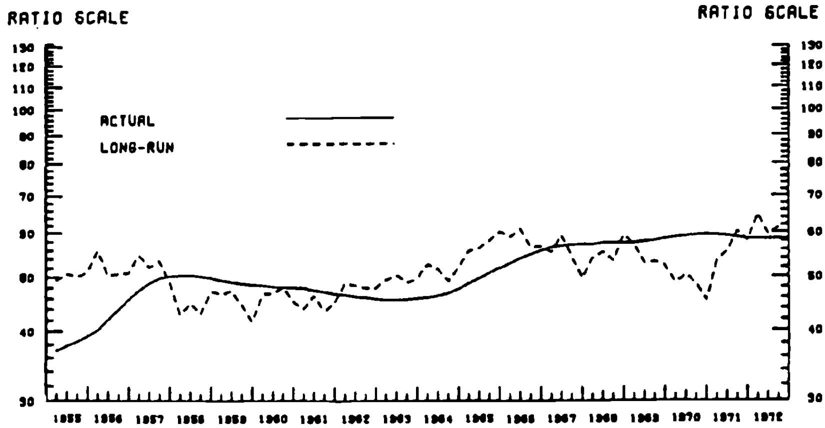

Fig. 2.11A Equipment (hundreds of millions of dollars), Actual versus Long-Run: SIC 371

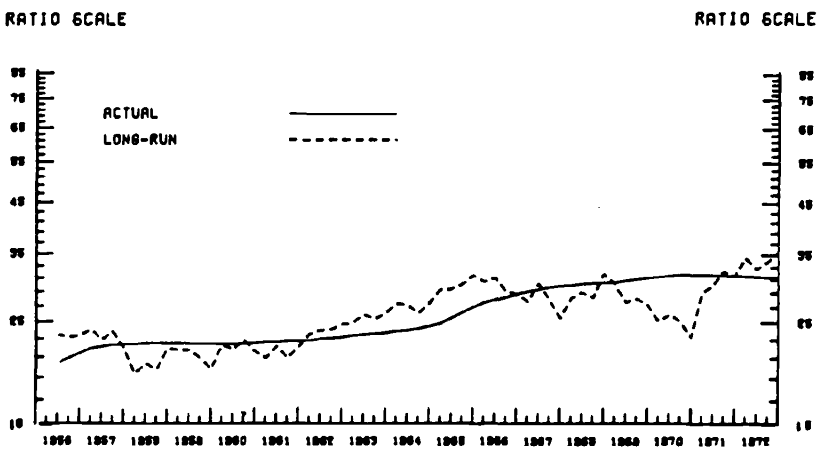

Fig. 2.11B Plant (hundreds of millions of dollars), Actual versus Long-Run: SIC 371

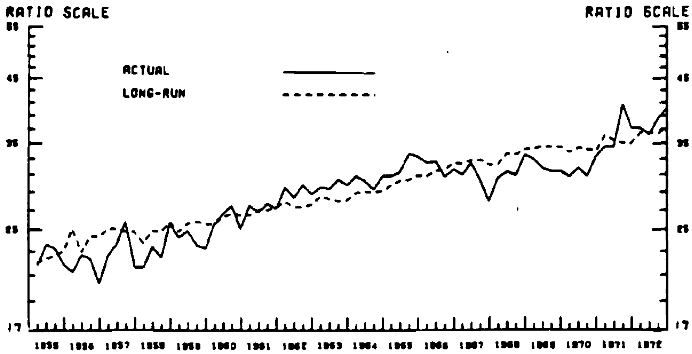

Fig. 2.11C Average Product per Production Worker Hour, Actual versus Long-Run: SIC 371

