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5 Decisions of Firms and Productivity Growth with Fixed Input Constraints: An Empirical Comparison of U.S. and Japanese Manufacturing

Catherine Morrison

5.1 The Background

In the last few years a substantial body of literature has developed on comparing labor and multifactor productivity growth in the United States and Japan.[1] These studies indicate that a productivity gap still exists in favor of the United States for most industries in terms of productivity levels. However, the recent strong productivity growth experience of Japan as compared to the United States has caused productivity in some industries, such as steel, to overtake the corresponding U.S. industries, and in others this growth has caused a significant narrowing of the productivity gap. This trend has been particularly evident in the United States since the 1973 energy shocks, when Japan appeared to respond much more quickly to the constraints imposed by more expensive energy. Thus, although the energy price shocks of the 1970s likely contributed to depressed conditions in all industrial nations, the common belief is that the "snapback" response of the Japanese industries, as well as their investment and labor practices, enabled them to exploit further their productivity growth advantage.

Sato and Suzawa (1983) attribute the observed greater productivity growth in Japan to the responsiveness of its production process. They postulate that both workers and capital exhibit more flexibility in Japan than in the United States, facilitating higher productivity growth in Japan after major exogenous shocks. This was evident, they argue, after the energy price shocks of 1973–74, when Americans tended to react in disbelief while the Japanese reacted to

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a "national emergency" (p. 156). According to Sato and Suzawa, these very different responses stimulated U.S. workers to attempt to retain the same standard of living by demanding higher wage increases for the same level of work effort and U.S. firms to attempt to substitute relatively less expensive capital and labor for energy. This substitution away from energy was difficult, however, since this necessity was not anticipated when the existing energy-using technology was originally acquired. By contrast, the Japanese took stronger measures, including increased saving and investment and greater work effort, both contributing to a strong responsiveness to the energy price shocks and thus a productivity snapback.

In Sato and Suzawa's view the greater responsiveness in Japan may have stemmed at least in part from the Japanese "forcing the energy-capital relationship into a substitutable relationship" by recognizing that saving energy required augmenting labor input by increased work effort. The Sato-Suzawa arguments imply that capital and energy tended to be complements in the United States as contrasted to substitutes in Japan, and that labor was more substitutable with energy in Japan; thus even in the short run, energy responsiveness to its own price was higher in Japan.[2] This argument specifically recognizes the importance of the short-run-versus-long-run nature of both the energy-capital relationship and the interrelationship of these inputs with labor.

Several researchers have attempted to assess the validity of the assertions about relative flexibility in Japan and its impact on productivity trends. One way to approach this is to model explicitly substitution possibilities and the resulting input mixes in the two countries. A major example of this approach is Norsworthy and Malmquist (1983). In that study the authors employed a specification of the production structure including capital (*K*), labor (*L*), energy (*E*), and materials (*M*) inputs, whereas earlier productivity measurement approaches often were based on more restrictive assumptions. Norsworthy and Malmquist determined their richer structure could be used constructively to assess productivity growth trends, since it was more capable of capturing important characteristics of Japanese as compared to U.S. production. One of the most important of these characteristics in their view is the capital-energy interaction noted by Sato and Suzawa, which cannot be assessed in the common value-added framework. According to Norsworthy and Malmquist, energy-capital complementarity reflects "vulnerability" of a country to exogenous shocks since greater substitutability would allow industries to respond more effectively and therefore to snap back more easily after exogenous shocks. The Norsworthy-Malmquist results of energy-capital complementarity in the United States and substitutability in Japan, however, still depend on data only up to 1978. These results also are based on strong assumptions about instantaneous adjustment, assumptions that bypass the issue of short-run as compared to long-run responses, recognized as being so important by Sato and Suzawa.

This distinction between short- and long-run responsiveness clearly has important consequences for productivity growth since short-run adjustment may differ dramatically from the final long-run responses to a shock. Fixity of inputs, which causes the short run to differ from the long run, will tend to vary across countries since the capability of firms to adjust inputs will depend on the production structure. Empirical assessment of the data is necessary, therefore, to assess these relationships and their impact on the alleged responsiveness of U.S. and Japanese firms.

It is evident, for example, that the capital-adjustment responses of many industries to the 1973–74 and 1979–80 energy price shocks were torturously slow, even though it was immediately clear that current energy-capital configurations were no longer optimal. Such a tendency was possibly even stronger in the United States than Japan, but this is not clear. The available evidence also suggests that capital accumulation proceeded at a prodigious rate in Japan during the last two decades, slowing only slightly after 1973 and 1979. However, it is not clear whether this reflects extra flexibility of the Japanese production structure, perhaps because the Japanese are simply more rapid in replacing obsolescent capital stock, or instead implies that the existing small stock of capital was so greatly overutilized in Japan compared to the United States that a large investment rate was required to close the "gap."

Other inputs may also exhibit fixity. For example, it is often postulated that because of labor-hiring practices in Japan, the labor input has an important "permanent" and therefore fixed component that has no counterpart in the United States. However, it has also been asserted by, for example, Sato and Suzawa (1983), that the Japanese labor force is in some sense very flexible. The short-run fixed or flexible nature of both the capital and labor inputs crucially affects production and thus productivity, and the differential impact of the labor structure on the United States as compared to Japan is not clear a priori.

Although the effect of short-run fixities or flexibility on production responsiveness is crucial to incorporate into analyses of the production process and productivity growth trends, the extent of the impacts is inherently difficult to quantify. One way to approach this issue is to develop and empirically implement a framework in which the production decisions of firms are explicitly formulated to depend on short-run input stock rigidities. This type of model can then be used to construct economic measures of capacity utilization, shadow values of fixed factors, and short- and long-run demand elasticities. The resulting measures depend explicitly on the fixity of such inputs as capital and labor in production, and can be used to determine the relative flexibility of the production processes and the resulting impact on productivity growth. This type of framework, applied to recent U.S. and Japanese data series, could provide a basis for assessing the differential responsiveness of the United States and Japan to events of the 1970s.

In this paper I employ a cost-based framework proposed by Morrison (1986b) to estimate and analyze the impacts of quasi-fixed inputs on firm behavior and thus observed demand behavior, capacity utilization and productivity growth in the manufacturing sectors of the United States and Japan. This procedure allows a direct adjustment of standard productivity growth measures to take fixity of inputs into account. This provides some insights about the extent of deviations in productivity growth that are generated simply from limitations on firm behavior in the short run. I proceed as follows. In section 5.2 I first briefly develop the short run or restricted generalized Leontief (GL) cost function and its use for calculation of shadow values and capacity utilization measures employed for adjusting the productivity growth measures. I then carry out empirical implementation of this framework using a model allowing for fixity of both capital (*K*) and labor (*L*) to incorporate both fixed plant and equipment and labor hoarding or implicit contractual obligations with workers. Then, in section 5.3, I discuss empirical results, focusing on indexes of productivity and capacity utilization, and measures of short- and long-run demand elasticities in the manufacturing industries of the United States and Japan through 1981. In section 5.4 I provide brief concluding remarks.

5.2 The Theoretical Structure

Most current studies of short-run behavior are based on restricted cost functions such as the translog or quadratic function. Morrison (1986b) has developed an alternative GL restricted cost function that avoids the inability to obtain closed-form solutions for long-run values and the lack of invariance to normalization, problems that plague the translog and the quadratic forms, respectively.

The GL restricted cost function with long-run constant returns to scale (CRTS) imposed can be written as

$$\begin{aligned} G = {} & Y^{.5}\cdot[(\Sigma_i \Sigma_j \beta_{ij}\, p_i^{.5}\cdot p_j^{.5} + \Sigma_i \alpha_{it}\, p_i\cdot t^{.5})\cdot Y^{.5} \\ & + \Sigma_i \Sigma_k \delta_{ik}\, p_i\cdot x_k^{.5} + 2\cdot\Sigma_i p_i\cdot\Sigma_k\alpha_{kt}\, x_k^{.5}\cdot t^{.5}] \\ & + \Sigma_i p_i\cdot\Sigma_k \Sigma_l \gamma_{kl}\, x_k^{.5}\cdot x_l^{.5}, \end{aligned} \tag{1}$$

where x_k and x_l refer to quasi-fixed inputs *k* and *l*, p_i and p_j denote the prices of variable inputs *i* and *j*, respectively, *Y* is output, and *t* represents the state of technology.[3]

The above form is quite general. In particular, it can be used to represent a model with only capital fixed and all other inputs variable, it can also include fixed labor as an x_k variable, and it can even capture costs of adjustment for capital (and/or for labor) by including investment in x_k, $\dot{x}_k$, as an argument of the function.

For econometric implementation, greater efficiency in estimation can be attained by adding to (1) the optimal input-output equations for variable inputs derived from Shephard's lemma. Here such equations are of the form

$$(2)\quad \begin{aligned} \frac{\partial G}{\partial p_i}\frac{1}{Y} = \frac{v_i}{Y} = \sum_j \beta_{ij}\cdot(p_j/p_i)^{.5} + \alpha_{it}\cdot t^{.5} \\ + Y^{-.5}\cdot(\Sigma_k\, \delta_{ik}x_k^{.5} + 2\cdot\Sigma_k\alpha_{kt}\cdot x_k^{.5}t^{.5}) \\ + \Sigma_k\Sigma_l\, \gamma_{kl}\, x_k^{.5}x_l^{.5}/Y, \end{aligned}$$

where v_i denotes variable input i.

In addition, this function provides information on the shadow values of the quasi-fixed inputs, since

$$(3)\quad -\frac{\partial G}{\partial x_k} \equiv Z_k\,,$$

where Z_k is the shadow value of quasi-fixed input x_k—the potential reduction in variable costs from having an additional unit of x_k. For example, for quasi-fixed input x_k, this shadow value is

$$(4)\quad \begin{aligned} Z_k = -.5\cdot\{\Sigma_i p_i\cdot\gamma_{kk} + x_k^{-.5}\cdot[Y^{.5}\cdot(\Sigma_i\delta_{ik}\cdot p_i + 2\cdot\Sigma_i p_i\,\alpha_{kt}\cdot t^{.5}) \\ + \Sigma_i p_i \Sigma_l \gamma_{kl(k\neq l)}\cdot x_l^{.5}]\}. \end{aligned}$$

Note that the shadow valuation depends on all price levels, stocks of all quasi-fixed inputs, cyclical variations in output, and the state of technology.

The shadow value expressions can also be used as equations for estimation. It is possible to determine the ex post return to the fixed inputs as the gross operating surplus, $P\cdot Y-G=R_{\text{net}}$, where P is the price of output and R represents revenue. Under long-run constant returns to scale, with the competitive price equal to marginal cost and with only one quasi-fixed factor, x_k, Z_k can be calculated as $Z_k = R_{\text{net}}/x_k$ for the dependent variable for equation (4). If more quasi-fixed inputs exist—although there is no way independently to identify the returns to each of the different quasi-fixed inputs—it is possible to estimate a "sum-of-the-shadow-value" equation $\Sigma_k Z_k\cdot x_k = -\Sigma_k(\partial G/\partial x_k)\cdot x_k$ where the dependent variable is R_{net} and the right-hand side is the sum of the expressions in (4), each weighted by the given input levels.