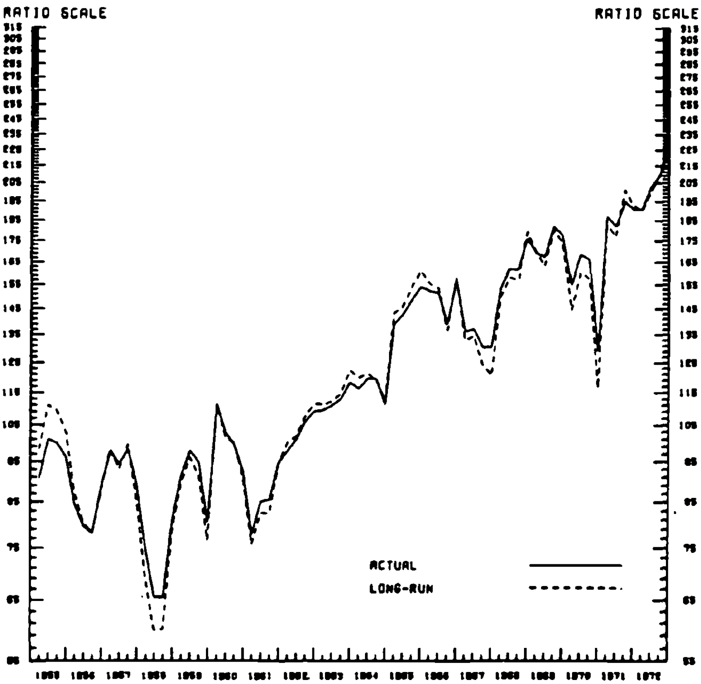

Fig. 2.11D Real Total Factor Cost (hundreds of millions of dollars), Actual versus Long-Run: SIC 371

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Comment David Burras Humphrey

Nontechnical Summary

Observed U.S. (aggregate) private-sector labor productivity grew at an annual average rate of 3.2% over the period 1947–66 but only expanded by 2.4% from 1966 to 1973. Could this slowdown in productivity growth be attributed to cyclical differences in the rate of growth of output demand between these two periods, or are other longer run, secular causes to blame for the observed decrease in productivity growth? This question is the main focus of the Mohr paper.

Using a model of interrelated (stock-adjustment) factor demand with quarterly data on six inputs for ten two-digit SIC manufacturing industries over the period 1956–72, the author concludes that the decline in labor productivity may be attributed to increased cyclical instabilities in output demands over the 1966–72 period, compared with earlier periods when output growth was relatively more stable. When industry output growth rates exhibit greater variation, and therefore are more uncertain, Mohr contends, firms increasingly adjust to changing output demands by altering production worker labor hours and capital capacity utilization in preference to adding to stocks of plant and equipment (which are more difficult and costly to adjust in response to uncertain variations in output). Correspondingly, measured labor productivity,

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output per unit of labor input, will be lower when output demands are more erratic because more of the "adjustable" short-run labor input is being utilized to produce a given output level than is utilized in periods where output growth exhibits greater stability. Since output growth rates may become more stable in the future, Mohr attributes the observed decline in measured labor productivity to potentially reversible causes and rejects the notion that labor productivity need be on a secular downward trend. Greater future stability in output growth rates should lead to a reduced reliance on labor inputs in favor of increments to stocks of capital, and output per unit of labor input should rise.

The Structural Model

Observed quarterly data on gross output (Y) and production worker man-hours (X_L) can be used to obtain a measure of labor productivity. Fluctuation in a quarterly industry labor productivity index ($PR_L = Y/X_L$) over time is due to the interaction of a number of different short-run (cyclical) and longer-run (secular) influences. These influences need to be identified and separately accounted for in order to determine the possibility that the observed decline in labor productivity over the 1966–72 period, relative to earlier periods, may be reversed in the future.

Changes in the measured U.S. aggregate private sector quarterly factor productivity index may be affected by (1) cyclical versus secular changes in the underlying composition of industry gross output (and therefore input usage); (2) changes in relative factor and intermediate input prices which affect measured input usage; (3) economies of scale which affect the efficiency of the inputs being utilized; (4) changes in relative input demands due to a differing "adjustability" among factors in response to output variation; (5) factor-biased technological change over time; and (6) shifts in the age-sex composition of the labor force. In sum, observed labor productivity measures are affected by changes in output composition or the level of industry aggregation used in the productivity index; changes in relative factor prices or operating costs; the level of output produced; the adjustment process; biased technological change; and the age-sex composition of the labor force.