Alternatively, the output price equation $P = MC$ proposed by Mork (1978) may be used for estimation, where MC is marginal cost, or $\partial G/\partial Y$ in the short run, and P is output price:

$$(5)\quad \begin{aligned} P = \frac{\partial G}{\partial Y} = \Sigma_i\,\Sigma_j\,\beta_{ij}\,p_i^{.5}\cdot p_j^{.5} + \Sigma_i\,\alpha_{it}\,p_i\cdot t^{.5} \\ + .5\cdot Y^{-.5}\cdot(\Sigma_i\,\Sigma_k\,\delta_{ik}\,p_i\cdot x_k^{.5} + 2\cdot\Sigma_i p_i\cdot\Sigma_k\,\alpha_{kt}\,x_k^{.5}\cdot t^{.5}). \end{aligned}$$

The output price equation should not be estimated along with the shadow value equation, however. Rather, because of their interdependence with constant returns to scale, they should be considered alternatives. Specifically, with CRTS, as shown by Lau (1978),[4]

$$(6)\quad 1 = \frac{\partial \ln G}{\partial \ln Y} + \Sigma_k\frac{\partial \ln G}{\partial \ln x_k} = \varepsilon_{GY} + \Sigma_k\varepsilon_{Gk}.$$

Thus the ε_{GY} and ε_{GK} elasticities are not independently identifiable for estimation; they must always sum to one.

The variable cost derivatives $\partial G/\partial p_i$, $\partial G/\partial x_k$, and $\partial G/\partial Y$ are not only the basis for constructing estimating equations, but they also contain useful information about short- and long-run input demands. Traditional price elasticities and elasticities of demand for v_i with respect to changes in output, or potential relaxation of the fixed input constraint, may be computed from the expression for $\partial G/\partial p_i$ based on (2). For example, since this expression represents v_i, short-run (SR) price elasticities are computed directly as

$$\varepsilon_{ij}{}^{\mathrm{SR}} = \partial \ln v_i/\partial \ln p_j \mid x_k = \bar{x}_k.$$

Calculation of the corresponding long-run (LR) elasticities requires appending the adjustment to the desired long-run level of the quasi-fixed inputs x_k^* from (7) below as

$$\varepsilon_{ijLR} = (p_j/v_i) \cdot [\partial v_i/\partial \mathrm{p}_j \mid x_k = \bar{\mathrm{x}}_k + \Sigma_k(\partial v_i/\partial x_k^*) \cdot (dx_k^*/dp_j)].$$

In addition, the variable cost derivatives include information on the shadow values of quasi-fixed inputs and therefore the extent to which a deviation exists between temporary and long-run equilibrium—the extent of "subequilibrium." This deviation can be expressed in terms of the costs of being away from full equilibrium, measured by the difference between the shadow values ($-G_k = Z_k$) and the ex ante rental or current market transaction values (p_k) of the individual quasi-fixed inputs. The extent of subequilibrium is even more directly measured by considering the difference between the given and "desired" (steady-state) levels of each the quasi-fixed inputs x_k and x_k^*, where x_k^* is the level of x_k implied by the steady-state equality $Z_k = p_k$.

Alternatively, subequilibrium indicators can be computed as scalar values combining all quasi-fixed inputs. Both cost and "primal" (quantity) perspectives can be represented in this scalar context analogous to the value and level or quantity measures for each individual input. Construction of such measures requires comparing the shadow and total cost function or the capacity and actual output levels, respectively. More specifically, the cost-capacity utilization index depends on the comparison of shadow costs defined as total costs with quasi-fixed inputs evaluated at their shadow values, SHCOST $= C^* = G + \Sigma_k Z_k x_k$, and total costs defined as $C = G + \Sigma_k p_k x_k$. On the primal side, capacity output is defined as the steady-state level of output, Y^*, calculated by solving for Y^* from the steady-state equality $C^* = C$ given quantities of all quasi-fixed inputs. Representation of the primal capacity-utilization measure then requires comparison of Y^* with the given output level Y.

Each of these measures of subequilibrium impacts is based on the difference between the Z_k and p_k and thus can be computed parametrically from the expression for Z_k in (4), even if this equation is not directly estimated. The resulting measures for x_k^* and Y^* may then be computed in a straightforward manner as closed-form solutions, given the GL framework.

More specifically, solving for x_k^* from the steady-state relationship $p_k = Z_k$ using (4) results in

$$(7)\quad x_k^* = \left[\frac{-Y^{.5}\cdot(\Sigma_i\delta_{ik}\cdot p_k + 2\cdot\Sigma_i p_i\,\alpha_{kt}\cdot t^{.5}) - \Sigma_i p_i \Sigma_{l\,(l\neq k)}\,\gamma_{kl}x_l^{.5}}{p_k + \Sigma_i p_i\cdot\gamma_{kk}}\right]^2.$$

An important point to note about this expression is that, although calculation of $x_k{}^*$ is straightforward for the one quasi-fixed input case, with multiple quasi-fixed inputs the long run depends on the movement of all quasi-fixed inputs. Thus, as long as $\gamma_{kl} \neq 0$, all the x_k^* expressions represented by (7) must be solved simultaneously to compute long-run values.

Capacity output can also be imputed given this ex ante price equals shadow value relationship, in which C^* equals C. Solving for the implied level of Y results in a steady-state value given variable input prices and the available stocks of quasi-fixed inputs or "capacity":[5]

$$(8)\quad Y^* = \left[\frac{-(\Sigma_k p_k\cdot x_k + \Sigma_i p_i \Sigma_k \gamma_{kk}\cdot x_k + \Sigma_i p_i \Sigma_k \Sigma_{l\,(l\neq k)}\,\gamma_{kl}x_k^{.5}x_l^{.5})}{\Sigma_i\Sigma_k\delta_{ik}\cdot p_{ik}x_k^{.5} + 2\cdot\Sigma_i p_i \Sigma_k\,\alpha_{kt}\cdot x_k^{.5}\cdot t^{.5}}\right]_2.$$

The comparison of these shadow value and quantity measures with their measured values is generally carried out in terms of ratios. Ratios in the scalar case in either form represent capacity utilization (CU). For example, on the primal side the ratio Y/Y^* is defined as capacity utilization, since it compares actual with capacity output. From (8), this measure is

$$(9)\quad \mathrm{CU}_y = Y/Y^* = Y\left[\frac{-(\Sigma_i\Sigma_k\delta_{ik}\cdot p_{ik}x_k^{.5} + 2\cdot\Sigma_i p_i\Sigma_k\,\alpha_{kt}\cdot x_k^{.5}\cdot t^{.5})}{\Sigma_k p_k\cdot x_k + \Sigma_i p_i\Sigma_k\gamma_{kk}\cdot x_k + \Sigma_i p_i\Sigma_k\Sigma_{l\,(l\neq k)}\,\gamma_{kl}x_k^{.5}x_l^{.5}}\right]^2.$$

With only one quasi-fixed input, CU_y is also equal to x_k^*/x_k from (7), reflecting the CRTS assumption. Thus, in this case x_k^*/x_k, a measure of *capital* utilization, is also a measure of *capacity* utilization; there are no cross-effects due to multiple fixed inputs.

The ratio of the desired to actual level of each quasi-fixed input, if $x_k^* > x_k$, reveals the proportional additional x_k required to reach a steady state, and therefore represents the amount the given stock of x_k is overutilized in terms of the short-run application of variable inputs. The converse—if $x_k^* < x_k$—is interpreted analogously. Similarly, if $Y > Y^*$, the CU_y ratio indicates the extent to which fixed inputs in general are overutilized—the shortage of available economic capacity. In reverse, if $Y < Y^*$, the fixed inputs are underutilized, and excess capacity exists.

The cost-side capacity-utilization measure CU_c, dual to $Y/Y^* = \mathrm{CU}_y$, can be calculated as C^*/C, where Z_k is evaluated at the given levels of x_k. This measure traces fluctuations similarly to CU_y, since both are based on a comparison of Z_k and p_k. However, CU may indicate larger or smaller variations, depending on the flatness of the short-run average cost (SRAC) curves. This CU_c measure is written as

$$\begin{aligned}(10)\qquad \mathrm{CU}_c &\equiv \frac{C^*}{C} = \frac{G + \Sigma_k Z_k x_k}{G + \Sigma_k p_k x_k} \\ &= 1 - \frac{\Sigma_k (p_k x_k - Z_k x_k)}{C} = 1 - \Sigma_k \varepsilon_{Ck},\end{aligned}$$

where $\varepsilon_{Ck} \equiv \partial \ln C / \partial \ln x_k$.

For a single fixed input, a similar indicator can be constructed as Z_k/p_k, which differs from CU_c because of the smoothing result of having G in both the numerator and denominator in the latter measure. Z_k/p_k represents the amount the particular input is over- (under-) valued relative to its market transaction cost to the firm and, therefore, indicates how much the firm will over (under) use input k by applying excess (insufficient) variable inputs to its use. Clearly this is also an indicator of investment incentives and, in fact, underlies the notion of Tobin's q, as has been shown by Abel (1979). CU_c reflects the same relationship for all fixed inputs in the aggregate.

Since these subequilibrium indicators reflect utilization that deviates from optimal levels, they can be used to compute the effects on productivity measures of misutilization of capacity. In the context of the cost framework in this study, this is equivalent to carrying out value adjustments for the quasi-fixed inputs to adjust for the impact of subequilibrium on observed productivity.

More specifically, Berndt and Fuss (1986) have demonstrated that a subequilibrium adjustment to productivity measures can be obtained by multiplying the prices of quasi-fixed inputs by a Tobin's q-type measure to revalue the quasi-fixed inputs at their shadow, instead of observed, prices. Alternatively, Morrison (1985b, 1986a) has used (10) as the motivation for a corresponding scalar CU adjustment of productivity for the effects of fixed inputs; her adjustment simply involves dividing the usual productivity growth measure by $\mathrm{CU}_c = 1 - \Sigma_k \varepsilon_{Ck}$.

To see this, say that total potential productivity growth measures from the cost side can be represented by $-\partial \ln C/\partial t = \varepsilon_{Ct}$. With quasi-fixed inputs, this becomes

$$(11)\qquad \varepsilon_{Ct} = (1 - \Sigma_k \varepsilon_{Ck}) \cdot \frac{\dot{Y}}{Y} - \Sigma_k \frac{Z_k x_k}{C} \cdot \frac{\dot{x}_k}{x_k} - \Sigma_j \frac{p_j v_j}{C} \cdot \frac{\dot{v}_j}{v_j}.$$

If one wishes to determine potential productivity, or true productivity with the effects of disequilibrium purged, it is necessary to calculate

$$(12)\qquad \varepsilon'_{Ct} = \frac{\varepsilon_{Ct}}{(1 - \Sigma_k \varepsilon_{Ck})} = \frac{\dot{Y}}{Y} - \Sigma_k \frac{Z_k x_k}{C^*} \cdot \frac{\dot{x}_k}{x_k} - \Sigma_j \frac{p_j v_j}{C^*} \cdot \frac{\dot{v}_j}{v_j},$$

where C^* represents shadow costs. Thus, to determine true productivity growth, it is sufficient simply to divide the observed productivity change by $(1-\Sigma_k \varepsilon_{Ck}) = \mathrm{CU}_c$.[6]

The shadow value, CU, and productivity measures discussed above provide one set of indicators that reflect the effects of subequilibrium. In addition, elasticities may be specified to determine the impacts of changes in exogenous variables on subequilibrium. For example, given the analytical representations of x_k^* in (7) and Y^* in (8), elasticities with respect to these values (and therefore with respect to the corresponding subequilibrium indicators such as CU_y) may be computed. In addition, although the expression is slightly more complex, (1) implies that CU_c may also be written analytically so elasticities of cost CU (CU_c) with respect to an exogenous change may also be computed.

For example, the desired fixed input and capacity output elasticities are

$$\text{(13a)} \qquad \varepsilon_{kj}^* = \frac{\partial \ln x_k^*}{\partial \ln p_j} = \frac{p_j}{x_k^*} \cdot \frac{\partial x_k^*}{\partial p_j}$$

and

$$\text{(13b)} \qquad \varepsilon_{Yj}^* = \frac{\partial \ln Y^*}{\partial \ln p_j} = \frac{p_j}{Y^*} \cdot \frac{\partial Y^*}{\partial p_j} ,$$

where x_k^* and Y^* are given by (7) and (8) above and where ε_{kj}^* is inversely related to ε_{Yj}^* if only one quasi-fixed input exists. ε_{kj}^* has the same sign as the elasticity of $\mathrm{CU}_y = Y/Y^*$ with respect to p_j. With multiple quasi-fixed inputs, the direct relationship between ε_{Yj}^* and the ε_{kj}^* is lost and the full relationship between changes in x_k^* and x_l^* must be recognized.[7] For example, the long-run desired level of each quasi-fixed input depends on the long-run level of the other inputs; not only the x_k^* but also all other long-run elasticities must be computed simultaneously.

To clarify this notion, consider the following, which is based on the CRTS assumption. CRTS conditions imply that the long-run output elasticity $d \ln x_k / d \ln Y$ is equal to one, or, equivalently, dx_k/dY is equal to x_k/Y. If this is not the case, some intermediate output elasticity of the quasi-fixed input with respect to Y is incorporated into this elasticity. For this condition to hold, the full long run must be captured by dx_k/dY, or, if the implications of this constraint from CRTS are derived from the expression for x_k^*, it must be the case that

$$\text{(14)} \qquad \frac{dx_k}{dY} = \frac{\partial x_k}{\partial Y} + \Sigma_l \frac{\partial x_k}{\partial x_l} \frac{dx_l}{dY}.$$

Clearly, since dx_k/dY and dx_l/dY are interdependent, they must be solved simultaneously. Note that this also has implications for construction of the long-run demand elasticities mentioned above since the long-run adjustment component is made up of the individual x_k^* elasticities.

The ε^*_{kj} and ε^*_{Yj} elasticities can be interpreted as utilization elasticities because they indicate whether an increase in the price of a variable input j causes further over- (under-) utilization, or whether the existing over- or underutilization is attenuated. If the existing stock of x_k is too low, for example, and an increase is p_j causes x^*_k to increase further relatively to x_k, this implies further overutilization of x_k relative to the optimum because optimally the firm wants to cut back on input j; inputs k and j are substitutes in the long run. Another way to interpret this is that, if an increase in input price p_j causes the desired capital level to increase, it is equivalent to an increase in x_k being input j saving. Thus when the stock of x_k is too low there is overutilization of x_k via extra use of input j in the short run, also indicating that x_k and v_j are substitutes.

The elasticity of Z_k with respect to p_j may also be computed. This elasticity, $\partial \ln Z_k/\partial \ln p_j$, is a valuation-utilization measure; if the price of a variable input increases, for example, and Z_k increases, the value of x_k on the margin has increased, implying additional overutilization of the existing x_k.

By definition, the total fixed input valuation elasticity $\partial \ln \mathrm{CU}_c/\partial \ln p_j$ will be a function of the individual $\partial \ln Z_k/\partial \ln p_j$ elasticities with the form

$$(15) \qquad \frac{\partial \ln CU_c}{\partial \ln p_j} = S^*_j \cdot (1 - CU_c) + \Sigma_k \frac{\partial \ln Z_k}{\partial \ln p_j} \cdot S^*_k = \varepsilon^*_{CUj},$$

Where S^*_j is defined as $p_j v_j/C^*$ and S^*_k is $Z_k x_k/C^*$. These value or cost-side elasticities are closely related to the primal elasticities ε^*_{kj} and ε^*_{Yj}. In particular, ε^*_{CUj} and ε_{Zkj} will have the same sign with one quasi-fixed input, as will ε^*_{kj}, although ε^*_{Yj} will be inversely related as mentioned above because it represents capacity output rather than utilization. If multiple quasi-fixed inputs exist, however, the individual shadow value and desired input elasticities ε_{Zkj} and ε^*_{kj} will be the same sign since an increased valuation of input x_j implies a greater desired level of the input, and the full capacity output elasticity that will depend on the overall pattern of all the fixed inputs will be the opposite sign of the utilization elasticity ε^*_{CUj}.

5.3 Comparing the United States and Japan: Empirical Results

5.3.1 Introduction

For empirical implementation of the framework discussed above, the relevant variable and fixed inputs and the estimating methods must be determined. The model used for the empirical results below includes four inputs: capital (K), labor (L), energy (E) and nonenergy intermediate materials (M), where both K and L are fixed in the short run. The cost function for this specification is therefore $G(K,L,p_E,p_M,t,Y)$. A priori information about quasi-permanent hiring of labor in Japan, as well as important rigidities in the United States from labor contracts, imply that this specification with fixed labor as well as fixed capital may provide useful insights.

Alternative specifications including a one quasi-fixed input model and also a dynamic specification were attempted, but the fixity of labor appeared important for reasonable computation of CU measures, and the dynamic specification generated less significant estimates and therefore less robust results. Thus the two quasi-fixed static specification was chosen as the preferred model for presentation. The overall patterns of the results for the alternative models were close to those generated by the specification reported here. In addition, previous estimation was also carried out using data from Norsworthy and Malmquist (1983). As will be noted, however, the results for the Japanese data including post-1978 information differ, in some cases substantially, from results based on the Norsworthy-Malmquist data omitting the second OPEC price shock.

The base estimating equations are the input-output equations for E and M. In addition, the shadow-share or output-price equation may be appended to this system. For the empirical results below the output-price equation was used as the additional estimating equation, although empirical results were quite robust when the alternative shadow-value equation was estimated instead. When neither the shadow-value nor output-price equation was employed, the γ_{KK} parameter—critical in determining the sign and size of Z_K—tended to be statistically insignificant, although close in magnitude to the other specifications.

The U.S. and Japanese data used to generate the results for U.S. manufacturing 1952–81 are from Berndt and Wood (1984) and for Japanese manufacturing 1955–81 are from Takamitsu Sawa (1986). The Sawa data were constructed using the same principles as the Berndt and Wood data, but from Japanese sources.

The pooling method used in this paper is a structural approach; different first-order terms are added to the cost function so that the derived input demand equations have country-specific intercepts. An additive disturbance term was appended to each of the demand and output-price equations, and the resulting vector was assumed to be independently and identically normally distributed with mean vector zero and constant nonsingular covariance matrix. Estimation of the equation system was carried out using the method of maximum likelihood.

The remaining subsections in section 5.3 provide empirical estimates of the different types of measures discussed in the previous section. Section 5.3.2 briefly summarizes the parameter estimates of the model. Section 5.3.3 outlines the unadjusted productivity growth estimates from the data, focusing on the similarities and differences of the trends in the United States and Japan. Section 5.3.4 includes measures of capacity utilization and their components—the desired to actual quasi-fixed input and shadow to market value ratios—to reflect the impacts of short-run rigidities. Section 5.3.5 returns to productivity measurement and discusses the adjustment of productivity indexes to take capacity-utilization fluctuations into account. Section 5.3.6 moves into an overview of substitution elasticities and the flexibility implied by these measures. Finally, based on CU elasticities, Section 5.3.7 provides evidence concerning the impacts of exogenous changes on capacity utilization.

5.3.2 Parameter Estimates

The first estimates to consider briefly are the parameter estimates presented in table 5.1. Differences in the first-order terms of the cost function between Japan and the United States are measured by the parameters α_{MJ}, α_{EJ}, γ_{KJ}, γ_{LJ}, and γ_{KLJ}. Note that, except for these country-specific parameters, most of the parameter estimates are statistically significant; the only country-specific parameter that is significant is α_{MJ}. This suggests that the determinants of manufacturing firms' demand for intermediate materials differs in the two countries, although in other dimensions production processes are quite similar in the two countries. For example, the statistical insignificance of γ_{LJ} and γ_{KLJ} indicate a lack of important deviations in Japanese labor practices from those in the United States. The above results suggest, therefore, that the structure of

Table 5.1 **General Leontief Restricted Cost Function Maximum-Likelihood Parameter Estimates for U.S. and Japanese Manufacturing**

Parameter	Estimate and Asymptotic *t*-Statistic	Parameter	Estimate and Asymptotic *t*-Statistic
β_{EM}	.0190	γ_{KJ}	−2.2303
	(6.366)		(1.7225)
β_{EE}	.2635	δ_{EK}	−.4058
	(9.224)		(3.206)
β_{MM}	1.7542	δ_{MK}	−2.0491
	(46.091)		(14.659)
α_{Et}	−.0141	γ_{LL}	.8804
	(5.384)		(2.182)
α_{Mt}	−.0569	γ_{LJ}	−.2550
	(11.671)		(.700)
α_{EJ}	.0076	δ_{EL}	−.5881
	(1.595)		(11.480)
α_{MJ}	.1526	δ_{ML}	−1.1272
	(15.597)		(17.575)
γ_{KK}	3.6858	γ_{KL}	−.4650
	(2.808)		(.6124)
α_{Kt}	−.0356	γ_{KLJ}	.7486
	(5.397)		(1.080)
α_{Lt}	.0385		
	(2.664)		

Note: Absolute values of asymptotic *t*-statistics are in parentheses.

the labor market in manufacturing, as well as that for energy and capital, does not differ fundamentally between the United States and Japan.

By themselves, the parameter estimates do not provide very much interpretable information. To assess the differential economic performance in U.S. and Japanese manufacturing, productivity growth must be computed along with measures of capacity utilization and demand responses to events in the 1970s. Further, their impact on productivity growth must also be assessed based on these parameter estimates.

5.3.3 Productivity Growth

Productivity growth estimates for the United States and Japan appear in table 5.2, in terms of percentage growth indexes of multifactor productivity by year and averages for selected periods. I first consider the unadjusted or traditional productivity growth measures.

An overview of table 5.2 suggests that trends in productivity growth were surprisingly similar for the two countries, although at different levels. At least three dominant differences draw attention, however.[8] First, when Japanese productivity increased, it often did so more dramatically than did U.S. productivity. This can be seen particularly clearly in 1958, 1960, and 1981. Not surprisingly, therefore, on average Japanese productivity growth was greater than for the United States. Second, the mid to late 1960s were years of particularly strong productivity growth for Japan but not for the United States. Finally, the downturn in 1974–75 was experienced even more dramatically by Japan (especially in 1974) than by the United States, although the subsequent upturn is better maintained in Japan.