To reduce the agregation or output-mix problem, the author looks at factor productivity at the two-digit SIC level of industry aggregation. The effect that changes in the adjustment process can have on input demands when output growth rates become more variable is measured by use of a model in which short-run stock-adjustment relationships are specified along with the introduction of certain short-run "inputs"—such as the degree of capital capacity utilization and production worker overtime hours—which may permit more accurate identification of the short-term adjustment aspect of factor demands between different time periods and over a business cycle. Price and output-related input substitution effects are also identified. The possible effects of factor-biased technological change or the age-sex composition of the labor force, however, are not considered in the empirical application of the model. The effect of these exclusions on the empirical results is not known.

Those familiar with the literature will find that the main specification novelty of the Mohr paper lies in the use of a so-called translog cost function in place of the Cobb-Douglas production function used in an earlier study of adjustment or disequilibrium influences on factor demand by Nadiri and Rosen (1973). Since Nadiri and Rosen's Cobb-Douglas model is unnecessarily restrictive, the specification of a translog function is reasonable, and the author is better able to measure the short-run adjustment influence on factor demands to the extent that input substitution elasticities differ from one and input demands are nonhomothetic (i.e., changes in output affect the relative composition of inputs being demanded).

The hypothesis that the translog stock-adjustment model is a significant empirical improvement over Nadiri and Rosen's use of a Cobb-Douglas stock-adjustment form was tested and accepted. As well, the (nested) hypothesis that the author's use of a translog function with a stock-adjustment sequence represents a significant improvement over a translog function without a stock-adjustment sequence (i.e., inputs "instantaneously" adjust to new equilibrium positions) was also accepted. Thus the model adopted in the paper, and applied to ten two-digit SIC U.S. manufacturing industries, is a translog cost function with a square matrix of own and cross stock-adjustment coefficients. From a statistical standpoint, this model is a close cousin to a reduced form system of derived demand equations, one for each input, with a first-order autoregressive process within and across all equations.

The model uses seasonally adjusted quarterly data over the period 1956–72 on ten industries, ranging from SIC 20 (food and kindred products) to SIC 371 (motor vehicles). Six inputs are explicitly considered: total production worker hours (including overtime hours), nonproduction worker employment, capital equipment, capital plant, a measure of capital capacity utilization (assumed to be equal for both plant and equipment), and materials inputs (including energy). The variation in total production worker hours reflects both the long-run variable of total number of workers working a "normal" workweek and the short-run adjustment input of overtime hours. Because the overtime hourly wage is almost always 1.5 times the straight-time wage, overtime and straight-time wages are highly collinear, preventing the consideration of overtime and straight-time labor hours as separate inputs. Capacity utilization is the short-run adjustment input for capital. A maintained hypothesis is that different types of intermediate inputs are

functionally separable from all other inputs to the production process, thus justifying their aggregation into a composite materials input. Without estimating a model which explicitly includes these inputs as separate arguments, this aggregation assumption cannot be tested.
of labor and other factor demands which are *independent of changes in*
In essence, the approach adopted in the paper is to obtain an estimate *the adjustment sequence* brought about by changing rates of output growth over the 1956–72 period. Such a quarterly "adjustment-free" demand for production worker man-hours is denoted by X^*_L. Using actual observed quarterly data on input demands (e.g., X_L without the asterisk), input prices, and output levels, a system of translog derived demand equations with a first-order stock-adjustment sequence is estimated. The estimated parameters of these derived demand equations, *excluding* the stock-adjustment coefficients, are used along with quarterly data on prices and output to generate a predicted "equilibrium" input cost share from which the short-run adjustment process has been (in effect) removed. This "equilibrium" cost share can be expressed as $S^*_i = P_iX^*_i/C^*$ for i inputs. It is from S^*_i that the desired X^*_i estimates are obtained. The observed or constructed quarterly prices (P_i) are presumed to reflect equilibrium values so that deflating the equilibrium shares by P_i gives $S^*_i/P_i = X^*_i/C^*$. Finally, to obtain X^*_i, an estimate of the "adjustment-free" total cost C^* is required.

If Mohr had chosen to estimate the system of translog derived demand equations *jointly* with the translog total cost function where all estimated equations are subject to a first-order stock-adjustment sequence, then C^* could simply be derived by substituting the quarterly data into the estimated total cost function, again excluding the stock-adjustment coefficients. This C^* estimate would reflect the influence of all of the derived demand equation parameters (excluding the stock-adjustment coefficients) which were used to generate S^*_i and, in addition, the influence of two parameters measuring Hicks-neutral technical progress (α_t) and homothetic returns to scale (α_Y). These two additional parameters enter the total cost function but not the derived demand equations (contrast Mohr's eq. [2] with eq. [4]). As Mohr only estimates the derived demand equations, he utilizes a two-step procedure to generate an estimate of C^* (the fact that the gross output variable Y is used in eq. [2] to estimate α_Y and in [4] to estimate β_i is not a problem which prevents joint estimation of [2] with [4]).

First, using the parameters of *all* the derived demand equations (excluding all the stock-adjustment coefficients) and one year *averages* of the quarterly data, Mohr generates a predicted quarterly average total cost estimate, say, PTC. PTC is the value of predicted average quarterly total cost which is "adjustment-free" and uncorrected for neutral technical progress (α_t) or homothetic returns to scale (α_Y). To obtain an estimate of C^* from PTC, α_t and α_Y must be estimated. The second step involves this estimation.

The difference between ATC and PTC, where ATC represents the actual one-year average quarterly total cost, is regressed on time and the one-year average quarterly output value in order to estimate α_t and α_Y, respectively. Once this second step is completed, then all the parameters of the translog total cost function are known. These parameters (excluding any stock-adjustment coefficients), multiplied by the quarterly data on all inputs and output, yield an estimate of C^*.

The goal of the paper is finally reached by using S^*_i, P_i, and C^* to derive a quarterly estimate of the adjustment-free input demand: $X^*_i = (S^*_i/P_i)C^*$. Mohr then computes a quarterly "adjustment-free" input demand labor productivity index $PR^*_L = Y/X^*_L$ which measures what quarterly labor productivity would have been during 1956–72 if labor demand could have immediately adjusted to the observed current quarterly output level (Y). The important contrast of the paper is between the observed quarterly labor productivity index $PR_L = Y/X_L$, which is affected by changes in input demands due to a differing "adjustability" among factors in response to output variation (i.e., influence (4) on page 230 above), and the constructed adjustment-free index $PR^*_L = Y/X^*_L$. This contrast over 1956–72 generates the basic empirical results of the study as it relates to this Conference.

The Productivity Results

The simplest way to present Mohr's results is to take unweighted arithmetic averages of three output measures and concentrate on labor productivity (as opposed to, say, total factor productivity). In table 2.C.1 below, the unweighted average annual peak-to-peak growth rate of PR_L, PR^*_L, and Y are shown for nondurables, durables, and all industries together. As the actual peak-to-peak time periods differ slightly between most of the ten industries, the dates shown are only approximate.

Table 2.C.1 Average Annual Peak-to-Peak Growth Rates for PR_L, PR^*_L, and Y for Durable and Nondurable Goods Sectors, 1956–72

Sector	Peak-to-Peak	PR_L (%)	PR^*_L (%)	Y (%)
Nondurables	1956–66	4.26	2.28	4.93
(SIC 20, 22, 26, 28, 30)	1966–72	3.23	3.97	3.63
Durables	1956–66	3.05	1.75	3.90
(SIC 32, 330, 333, 35, 371)	1966–72	1.87	2.33	.40
Total	1956–66	3.66	2.02	4.42
(all 10 SIC industries)	1966–72	2.55	3.15	2.02

Source: Computed from Mohr's table 2.1 for ten SIC industries.

For the two periods shown, 1956–66 and 1966–72, a least-squares regression line is fitted to quarterly data on PR_L, PR^*_L, and Y and an implied annual growth rate is computed. The growth rate of observed production worker labor productivity PR_L for nondurables over 1956–66 is thus 4.26% per year but for the later period 1966–72 it falls to 3.23%. This observed productivity slowdown is even more marked for durables and, for all industries, the growth rate falls by 1.11 percentage points.