One important implication of these traditional measures is that, although Japanese productivity growth is generally better than in the United States, it did not clearly snap back after 1975, leaving the United States behind; 1976 and 1977 were years of very similar productivity growth in both countries. In addition, these numbers imply that the Japanese manufacturing sector really did have a more critical post-1973 crisis. Although U.S. productivity took a sudden downturn, Japanese productivity fell even more abruptly at a negative growth rate of over 5%. While this downward productivity shock was severe, the overall trend is not strongly downward from that point onward in either country.

This last conclusion is not directly obvious from the productivity growth averages presented at the bottom of table 5.2. The post-1973 traditional productivity growth rates for both the United States and Japan are substantially below the average for the entire sample and, in fact, are very similar for both countries at approximately .5% per year. However, from the 1973–76 and 1973–78 averages it is evident that this result is due to the terrible productivity growth performance in 1974–75. In fact the averages after 1975 are very high, especially for Japan; they are much higher than the average over the entire time period and are nearly as high as they were in the United States during

Table 5.2 **Primal Output and Dual Cost Productivity Growth (%) Indexes and Productivity Growth Average for U.S. and Japanese Manufacturing**

	U.S. Traditional		U.S. Adjusted		Japanese Traditional		Japanese Adjusted	
Year	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity
Growth by years:								
1952	.334	.362	.317	.319				
1953	1.320	1.320	1.259	1.117				
1954	−.664	−.664	−.642	−.615				
1955	3.035	3.035	2.908	2.733				
1956	−.880	−.881	−.859	−.830				
1957	−.692	−.692	−.680	−.663	.645	.646	.574	.523
1958	1.622	1.623	1.585	1.540	4.596	4.592	4.212	3.932
1959	.716	.716	.705	.690	.325	.325	.291	.263
1960	2.071	2.073	2.009	1.925	4.414	4.414	3.837	3.264
1961	.331	.331	.322	.310	1.153	1.154	.995	.824
1962	2.679	2.679	2.601	2.488	1.843	1.841	1.614	1.366
1963	−.188	−.188	−.183	−.175	.726	.725	.641	.554
1964	2.431	2.431	2.364	2.260	.302	.302	.266	.226
1965	.800	.800	.776	.736	.132	.132	.118	.102
1966	−.957	−.957	−.937	−.905	1.525	1.525	1.336	1.118
1967	−.184	−.184	−.182	−.179	3.164	3.164	2.734	2.161

1968	1.051	1.051	1.049	1.045	2.935	2.935	2.526	1.935
1969	.430	.430	.431	.432	2.294	2.294	1.988	1.514
1970	−1.198	−1.198	−1.229	−1.276	2.658	2.658	2.310	1.749
1971	1.494	1.494	1.525	1.572	−.345	−.346	−.309	−.256
1972	2.266	2.266	2.268	2.272	1.161	1.161	1.045	.871
1973	2.636	2.636	2.586	2.505	1.269	1.269	1.132	.922
1974	−1.124	−1.156	−1.110	−1.124	−5.438	−5.438	−5.269	−5.174
1975	−1.107	−1.109	−1.111	−1.117	−1.253	−1.255	−1.279	−1.302
1976	1.838	1.844	1.797	1.755	1.627	1.627	1.615	1.605
1977	1.491	1.491	1.448	1.398	1.030	1.030	1.007	.988
1978	.648	.647	.633	.615	2.423	2.423	2.445	2.468
1979	.642	.640	.628	.613	1.999	1.999	2.007	2.015
1980	.204	.197	.207	.202	.328	.316	.334	.326
1981	1.505	1.506	1.552	1.582	2.954	2.954	3.000	3.027
Average annual growth rate:								
1956–81	.7746	.7762	.7622	.7400	1.2987	1.2979	1.1668	1.0008
1956–65	1.0859	1.0855	1.0554	1.0123	1.5707	1.5701	1.3942	1.2282
1965–73	.6922	.6922	.6889	.6832	1.8326	1.8325	1.5952	1.2518
1973–76	−.1403	−.1310	−.1413	−.1620	−1.6880	−1.6887	−1.6443	−1.6237
1973–78	.3434	.3492	.3314	.3054	−.3222	−.3226	−.2962	−.2830
1973–81	.5075	.5121	.5055	.4905	.4588	.4570	.4825	.4942
1975–81	1.0541	1.0547	1.0442	1.0275	1.7268	1.7248	1.7347	1.7382

1956–65 and in Japan during 1965–73, the previous maxima. This is the case even with the decrease to a .33% growth rate in 1980 in Japan following the 1979 energy price shocks. The impact was not nearly as severe as it was after 1973 and was accommodated quickly, particularly in Japan. Assertions about a substantial post-1973 productivity slowdown in the United States, therefore, as well as those postulating much stronger and faster recovery in Japan, appear from this data to have less basis than casual empiricism would suggest.[9]

The average growth rates also highlight other earlier similarities and differences between U.S. and Japanese productivity patterns. For example, both countries exhibited high growth rates in the 1956–65 time period, with Japanese productivity in manufacturing almost .5% higher per year than in the United States. It is significant that the 1965–73 period for the United States is the beginning of a downturn, whereas this period for Japan is one of even higher productivity growth.

One interpretation of the strong decrease in productivity growth in 1974–75 is that the decrease can be attributed to the energy price shocks of 1973–74, as can the smaller drop in 1980 after the 1979 shock. Assuming this is the case, the response to and recovery from the first energy price increase appears relatively slow for both countries, contrary to the postulated comparative productivity patterns suggested from the literature. The response to the 1979 price shock, however was relatively rapid in Japan.

These productivity measures suggest that the difference between countries does not seem nearly as strong as is often suggested. It is, however, true that Japan recovered from a far worse crisis in 1974 and retained its larger productivity growth for a more complete recovery, including even the 1979 experience with further price increases. This recovery may have been a result of numerous characteristics of the production process, many of which were postulated in the introduction to this paper, such as differences in capacity utilization and overall flexibility of the substitution process in Japanese as compared to U.S. manufacturing. Such issues can be addressed by considering (i) capacity utilization indexes and their impact on productivity measures, (ii) shadow values (and implied desired levels) of the fixed inputs, and (iii) elasticities of both demand and capacity with respect to exogenous shocks.

5.3.4 Capacity Utilization

Greater overall flexibility has been postulated to be an important determinant of relative productivity trends in the United States and Japan. This may manifest itself as stronger short-run responses and therefore more optimal short-run capacity utilization performance in Japan as compared to the United States. The empirical issue is, therefore, how much impact fixity has on shadow values and utilization and thus on productivity and demand responses. Measures of capacity utilization and elasticities developed in the previous section can be used to assess this impact.

First consider the estimated CU indexes presented in table 5.3. Recall that

Table 5.3 **Cost and Quantity CU indexes, CU_c and CU_y**

	United States		Japan	
Year	CU_c	CU_y	CU_c	CU_y
1952	1.0535	1.1328		
1953	1.0485	1.1247		
1954	1.0340	1.0802		
1955	1.0436	1.1103		
1956	1.0253	1.0619	1.0997	1.1707
1957	1.0186	1.0440	1.1235	1.2358
1958	1.0235	1.0540	1.0912	1.1679
1959	1.0158	1.0381	1.1178	1.2364
1960	1.0310	1.0767	1.1502	1.3524
1961	1.0270	1.0662	1.1592	1.4002
1962	1.0300	1.0768	1.1414	1.3484
1963	1.0276	1.0725	1.1318	1.3101
1964	1.0282	1.0754	1.1355	1.3364
1965	1.0312	1.0872	1.1228	1.2956
1966	1.0208	1.0567	1.1415	1.3642
1967	1.0109	1.0288	1.1573	1.4638
1968	1.0021	1.0056	1.1619	1.5170
1969	.9986	.9964	1.1540	1.5153
1970	.9748	.9394	1.1505	1.5202
1971	.9797	.9507	1.1168	1.3536
1972	.9990	.9975	1.1117	1.3324
1973	1.0191	1.0520	1.1204	1.3759
1974	1.0125	1.0293	1.0321	1.0680
1975	.9966	.9930	.9800	.9641
1976	1.0229	1.0504	1.0076	1.0139
1977	1.0294	1.0663	1.0227	1.0428
1978	1.0232	1.0527	.9908	.9816
1979	1.0212	1.0445	.9960	.9922
1980	.9860	.9757	.9820	.9706
1981	.9696	.9520	.9784	.9761

CU indexes are defined to exceed unity when the valuation of the fixed inputs on the margin exceeds their ex ante market value, that is, when there is a shortage of existing capital and/or labor and thus these stocks are overutilized in terms of the application of variable inputs. These indexes summarize information, therefore, on the measured shadow values and K^* and L^*; CU > 1 if $Z_K > p_K$ and $Z_L > p_L$, which implies that $K^* > K$ and $L^* > L$. If, however, one fixed input is over- and one underutilized, the combined effect will depend on which impact is dominant.

The first comparison is that between the output or primal CU measure, CU_y, and the cost CU measure, CY_c. CU_c is always closer to 1.0, which implies that costs change less than output in response to shocks and that the corresponding short-run average total cost curves are somewhat "flat." This is particularly true for Japan, where the primal measure is in some cases quite large (around 1.5 in the late 1960s), indicating substantial shortage of capacity until 1978. Note also that the CU values tend to exceed one in most years, consistent with previous economic CU measures computed by, for example, Morrison and Berndt (1981).

The most important comparison of the CU measures is, however, across countries. As with the productivity measures, one surprising and dominant tendency is that the capacity utilization measures exhibit similar trends for both countries. In particular, both 1975 and 1980–81 were periods of substantial drops in capacity utilization, particularly for Japan. In addition, there is a general downward trend in utilization of capacity in both countries. Differences are also evident, however, including an increase in capacity utilization (overutilization) in Japan in 1970, whereas CU decreased substantially in the United States from 1969–72. Also, both the downward trend over time, and the drops in CU in 1975 and the late 1970s to early 1980s are more dramatic in Japan than for the United States.

Note also that the difference between pre- and post-1973 capacity utilization was more substantial in Japan than in the United States. Japan, in fact, appears to have adjusted further from events in 1973 than did the United States, at least in terms of capacity utilization. Although before 1973 a shortage of capacity of nearly 50% (or 14% in terms of costs) was evident, after 1973 the existing capacity was sufficient and, in fact, in many cases excessive. In 1980, after the 1979 energy price shocks, utilization remained below one, and was lower than for the United States except for 1981.

One important tendency to recognize is that the Japanese capacity utilization indexes suggest greater deviations from optimal capacity utilization over time, at least before 1973. This may imply that the production process is not as flexible as is sometimes postulated. If great flexibility existed, adjustment of the quasi-fixed inputs would be carried out to a more optimal level—CU would more closely approximate one. Alternatively, it more likely reflects the very large capacity gap existing early in this time period from a very low postwar level of capital stock and high and increasing demand for products, so that even with rapid adjustment Japan was not able to close the gap quickly.