In contrast, the adjustment-free measure of labor productivity between these two periods rises, not falls, for durables and nondurables and increases overall by 1.13 percentage points. In effect, this contrasting result says that if output variations within both of these two periods were very similar, then the actual rate of productivity growth in manufacturing need not have fallen because the productivity growth rate computed with the adjustment process "removed" did not fall between these same two periods. As can be seen from the growth rates for gross output (Y) in table 2.C.1, average output growth was slower for the second period compared with the first; it was slower on average because during 1966–72 periods of recession were mixed in with quarters of higher growth. In sum, output demands were more erratic during 1966–72 than during 1956–66. This led firms to increasingly adjust to output variations by altering labor hours and capital capacity utilization in preference to adding to stocks of plant and equipment (which are more difficult to adjust). Mohr has demonstrated that this influence alone (given that one accepts the structural model) is sufficient to "explain" the observed decline in actual labor productivity growth.[1]

More Detailed Comments

Since the author has emphasized the more technical aspects of the topic he raises, our comments necessarily reflect a similar focus. This is somewhat unfortunate since Mohr has devoted considerable energy and time to developing new data (particularly on capital) which apparently are discussed in greater detail, and contrasted with existing series, in the referenced BLS Working Paper (Mohr 1978).

Our main comments on the Mohr paper deal with the two-step process used to generate the C^* (and thus the X^*_L) estimates, and with various "tests" or extensions of the analysis which would have usefully served to place this paper in better perspective relative to existing studies. One

1. Since, in the early part of the first period (1956–66), output demand was more erratic than in the latter part, the computed growth rates for PR_L can be larger than those computed for PR^*_L. This is because the *level* of PR^*_L in the late 1950s will be higher than the level of PR_L but will tend to converge to more similar values toward the mid 1960s as output growth becomes much more stable. This level difference, of course, can affect the computed growth rates.

overall comment is that the paper's technical orientation will significantly limit its audience. The model used in the paper is very complex.

The two-step process used to develop the C^* (and hence the X^*_i) estimates, summarized above, suggests a dichotomy regarding the identification of adjustment effects. Recall that the author uses the estimated parameters of each translog derived demand equation (net of the estimated stock-adjustment coefficients) in conjunction with observed quarterly data on prices and output to generate an estimate of the equilibrium quarterly adjustment-free cost share S^*_i ($= P_iX^*_i/C^*$). Here the adjustment process is explicitly accounted for in the statistical estimation of the stock-adjustment coefficients appended to the system of translog derived demand equations. Consistency would argue that a similar method should be used to determine C^*.

Instead of *jointly* estimating the translog total cost function with the derived demand equations and explicitly identifying the stock-adjustment parameters of *both* the total cost function and the derived demand equations so that both S^*_i and C^* can be derived from the jointly estimated parameters (net of all estimated stock-adjustment coefficients), Mohr utilizes the two-step process discussed above. This process utilized the parameters of all derived demand equations (excluding the stock-adjustment coefficients) and the one-year average of quarterly values of prices and output to generate a predicted one-year average quarterly value of total cost (PTC). The actual one-year average quarterly value of total cost (ATC) was also computed. The difference ATC — PTC is then regressed on time and the average quarterly value of output in order to estimate two parameters which are in the total cost function but not in the derived demand equations—α_t and α_Y.

The reason why there is no stock-adjustment term in this second step in determining the "adjustment-free" value of C^* is that the averaged quarterly data themselves are presumed to be reflective of adjustment-free equilibrium input usage of all inputs. If this is indeed true, then the averaging process itself generates the X^*_i estimate directly, and the specification and estimation of the structural model is of course unnecessary. If the simple averaging process does not really give the author an estimate of X^*_i, then there needs to be some sort of direct, explicit stock-adjustment coefficient incorporated in the regression used to estimate α_t and α_Y; otherwise the author's estimate of C^*, used to derive X^*_i from S^*_i, will not be entirely adjustment-free as the estimates of α_t and α_Y are not entirely adjustment-free themselves.

This whole problem, and the dichotomy regarding identification of adjustment effects, could have been avoided through joint estimation of the total cost function and the system of derived demand equations where *all* equations have stock-adjustment coefficients. In all probability, the error introduced into the analysis by this two-step procedure is much more likely to affect the numbers computed from the estimated parameters than it is to reverse any conclusions already reached. Just the same, consistency would have been better served through joint estimation with stock-adjustment coefficients on all estimated equations.

Regarding estimating procedures, Mohr states that while he recognizes that iterative three-stage least squares is theoretically preferable to the iterative two-stage technique actually used, the extra effort required "seemed to be an unnecessary refinement" considering the fact that so many industries were involved and that much of the data (on capital) was constructed to begin with. This argument would have been more acceptable if for at least one industry three-stage procedures were used and, when contrasted to the two-stage results, shown to have little effect. Both estimating procedures were available on the TSP computer package which was used. In this manner, readers could indeed see if this refinement was unnecessary or not, and thus whether the possible simultaneity in the determination of input usage, input prices, and output is a problem requiring correction.

In addition, as the model represents a disequilibrium system of six interrelated factor demands by the specification of a (5×5) square matrix of own and cross stock-adjustment coefficients, it would have been of illustrative interest if these results were contrasted (again for at least one industry) with a model where the cross stock-adjustment coefficients were restricted to equal zero. In such a model only the five own adjustment coefficients are estimated. (Recall that one equation is deleted from the six-input model so that only five equations are actually estimated.) If the two sets of derived demand parameter estimates were very similar, it would be clear that specification of the cross stock-adjustment coefficients (which can easily make very large demands on the information contained in the data set) is not worth the extra effort. With fewer stock-adjustment coefficients to estimate, efficiency would increase.

Efficiency would also likely rise if the information contained in the total cost function were utilized by jointly estimating the five derived input demand equations with the total cost function. Only two extra parameters need be estimated (i.e., α_t and α_Y), but total observations would rise by 20% (instead of five equations each with n observations, we now have $6(n)$ total observations) and degrees of freedom would rise.

The author's results lead him to question whether the capital-energy and capital–nonproduction worker complementarity found by previous researchers (Berndt and Wood 1975; Berndt and Christensen 1974) could possibly be due to their use of an "instantaneous adjustment" model. Mohr, using a translog stock-adjustment model, did not find complementarity between capital and nonproduction workers (energy was included in materials inputs, so there is no direct estimate of the capital-energy relationship). Actually, this need not have been only a conjecture. Since the author estimated both a translog instantaneous adjustment model and a translog stock-adjustment model in order to apply an F-test on the significance of adding a stock-adjustment process to the translog function, estimates of substitution elasticities from both models could have been directly contrasted to see if the conjecture made is correct. The fact that the reported F-tests indicate that adding a stock-adjustment sequence to the translog model results in a significant improvement in explanatory power is not sufficient to conclude that the sign of the capital–nonproduction worker elasticity is altered in moving from one model (instantaneous adjustment) to another (stock adjustment). Unfortunately, this interesting conjecture was not "tested," although the means to do so were readily at hand.

Another candidate for reconciling the apparent difference in capital–nonproduction worker results would be the fact that Berndt and Christensen used aggregate U.S. manufacturing data while Mohr uses two-digit SIC industry data. It would have been interesting if this two-digit data were aggregated and the model rerun with and without a stock-adjustment sequence in order to assess the possible effects disaggregation can have on the identification of substitution or complementarity between inputs. In this manner the reader would be better able to see just how the present study fits in with existing studies.

On a different level, the author's use of relatively unavailable two-digit capital plant and equipment data gave him the unique opportunity to examine, through model simulation, the impact that "reasonable" changes in capital data construction can have on his results. It would be useful information indeed if Mohr were able to tell us that his results are reasonably insensitive to changes in the methodology used to construct the capital data.

It is difficult to know what to make of the empirical result that various Allen own partial substitution elasticities are positive and/or that the price concavity condition is not met. From a strict theoretical point of view, this empirical result means that the underlying data do not meet the basic duality–cost-minimization condition at all points in the data set so that use of the cost function model is, in this case, empirically unsupported. On the other hand, in some of my own work, I have found the price concavity condition to be a very sensitive restriction, a restriction in which minor changes in the data set (through use of theoretical a priori information) will generate the correct theoretical result with only small changes in coefficient estimates.

In closing, after concentrating on the apparent weaknesses of the Mohr paper, it should be emphasized that, overall, this paper represents a significant addition to our understanding of the determinants of measured labor productivity variation over time. The modeling effort described here would have been useful by itself but is further enhanced by the development and use of new data on capital by two-digit industry. These data, presented and discussed in the referenced BLS Working Paper, should provide a useful base from which other researchers will be able to further investigate the subject of this Conference.

References

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