The patterns noted in the CU measures could result from adjustment trends of either labor or capital. The resulting implications, therefore, could differ substantially depending on which of these inputs is imposing the constraints. From the raw data, for example, it appears that in Japan capital has adjusted amazingly quickly; capital accumulation has been extremely rapid during most of the time period under discussion. Note that the difference between the U.S. and Japanese investment to capital rates declined but was still evident after 1974. By contrast, labor input has remained fairly steady throughout the period. This is reflected in the trends of the shadow value to market rental price ratios for capital and labor, and the ratios of the desired to existing levels of these fixed inputs, presented in table 5.4. These ratios suggest that the shortage of capacity appearing in table 5.3 results primarily from a shortage in the capital input for both countries. Labor does not have much of an impact, and, particularly in the United States, actually tends to temper the evidence of a shortage of capacity.

In particular, note that these ratios reflect a strong incentive for investment in capital in both countries. In some years the capital quantity ratio suggests that more than twice as much capital as was available would have been desired by Japanese manufacturing firms. This ratio peaks in the late 1960s, when productivity was very high in Japan. Its lowest value is in the 1980–81 period, a level which, it should be noted, appears to result not only from energy price increases but at least partly from a substantial increase in the ex ante market rental price, p_K, as well.

At the same time, some incentives to expand employment existed in Japan, although this pressure was relatively negligible. At its peak in 1961, less than a 20% expansion would have been desired, and after 1971 lower employment than was actually hired would have been desired. For the United States the labor stock seems always to have been too high; excess labor is evident for all years in the sample, although the difference is rather small in 1980–81.

These patterns provide limited evidence of more flexibility in Japanese than U.S. production, especially with respect to capital. Although the desired to actual capital stock ratio in Japan is higher than for the United States, a larger percentage of the "gap" is closed each period;[10] for similar differences in levels a much larger investment rate is reflected in the Japanese data. This flexibility is also somewhat evident for labor, not due to more substantial employment expansion but because the ratios more closely approximate one in Japan than in the United States. Therefore, although the overall capacity-utilization ratios suggest that Japan is further from optimality, these individual input ratios suggest more adjustment toward the optimum, especially for capital, which is the main factor behind the deviation from one in the CU ratio. The reason that the United States appears closer to the optimum in total is at least partly because of the tempering effect of the low levels of desired labor stock.

Although the investment incentive for capital was smaller in the United States than Japan, peaking at an extra 75% of the existing capital stock desired in 1965, the strength of this investment incentive is surprising given the much lower investment rate in the United States as compared to Japan. This may arise, however, because of obsolescence. Specifically, one interpretation of this result is that, on the margin, investment in capital is desirable in the United States, but the manufacturing sector is weighted down by excessive capacity from previous years, so the average valuation of the existing capital is very low. This may cause sluggish responses by firms "stuck" with this inefficient capital. By contrast, in Japan most capital is relatively new given the recent history of rapid investment, so the marginal and average valuations of the capital stock may be more closely related.

One other interesting feature of the fixed input and shadow-value ratios

Table 5.4 **Shadow Value and Fixed Input Ratios**

	United States				Japan			
Year	Z_K/p_K	Z_L/p_L	K^*/K	L^*/L	Z_K/p_K	Z_L/p_L	K^*/K	L^*/L
1952	2.217	.910	1.451	.926				
1953	2.322	.871	1.514	.893				
1954	2.210	.843	1.416	.870				
1955	2.104	.870	1.445	.891				
1956	1.856	.833	1.382	.860	1.626	1.057	1.544	1.023
1957	1.957	.800	1.390	.831	1.767	1.160	1.701	1.069
1958	2.107	.808	1.378	.836	1.568	1.040	1.509	1.019
1959	2.068	.772	1.429	.801	1.698	1.134	1.650	1.066
1960	2.554	.762	1.565	.792	1.904	1.282	1.883	1.154
1961	2.532	.751	1.553	.781	1.934	1.306	1.913	1.191
1962	2.638	.738	1.637	.767	1.792	1.215	1.749	1.149
1963	2.689	.724	1.674	.750	1.761	1.118	1.693	1.087
1964	2.689	.718	1.702	.744	1.752	1.137	1.694	1.110

1965	2.651	.717	1.756	.738	1.681	1.069	1.613	1.059
1966	2.575	.687	1.746	.711	1.820	1.100	1.746	1.081
1967	2.455	.674	1.672	.696	1.953	1.141	1.911	1.136
1968	2.331	.661	1.631	.677	2.080	1.112	2.040	1.116
1969	2.336	.649	1.633	.664	2.038	1.067	2.032	1.074
1970	2.026	.631	1.470	.646	1.994	1.045	2.006	1.053
1971	1.957	.652	1.433	.664	1.780	.916	1.736	.899
1972	2.113	.670	1.532	.680	1.810	.851	1.750	.818
1973	2.194	.705	1.587	.719	1.810	.875	1.785	.842
1974	1.575	.812	1.251	.844	1.230	.862	1.174	.846
1975	1.417	.824	1.145	.857	1.071	.759	1.047	.737
1976	1.873	.819	1.270	.851	1.176	.786	1.114	.766
1977	1.925	.827	1.292	.858	1.263	.775	1.168	.748
1978	1.821	.814	1.280	.847	1.119	.738	1.090	.693
1979	1.653	.854	1.201	.888	1.099	.792	1.073	.760
1980	1.046	.923	1.011	.947	.969	.917	.981	.914
1981	.841	.959	.952	.973	.985	.906	.992	.903

worth noting is that Japan's decrease in overall capacity utilization over time results from a decrease in the desired levels of both capital and labor stocks, even though pressure in the capital market is the dominant force. By contrast, in the United States the downward trend in capacity utilization stems primarily from capital utilization; the desired labor stock relative to its existing level drops to its lowest value in the late 1960s and then recovers to above its original levels.

Finally, it should be noted that changes in the production structure that apparently resulted from the dramatic increases in energy prices in 1973, and the correspondingly smaller adaptations due to the 1979 price increases, had a very strong impact on the desired to actual capital ratio for both countries. In particular, in 1974 the desired capital ratio in the United States dropped 21% from 1.587 to 1.251, and in Japan it decreased 34% from 1.785 to 1.174, indicating a strong difference in the production structure. Similarly, in 1980 the ratios dropped 17% from 1.201 to 1.001 (and then 5% more to .952 in 1981) for the United States and 1.073 to .981 (a 9% drop followed by a 1% increase to .992 in 1981) for Japan. One important point to note here is that although the implied "gap" between desired and actual levels of capital therefore decreased more substantially in Japan than in the United States, the investment response was different in the two countries; Japanese investment remained relatively strong.

By contrast, the desired to actual labor ratio in 1974 and 1980 increased in the United States from .719 to .844, and .888 to .947, respectively, and, during those same time periods, in Japan from .842 to .846 and .760 to .914. Although this is not nearly as strong an effect, it suggests that the energy price increases stimulated relative labor as compared to capital efficiency as seen by manufacturing firms.

5.3.5 Adjusting Multifactor Productivity for Capacity Utilization

The impact of capacity utilization, as reflected in the CU measures in table 5.3, may be used to adapt measured productivity growth, as presented in table 5.2, to take into account the impacts of short-run fixity. This results in the adjusted indexes presented in table 5.2. Since the CU measures fluctuate much less than the productivity measures, the impact of this adjustment is not large on either the indexes or the averages.

For example, for the United States, over the 1956–81 time period the traditionally measured average annual productivity growth rate is approximately .77%, while the adjusted rate is .74% to .76%, depending on whether the adjustment is carried out on the primal or dual cost side. The larger pre-1975 than post-1965 productivity growth and short 1973–76 productivity slowdown remains almost unaffected in the adjusted averages; the 1965–73 growth rate is .69% and the 1973–76 rate is −.13% for the traditional numbers (cost side), and approximately .68% and −.14% to −.16% respectively, once adjusted. Similarly, the 1973–81 rates and 1975–81 rates, traditionally measured averages of .51% and 1.05%, correspond to adjusted averages of .49% to .50% and 1.03% to 1.04%. Therefore, although the trends in CU in the United States are substantive, their impact on productivity fluctuations is modest at best and the traditionally measured productivity growth trends remain.

The implications from the capacity-utilization adjustments to productivity trends for Japan are similar, although the adjustments are slightly larger. For example, the traditionally measured overall average is 1.3% per year, which corresponds to the CU-adjusted average of between 1.0% and 1.2%. This average is made up of a 1.57% traditional—or 1.23% to 1.39% adjusted—average growth rate in the first part of the time period, increasing to a 1.83% traditional—1.25% to 1.6% adjusted—annual increase in the 1965–73 time period. The drop to a 1.67% (1.62% to 1.64% adjusted) *decline* in productivity during the 1973–76 period remains in the adjusted numbers as a 1.62% to 1.64% decrease on average, still driven by the extreme value in 1974 even though it is tempered somewhat by a corresponding decrease in CU. This average increases to a .46% (.48% to .49%) rate of growth in the 1973–81 period or 1.73% (1.74% adjusted) productivity growth after 1975.

One point worth noting about these values in Japan is that the adjusted 1975–81 average yearly growth in productivity appears even stronger than the maximum traditionally measured productivity growth average from the 1965–73 time period. This again emphasizes that productivity growth does not appear to be on a general downward trend following the 1974–75 fiasco.

In summary, the measured post-1973 productivity growth indexes for Japan slightly underestimate average productivity growth, whereas for pre-1973 they overestimate productivity. That is, the shortage of capacity in earlier years caused the marginal productivity of the quasi-fixed inputs to be higher than traditionally measured, implying that "true" productivity must be revalued downward. Thus only a small part of the alleged decrease in Japanese productivity growth may be attributed to changes in capacity utilization. This trend also appears very weakly in the U.S. indexes; it is not as powerful because the downward trend in capacity utilization is not as evident. The overall effect of fixity for both countries, however, is small compared to the extreme variations in productivity.

5.3.6 Substitution Elasticities

Another way to assess the flexibility of the production processes in the U.S. and Japan is in terms of substitutability patterns among inputs. The relevant elasticities necessary for consideration of relative substitutability in the short and long run are presented in table 5.5.

One striking implication of these elasticities is the similarities among them for the two countries. At first glance it may appear that this is simply the result of the structural pooling process with different first-order terms but equal second-order effects. However, preliminary work presented in Morrison (1985c) using the same procedures but data only through 1978 did not find

Table 5.5 **Selected Elasticities (reported for 1980)**

Parameter	United States		Japan	
	A. Variable Input Price Elasticities			
	SR	LR	SR	LR
ε_{EE}	−.1586	−.5906	−.1577	−.4776
ε_{EM}	.1586	.5584	.1577	.7311
ε_{EL}		.2914		.3739
ε_{EK}		−.2592		−.6274
ε_{EY}	.4506	1.0000	.3326	1.0000
ε_{ME}	.0285	.1005	.0309	.1316
ε_{MM}	−.0285	−.4511	−.0309	−.5972
ε_{ML}		.2445		.1138
ε_{MK}		.1061		.3517
ε_{MY}	1.6354	1.0000	1.7804	1.0000

Parameter	United States	Japan
	B. Long-Run Fixed Input Elasticities	
ε_{LE}	.1376	.3254
ε_{LM}	.6416	.5506
ε_{LL}	−.7259	−1.0840
ε_{LK}	−.0533	.2080
ε_{LY}	1.0000	1.0000
ε_{KE}	−.3001	−.2482
ε_{KM}	.6824	.7732
ε_{KL}	−.1306	.0945
ε_{KK}	−.2516	−.6195
ε_{KY}	1.0000	1.0000
	C. Shadow-Value Elasticities	
$\varepsilon_{ZL,E}$	.2633	.2376
$\varepsilon_{ZL,M}$	.7367	.7624
$\varepsilon_{ZL,L}$	−1.5106	−.9898
$\varepsilon_{ZL,K}$	.3197	−.3491
$\varepsilon_{ZL,Y}$	1.1908	1.3389
$\varepsilon_{ZK,E}$	−1.2515	−.4367
$\varepsilon_{ZK,M}$	2.2515	1.4367
$\varepsilon_{ZK,L}$	.7309	−.1666
$\varepsilon_{ZK,K}$	−3.9712	−1.8430
$\varepsilon_{ZK,Y}$	.0036	.0020
	D. Capacity-Utilization Elasticities	
$\varepsilon_{CU,E}$	−.0609	−.0758
$\varepsilon_{CU,M}$	.3856	.4394
$\varepsilon_{CU,L}$	−.2581	−.1512
$\varepsilon_{CU,K}$	−.3095	−.4776
$\varepsilon_{CU,Y}$	.2819	.1770

Table 5.5 (***continued***)

Parameter	United States	Japan
	E. Shadow-value and Utilization Elasticities with Respect to t	
$\varepsilon_{ZK,t}$	.0205	.0127
$\varepsilon_{ZL,t}$	−.0162	−.0183
$\varepsilon_{CU,t}$	.0188	.0245

Note: SR = short run; LR = long run.

this to be the case. In particular, using this shorter data set it was found that each of the pooling parameters except α_{EJ} was significantly different from zero, and, as a result, Japan's responses to exogenous shocks as measured by the estimated elasticities were significantly larger. With the more recent data, however, this pattern is not evident, even when only data to 1978 is used for estimation.

As seen in table 5.5, the price elasticity estimates provide ambiguous evidence about the hypothesis of greater Japanese than U.S. flexibility with respect to price shocks.[11] For example, the short-run own-price elasticity for materials is slightly larger in Japan (−.031) than in the United States (−0.28), as is the implied substitutability between materials and energy in the short run. However, the own-price elasticity for energy is slightly smaller in Japan (−.158) than in the United States (−.159). Since this elasticity is very important for assessment of responses to the energy price shocks, this is particularly surprising. In addition, the small energy-output elasticity suggests that energy use does not respond quickly to output changes, and this response is even smaller in Japan than in the United States; this suggests that "overhead" use of energy may be very important in manufacturing. Materials usage, by contrast, adjusts quickly in response to output fluctuations, more in Japan than in the United States. This result, along with the larger materials elasticity in Japan and the earlier finding of significant difference between materials demand in the United States and Japan, suggests that materials demand responses may be important for facilitating flexibility in Japan.

The long-run elasticities provide important implications about the relationships of capital and labor demand with energy and materials. First, note that the difference between the short- and long-run elasticities is quite large; long-run own-price elasticities for energy and for materials are about four and fifteen times the size of the short-run elasticities, respectively. This does not cause a significant difference between U.S. and Japanese responses, however. In fact the long-run demand elasticities for energy and materials exhibit the same relative patterns between the United States and Japan as do the short-run elasticities, and energy and capital appear to be even stronger complements and labor and energy less substitutable in Japan than in the United States.

There seems to be little reason, therefore, to think that there is more difficulty substituting capital and labor for energy in the United States as compared with Japan. By contrast, capital and labor are both substitutes with materials, and *K–M* substitutability is quite large in Japan. This substitutability may imply that adjustment with respect to materials is an important response by manufacturing firms to exogenous shocks.

Although long-run responses of Japanese as compared to U.S. firms appear quite comparable, the more rapid adjustment of capital and labor input stocks suggested by the raw data may imply greater differences than are immediately apparent. Reaching the long run may simply take longer for the United States as compared to Japan, particularly when the exogenous shock stimulating the response is not as strong in the United States, which was true of the productivity crisis in 1974.

The fixed input elasticities presented in table 5.5 reflect the impact on the desired values of labor or capital when an exogenous variable changes. These provide similar information about relationships between the fixed and variable inputs. That is, the negative elasticity value for the capital-energy elasticity suggests that the desired capital stock decreases with an energy price increase—*K* and *E* are complements for both countries. Again, this is inconsistent with the hypothesis of greater vulnerability of the U.S. production process to energy price changes because of energy-capital complementarity suggested by Norsworthy and Malmquist (1983) and alluded to by Sato and Suzawa (1983). It is consistent, however, with the evidence from the productivity indexes that the 1973 energy price shock had a large, if short, impact on Japanese manufacturing, and from the capacity indexes that the effect on the desired capital ratio was strong.

These elasticities, however, also provide information about the relationship between the capital and labor inputs. In particular, one difference evident from the elasticities is the complementarity of labor and capital in the United States whereas substutability exists in Japan, suggesting one area where additional flexibility may exist in Japanese production. Desired capital decreases with an increase in the price of labor in the United States but increases in Japan. Also, the own-price responsiveness of both capital and labor is larger in Japan than in the United States, implying that not only is capital accumulation responsive, as would be found from casual empiricism due to the enormous observed investment rate in Japan, but also that labor is quite flexible which may not be expected a priori.

Perhaps the most significant finding from the fixed input elasticities is that more substitutability is evident in Japan than in the United States. In particular, when variable inputs are substitutable with the fixed capital and labor inputs, as with ε_{LE}, the larger value for Japan reflects a larger increase in the desired amount of labor with an upward price shock for energy than found for the United States. Similarly, when inputs are complements, such as for capital and energy, the complementarity appears less in Japan; if energy prices increase, the desired capital stock decreases less than for the United States. The own-price elasticities for both labor and capital are also larger in Japan; for both inputs, if the price increases the responsiveness is greater in Japan. These results strongly suggest more flexibility in the production technology for Japan relative to the United States, even if the adjustment proportion is the same for both countries given a gap between the desired and actual levels of the stock input; the gap itself changes more for Japan. With a larger proportion of the gap also closed with more rapid investment in Japan, as was conjectured above, the larger adjustment implied by the desired fixed input response is augmented.

5.3.7 Shadow Value and CU Elasticities

Next, consider the shadow value and capacity-utilization elasticities reported in table 5.5. The shadow value elasticities represent information reflected by the quasi-fixed input elasticities; increases in the desired capital (labor) stock with an exogenous change correspond to increases in the shadow value of the stock. The Z_k elasticities, however, provide information on the valuation rather than quantity changes, and the capacity utilization measures summarize the total impact.

Again it is evident from the Z_L elasticities that all inputs are substitutes with labor for Japan but labor and capital are complements for the United States; increases in the price of energy, materials, or the capital stock (this is not a price elasticity but a stock level elasticity) cause an increase in the shadow value of labor in the United States, although an increase in K implies a decrease in Z_L for Japan. A similar relationship holds for output; output increases imply a large increase in the shadow value for both countries. The own elasticity is also substantial, indicating a strong response of the shadow value of labor to changes in its own stock, particularly for the United States.

For capital the own elasticity of Z_K with respect to K is very large, and larger in the United States than in Japan. This suggests that responsiveness is lower in the United States, since any augmentation of the capital stock substantially decreases further incentives for investment, consistent both with the ε_{KK} elasticity results and with the larger investment rate in Japan as compared to the United States for a given gap between the desired and actual capital stock. The responsiveness to energy and material prices is also substantial, although for energy it is negative (complements) and for materials it is positive (substitutes).

The capacity-utilization elasticities imply that increases in energy prices cause decreases in overall capacity utilization. Similarly, additions to labor or capital stocks result in more capacity to utilize and therefore a decline in CU. An increase in the price of materials, however, increases capacity utilization, since labor and capital are substituted for the previously used partly finished goods. These results imply that a strong energy price shock or increase in capital or labor stocks, and resulting decrease in capacity utilization, bias the observed productivity level downward. This was found above for Japan, although, as noted, the effect was weak compared to the large fluctuations in productivity growth.

Finally, it may be useful to consider the elasticities of the shadow values and capacity utilization with respect to changes in technology, or technical progress. This can be interpreted as the reverse of assessing how productivity is affected by fixed inputs; a change in technology may affect the various fixed inputs differently. As can be seen from the last set of elasticities presented in table 5.5, an increase in technology increases overall CU in both countries. This change is composed of two components, an increase in the shadow value of capital and decrease in the shadow value of labor for both countries, although these elasticities do vary over time. The capital effect dominates, therefore, generating the overall increase in efficiency reflected in the CU elasticities. These results imply that technical change has a tendency to cause capital to be noticeably more efficient and labor to be slightly less efficient, implying that technology is capital using and labor saving. This suggests an interpretation for the small desired labor ratio relative to that for capital found above, which reflects pressure for increasing capital intensity over time. This may, therefore, provide some support for the idea that the greater capital accumulation rate observed in Japan is consistent with a greater increase in efficiency of the capital stock, and therefore increases in overall productivity in Japan as compared to the United States.

5.4. Summing Up

It is clear that short-run fixities and the resulting short- and long-run substitution possibilities are important elements in the response of U.S. and Japanese firms to exogenous shocks. These possibilities are particularly important for comparisons across countries, since different patterns of industrial structure and rigidities may have a decisive impact on observed economic indicators. In this study, a framework has been developed capable of capturing underlying relationships among variable and quasi-fixed inputs, and has been used for an empirical comparison of the manufacturing industries of the United States and Japan. This framework provides a rich basis for analysis of input substitutability, CU, and productivity trends because it is capable of quantifying differences in short-run utilization and long-run input adjustment responses to exogenous shocks, differences which may cause important variations in economic performance.

More specifically, most hypotheses about the relative production structures and resulting productivity growth trends in the United States and Japan have focused on the alleged greater flexibility of Japan in response to exogenous shocks and the resulting potential for greater productivity growth. Flexibility appeared evident from the decrease in energy intensity of production in Japan after 1973, whereas in the U.S. little responsiveness was directly evident before the second energy price shock in 1979.

The data and econometric analysis of the problem presented in this study, however, suggests that the differences between U.S. and Japanese production structures in manufacturing may not be as large as alleged. The findings can be summarized as follows.

1. Productivity growth has been larger in Japan by 30% to 50% on average over the 1956–81 period, although the magnitude of the differences varies over time and appears slightly smaller since 1975. Important characteristics of the productivity growth profile that stand out are: (*a*) there is a larger drop in productivity growth in 1974 in Japan than the United States, supporting the idea of a "crisis" mentality in Japan as compared to the United States; (*b*) 1975 was a comparably low productivity growth year and 1976 and 1977 strong productivity growth years for both countries; and (*c*) Japan better managed to sustain this post-1974 growth even with a drop in 1980 after the 1979 energy price increases, whereas the United States experienced another less severe decline in productivity growth. Japan was able, therefore, to recover from a more severe decline in productivity growth and maintain it more effectively than U.S. manufacturing, but the differences were not as substantial as have sometimes been suggested.

2. Short- and long-run energy demand responsiveness in the two countries appears quite similar. There are insignificant differences in pooling parameters for the energy demand relationship in the two countries and elasticities are comparable. Short-run elasticities are small, and long-run own elasticities are quite large for both countries (yet still price inelastic); energy and labor are long-run substitutes, and energy and capital are long-run complements.

3. The labor structure in the two countries also does not appear to be different. The pooling parameters for labor are insignificant and the energy-labor and materials-labor relationships appear quite similar. The major difference is slight capital-labor complementarity in the United States contrasted to substitutability in Japan. In addition, more flexibility of labor in Japan may be implied by the L^*/L ratios presented in table 5.4, which are closer to one in Japan than in the United States.

4. Capacity-utilization ratios are not substantially different in the two countries in terms of trends, although those for Japan exhibit a stronger decreasing trend over time as capital and labor adjustment takes place in response to overutilization of both fixed inputs in the beginning of the sample. The fixity represented by these indexes, however, does not provide much information about productivity growth trends, because productivity growth fluctuates much more dramatically than do the impacts of fixity. The capacity utilization adjustment of productivity growth therefore has a relatively modest impact.

5. One important difference appears to involve substitution with intermediate materials. The country-specific intercept parameter in the materials equa-

tion is the only one that is significantly different from zero, indicating a different embedded technology and demand structure in Japan as compared to the United States. Also, firms in Japanese manufacturing appear to carry out a substantial part of their adjustment following exogenous changes by substituting intermediate materials; the substitution possibilities as exhibited by the demand elasticities are larger in Japan than in the United States. This may result in faster response time because adjustment of this relatively variable input may be accomplished more quickly than that for the more fixed inputs.

6. Overall the most important difference between these two countries may be capital accumulation in response to investment incentives. Capital accumulation has been much stronger in Japan than in the United States, although the investment incentives, as measured by the ratio of desired to actual capital stock or the shadow value as compared to market value of capital is not correspondingly large. The small own-capital elasticities found in the United States as compared to Japan also highlight this difference.

It is difficult, based on these observations, to reach a final conclusion about the reasons underlying differences in Japanese and U.S. manufacturing productivity growth, because greater overall flexibility is not strongly evident from the data. It does appear, however, that there were many determinants, including a very high investment rate in Japan, which may have contributed to more observed flexibility of the Japanese production process, especially in response to the energy price shocks of the 1970s.

In particular, the greater dependence of Japanese manufacturing on imported energy resulted in a severe impact of energy prices on productivity growth in 1974. The response to this by the Japanese as compared to U.S. manufacturing firms may partly be a result of this greater "crisis," but also is likely due to more rapid capital adjustment resulting in newer more energy-efficient capital in place. This is consistent with evidence of an enormous amount of competition in Japanese industry both to produce and use energy efficient technology after the price increases in 1973 and 1979; see, for example, Uchida and Fujii (1986). The post-1973 rapid investment to expand new technology developed sufficiently by 1979 to make the 1980 impact small and short compared to that in 1974 for Japan. The Japanese response to the second energy price shock was also smaller than that in the United States, which did not experience a correspondingly strong post-1974 capital accumulation response.

In addition, greater flexibility of workers, in the sense of their ability to accept and use new technology and readjust working patterns, has been suggested by researchers such as Sato and Suzawa. This could be reflected in the higher capital/labor ratio and capital replacement patterns found for Japanese manufacturing and the greater substitutability that appears to exist with respect to labor and capital in Japan.

Thus, although long-run variable input elasticities are roughly equal in the United States and Japan, the fixed input elasticities indicate greater long-run substitutability. This, along with faster capital and labor adjustment may have caused Japanese manufacturing to move toward the long run more quickly, resulting in better productivity performance in the late 1970s.

Notes

1. See, e.g., Jorgenson and Nishimizu (1978), Norsworthy and Malmquist (1983), Conrad and Jorgenson (1984), Sato and Suzawa (1983), and Jorgenson and Kuroda (in this volume).

2. Higher investment in new capital and increasing work effort (and possibly quality—investment in human capital) may also result from these interrelationships, providing Japan with an increasingly efficient capital and labor stock. This component of the substitutability or flexibility hypothesis cannot be assessed directly in the kind of econometric model used here; for explicit consideration of these potential forces see Isamura (in this volume), Tan (in this volume), and Dean, Darrough, and Neef (in this volume).

3. See Morrison (1986b) for further development of this function and a corresponding nonconstant returns to scale generalization.

4. See Morrison (1986a) for further development of this interdependence.

5. Note that this measure, since it is based on static optimization, does not require that nonstatic expectations assumptions be specified. If dynamic aspects were incorporated, however, this measure as well as the K^* measure must be adapted to take present value optimization into account as in Morrison (1985a).

6. See Morrison (1985b, 1985c, 1986a) for further elaboration and for an alternative, more rigorous proof proposed by Ingmar Prucha.

7. Note that it also appears possible and potentially useful similarly to define elasticities of the change in Y^* with respect to a relaxation of the constraint on x_k or the change in x_k^* with a change in output demand—$\partial \ln Y^* / \partial \ln x_k$ and $\partial \ln x_k^* / \partial \ln Y$. However, if these are long-run elasticities, these are trivially equal to one.

8. With previous data these trends appeared very different. In particular, using the Norsworthy and Malmquist (1983) Japanese data, 1971 and especially 1973 were catastrophic years for productivity growth, but productivity recovered substantially after 1973, particularly during 1974 and 1975. The numbers presented in the current study are much more consistent with a priori information about the trends in Japan.

9. Note that previous studies using the data set by Norsworthy and Malmquist generate a different type of pattern inconsistent with the well-documented decline in Japanese economic performance following the OPEC price shocks. See, e.g., Norsworthy and Malmquist (1983) or Morrison (1985c).

10. To assess directly the speed of adjustment, a dynamic model explicitly representing the adjustment process, such as Morrison and Berndt (1981), must be utilized. A recent study by Ingmar Prucha and M. I. Nadiri (1986), however, has suggested that different methods of dealing with dynamic models may yield very different results. For this study, therefore, use of a dynamic model was rejected in favor of using a model based on static optimization and imputing an adjustment speed based on the implied gap between desired and actual stocks and the rate of change of the stock. Moreover, capital markets may be different in the United States and Japan, implying different external costs of adjustment.

11. Morrison (1985c) found much larger elasticities, for example for the own-price response to energy, in Japan as compared to the United States using the data from

Norsworthy and Malmquist (1983) that only included information to 1978. The data used here differs somewhat for Norsworthy and Malmquist up to 1978, and includes the second OPEC price shock years of 1979–81.

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Comment

Ingmar R. Prucha

Overview

Catherine Morrison's paper represents an interesting new analysis and comparison of the production structure of the U.S. and Japanese manufacturing sector. The paper pays particular attention to the quasi fixity of some of the inputs and finds that the differences between the production structure of the U.S. and Japanese manufacturing sector may not be as large as has often been suggested in the literature.

The paper consists essentially of two parts: one theoretical, the other empirical. In the theoretical part Morrison introduces a new restricted cost function as the basic modeling device for the quasi fixity of some of the inputs. This restricted cost function represents an extension of the generalized Leontief cost function introduced by Diewert (1971). The paper further derives corresponding measures of productivity, capacity utilization, and various short- and long-run elasticities.

In the empirical part Morrison applies the modeling framework to U.S. and Japanese total manufacturing data. The empirical specification includes four inputs: capital, labor, energy and nonenergy material inputs. Both capital and labor are allowed to be quasi fixed. Expectations are taken to be static and returns to scale are assumed to be constant. The U.S. data are from Berndt and Wood (1984) and cover the period 1952–81. The Japanese data set has been provided by Takamitsu Sawa and covers the period 1955–81. The estimating equations consist of the demand equations for energy and material inputs, and an output price equation. Those equations are estimated by pooling the U.S. and Japanese data and allowing for country-specific first-order terms in the restricted cost function. Based on the parameter estimates the paper reports estimates for productivity growth, capacity utilization, and short- and long-run elasticities of substitution for the U.S.and Japanese total manufacturing sector. The most striking finding (among the wealth of information provided by those estimates) is that the results indicate much smaller

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differences between the U.S. and Japanese production structures in manufacturing than typically found in the literature.[1] One explanation for Morrison's novel findings may be that her study is based on a new Japanese data set that includes post-1978 information. Still, it seems of interest to explore in future work the robustness of those findings, in particular, against alternative functional specifications.

In motivating her restricted cost function Morrison points out some of the shortcomings of existing functional forms. She notes, in particular, that the linear-quadratic restricted cost function is not invariant to normalization. Morrison's choice of taking the Generalized Leontief cost function as a starting point for a new restricted cost function is a good one. However, such an extension of the Generalized Leontief cost function may take different forms. In the following remarks, I point out some properties of Morrison's extension that seem restrictive. Furthermore, I introduce alternative extensions of the Generalized Leontief cost function that may be useful for empirical research and can be used to check the robustness of Morrison's findings. One of those restricted cost functions is shown to have the property that the corresponding long-run cost function is again of the form of a Generalized Leontief cost function.

Extensions of the Generalized Leontief Cost Function

Consider a firm that produces a single output good, Y, from m variable inputs, $v = [v_1, \ldots, v_m]^T$, and n (possibly) quasi-fixed inputs, $x = [x_1, \ldots, x_n]^T$. Let $p = [p_1, \ldots, p_m]^T$ be the corresponding vector of prices for the variable inputs and $r = [r_1, \ldots, r_n]^T$ the corresponding vector of ex ante rental prices for the quasi-fixed inputs. We adopt the following convention: If z is a vector (matrix), then $z^{.5}$ denotes the vector (matrix) whose elements are the square roots of those of z. Using matrix notation, Morrison's extensions of the Generalized Leontief cost function with long-run constant returns to scale can then be written as:[2]

$$\text{(1)} \qquad \begin{aligned} G(p,x,Y) &= Yg(p,x/Y) \\ &= Y\left[(p^{.5})^T B p^{.5} + p^T D\left(\frac{x}{Y}\right)^{.5} + \left(\sum_{i=1}^{m} p_i\right)\left(\frac{x^T}{Y}\right)^{.5} C\left(\frac{x}{Y}\right)^{.5}\right], \end{aligned}$$

where $B = B^T = (b_{ij})$, $C = C^T = (c_{ij})$, $D = (d_{ij})$ are matrices of parameters of dimension mxm, nxn, and mxn, respectively. The term $\Sigma_{i=1}^{m} p_i$ in (1) needs to be interpreted with care. Clearly, we can only sum over variables that are measured in equal units. Hence, if the p_i are measured in, say, dollars per unit of the input v_i then $\Sigma_{i=1}^{m} p_i$ could be interpreted as $\Sigma_{i=1}^{m} p_i a_i$ where $a_i = 1$ denotes one unit of v_i. Given this interpretation we sum over variables measured in equal units. While this observation is trivial it is nevertheless important if we change the units of measurement for p_i and v_i, as discussed in more detail below.

Morrison assumes that $G(\cdot)$ satisfies standard properties. The function $G(\cdot)$ is clearly linear homogeneous in p and invariant to normalization by a particular variable input. It follows immediately from Diewert (1971) that a sufficient condition for $G(\cdot)$ to be concave in p is that the b_{ij} are nonnegative. The demand equations for the variable inputs can be readily obtained via Shephard's lemma, that is, $v_i = \partial G / \partial p_i$.

To discuss the specification issues stemming from the term $\Sigma_{i=1}^{m} p_i$ in more detail, it is useful to consider the case of two variable factors, $m = 2$, and one quasi-fixed factor, $n = 1$. In this case the demand equations for the variable factors derived from (1) are given by

$$v_1 = Y[b_{11} + b_{12}(p_2/p_1)^{.5}] + d_{11}(x_1 Y)^{.5} + c_{11}x_1, \tag{2a}$$

$$v_2 = Y[b_{22} + b_{12}\,(p_1/p_2)^{.5}] + d_{21}(x_1 Y)^{.5} + \tag{2b}$$

Inspection of (2) shows that the coefficient corresponding to x_1 (by itself) is the same in both demand equations. Now suppose we change the units of measurement of the first variable input. Let $v_1^{\circ} = sv_1$ and $p_1^{\circ} = s^{-1}p_1$ denote, respectively, the quantity and price of the first variable factor in new units where s is the scale factor. Upon interpreting $\Sigma_{i=1}^{m} p_i$ as $\Sigma_{i=1}^{m} p_i a_i$ the demand system (2) then becomes

$$v_1^{\circ} = Y[b_{11}^{\circ} + b_{12}^{\circ}(p_2/p_1^{\circ})^{.5}] + d_{11}^{\circ}\,(x_1 Y)^{.5} + c_{11}^{\circ}x_1, \tag{2°a}$$

$$v_2 = Y[b_{22} + b_{12}^{\circ}(p_1^{\circ}/p_2^{\circ})^{.5}] + d_{21}(x_1 Y)^{.5} + c_{11}x_1, \tag{2°b}$$

where $b_{11}^{\circ} = sb_{11}$, $b_{12}^{\circ} = s^{.5}b^{12}$, $d_{11}^{\circ} = sd_{11}$, and, in particular, $c_{11}^{\circ} = sc_{11} \neq c_{11}$. This suggests that the restricted cost function (1) may be restrictive in that it imposes, a priori, the same coefficient for the quasi-fixed factors across the demand equations for the variable inputs. This problem can be readily alleviated if $\Sigma_{i=1}^{m} p_i$ is replaced by $\Sigma_{i=1}^{m} p_i c_i$ where the c_i (with $c_1 = 1$ for reasons of identifiability) are parameters that are estimated from the data. The demand equations corresponding to (2) are then given by

$$v_1 = Y[b_{11} + b_{12}(p_2/p_1)^{.5}] + d_{11}\,(x_1 Y)^{.5} + c_1 c_{11}x_1, \tag{3a}$$

$$v_2 = Y[b_{22} + b_{12}(p_1/p_2)^{.5}] + d_{21}(x_1 Y)^{.5} + c_2 c_{11}x_1. \tag{3b}$$

It seems of interest to check if Morrison's empirical results are robust against the above-described generalization of the functional form of the restricted cost function. Of course, one may also define and consider various alternative forms of restricted cost functions that extend the Generalized Leontief cost function, for example,

$$\begin{aligned} G(p,x,Y) &= Yg(p,x/Y) \\ &= Y\left[(p^{.5})^T B p^{.5} + p^T D\left(\frac{x}{Y}\right) + \left(\sum_{i=1}^{m} p_i c_i\right)\left(\frac{x^T}{Y}\right) C \left(\frac{x}{Y}\right)\right]. \end{aligned} \tag{4}$$

The appealing feature of the above linear quadratic specification is that it allows for explicit solutions for the quasi-fixed factors even in the dynamic case with explicitly modeled adjustment costs; for corresponding estimation procedures see, for example, Epstein and Yatchew (1985) and Madan and Prucha (1989).

The long-run cost function is given by $C(p,r,Y) = G(p,x^*,Y) + r^Tx^*$ where x^* denotes the long-run optimal quasi-fixed inputs. None of the above restricted cost functions has the property that the corresponding long-run cost function is of the form of the Generalized Leontief cost function, that is,

$$C(p,r,Y) = Y\left[(p^{.5})^TBp^{.5} + 2(r^{.5})^TEp^{.5} + (r^{.5})^TFr^{.5}\right], \tag{5}$$

where $B = B^T = (b_{ij})$, $E = (e_{ij})$ and $F = F^T = (f_{ij})$ are matrices of parameters of dimensions mxm, nxm, and nxn, respectively. We assume that the elements of B, E, and F are nonnegative. This condition is sufficient for $C(p,r,Y)$ to satisfy standard properties, that is, to be nondecreasing, concave, and homogeneous of degree one in (p,r) and nondecreasing in Y; compare Diewert (1971). We introduce the following alternative restricted cost function with constant return to scale:[3]

$$\begin{aligned} \underline{G}(p,x,Y) &= Y(p^{.5})^T[B + E^T(X-F)^{-1}E]p^{.5}, \\ X &= \text{diag}(x_1/Y_1 \ . \ . \ . \ , x_n/Y), \end{aligned} \tag{6}$$

where we take $\underline{G}(\cdot)$ to be a real valued function defined on $R^m_+ \times \Theta$, $\Theta \subseteq R^{n+1}_+$. Here R^m_+ and R^{n+1}_+ denote the interior of the nonnegative orthants of R^m and R^{n+1}. Θ is taken to be an open convex subset of R^{n+1}_+ such that for each element of Θ the matrix $X-F$ is positive definite and the elements of the matrix $(X-F)^{-1}$ are nonnegative. In the appendix we show that $\underline{G}(\cdot)$ has the usual properties of a restricted cost function, that is, it is nondecreasing, concave, and homogeneous of degree one in p, nonincreasing and convex in x, and nondecreasing in Y. Let $B^* = (b^*_{ij}) = B + E^T(X-F)^{-1}E$, then the demand equations for the variable inputs are given by

$$v_i^* = Y\sum_{j=1}^{m} b^*_{ij}p_j^{.5}/p_i^{.5}, \quad i = 1, \ . \ . \ . \ , m. \tag{7}$$

The long-run cost function is obtained by minimizing $\underline{G}(p,x,Y) + r^Tx$. Given r is such that an interior solution exists we show in the appendix that the optimal long-run quasi-fixed inputs x^* satisfy:

$$(X^*-F)^{-1}Ep^{.5} = r^{.5}, \quad X^* = \text{diag}(x_1^*/Y, \ . \ . \ . \ ,x_n^*/Y), \tag{8}$$

or, equivalently,

$$x_i^* = Y\left(\sum_{j=1}^{m} e_{ij}p_j^{.5}/r_i^{.5} + \sum_{j=1}^{n} f_{ij}r_j^{.5}/r_i^{.5}\right), \quad i = 1, \ . \ . \ . \ , n. \tag{9}$$

Because of (8) we have $(p^{.5})^TE^T(X^*-F)^{-1}Ep^{.5} = (p^{.5})^TE^Tr^{.5}$, and $r^Tx^* = Y(r^{.5})^TX^*r^{.5} = Y[(r^{.5})^TEp^{.5} + (r^{.5})^TFr^{.5}]$. Substitution of those expressions into

$\underline{G}(p,x^*,Y) + r^Tx^*$ yields (5). That is, the restricted cost function $\underline{G}(p,x,Y)$ has the property that the corresponding long-run cost function is the Generalized Leontief cost function $C(r,p,Y)$.

Appendix

In the following we verify the claims made with respect the restricted cost function $\underline{G}(p,x,Y)$. We make use of the following matrix differentiation formulae: Let α and β be two $n \times 1$ vectors of constants and let x/Y be such that $\Phi = X-F$ is nonsingular, then

$$\text{(A1)} \qquad \partial(\alpha'\Phi^{-1}\beta)/\partial x = -Y^{-1}[\alpha^T\phi^1\beta^T\phi^1, \ldots \alpha^T\phi^n\beta^T\phi^n]^T$$

$$\text{(A2)} \qquad \partial(\alpha'\Phi^{-1}\alpha)/\partial x\partial x^T = Y^{-2}\text{diag}(\alpha^T\phi^1, \ldots, \alpha^T\phi^n) \cdot \Phi^{-1}\text{diag}(\alpha^T\phi^1, \ldots, \alpha^T\phi^n),$$

where ϕ^i denotes the ith column of Φ^{-1}. Formula (A1) can be readily obtained by using propositions 98 and 105 and corollary 22 in the appendix of Dhrymes (1978). Formula (A2) is obtained by using (A1) and observing that $\alpha^T\phi^i = \alpha^T\Phi^{-1}e_i$, where e_i is the ith column of the nxn identity matrix.

Since the element of $B + E^T(X-F)^{-1}E$ are nonnegative, it follows immediately that $\underline{G}$ is nondecreasing, concave, and homogeneous of degree one in p; compare Diewert (1971). Applying (A1) and (A2) we get

$$\text{(A3)} \qquad \partial\underline{G}/\partial x = -\{[(\phi^1)^TEp^{.5}]^2, \ldots, [(\phi^n)^TEp^{.5}]^2\}^T < 0,$$

$$\text{(A4)} \qquad \partial^2\underline{G}/\partial x\partial x^T = 2Y^{-1}\Psi\Phi^{-1}\Psi, \quad \Psi = \text{diag}\{(\phi^1)^TEp^{.5}, \ldots, (\phi^n)^TEp^{.5}\},$$

thus verifying that $\underline{G}$ is nonincreasing in x and convex in x (upon observing that Φ is positive definite). Similarly we find that $\partial\underline{G}/\partial Y > 0$. Equation (8) follows by observing that $\partial\underline{G}/\partial x + r = 0$ implies $(\phi^i)^TEp^{.5} = r_i^{.5}$ for $i = 1, \ldots, n$, or equivalently $\Phi^{-1}Ep^{.5} = r^{.5}$. (Note that $(\phi^i)^TEp^{.5}$ is positive.)

Notes

1. Compare, e.g., Norsworthy and Malmquist (1983), Mohnen, Nadiri, and Prucha (1986).

2. To keep the notation simple I have dropped the technology index from Morrison's specification. Note that the subsequent discussion also applies with obvious modifications to the case where a technology index is included. Note further that all of the subsequent discussion can be readily generalized to the case of a homothetic technology by replacing in the respective formulas Y by $h(Y)$, h nondecreasing. In this case the scale elasticity is given by $h(Y)/[Yh'(Y)]$.

3. The functional form was found by considering the problem $\sup_r[C(p,r,Y) - x^Tr]$. This restricted cost function can be readily generalized to the homothetic case by replacing Y by $h(Y)$; cf. n. 2 above.

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