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6 Energy Price Shocks and Productivity Growth in the Japanese and U.S. Manufacturing Industries

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6.1 Introduction

The coincidence of the energy price shocks in the 1970s and the sharp changes in productivity growth rates in industrialized economies have presented a puzzle for productivity growth analysts. Traditional productivity accounting procedures, measuring multifactor productivity growth as output growth minus the value share weighted growth in factor inputs, have been unable to attribute much significance to the coincidence of the energy price shocks and sharp changes in multifactor productivity growth. For example, Edward Denison, a distinguished productivity analyst, concludes that "I do not think that much of the productivity slowdown can be ascribed to energy prices" (1979, p. 138).[1]

Yet the apparent simultaneity is striking; between 1973 and 1975, real energy prices faced by Japan and U.S. manufacturing establishments roughly doubled, while multifactor productivity growth fell at the rate of 2.43% and 0.70% per year in Japan and the United States, respectively.[2] More generally, multifactor productivity growth rates decreased sharply for both countries in the postembargo period while the pattern of real energy prices shifted from being relatively stable to increasing dramatically. In Japan (the United States), productivity growth rates fell from 1.58% (1.11%) per year to 0.42% (0.52%)

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per year between 1958 and 1973 and 1973 and 1981, while real energy price changes grew at a rate of -1.43% (0.14%) to 19.9% (17.2%) per year for the comparable periods. Although these numbers are striking, traditional growth accounting methods have only been able to locate coincidence, not causality, in the arithmetic drama.

The basic problem faced by productivity growth analysts involves the following structural issue: By what mechanism could unexpected energy price changes have been related to sharp changes in multifactor productivity growth? Whatever the mechanism is, it must be consistent with two important facts. First, the average energy efficiency of durable capital goods changes only gradually, depending upon replacement investment in fully depreciated capital, new additions to the capital stock, and the change in average energy efficiency of capital goods between the pre– and post–price shock periods. Since the deterioration rate for equipment goods is about 13.5% per year in both Japanese and U.S. manufacturing, it would seem that nearly simultaneous reductions in energy input growth and energy price increases are ruled out by the more gradual adjustment of the average energy efficiency of durable goods.

The second fact that the energy price shock/productivity growth mechanism must account for is the relatively small value share of energy inputs in total production costs (only about 10% in both Japanese and U.S. manufacturing in 1981, up from about 4% in 1973). This implies that even large energy price changes translate into only relatively small changes in total costs and energy value shares, the latter being the weights employed in computing the energy input contribution to multifactor productivity growth.[3]

The combined effect of these two "facts"—that (1) large energy price changes have a modest effect upon total production costs and energy value shares and (2) energy input growth rates depend critically upon the slowly adjusting average efficiency of the energy using durable goods—suggests that sharp changes in traditionally measured multifactor productivity growth cannot be attributed to unexpected energy price shocks.

Recent research by Berndt and Wood (1984, 1987a, 1987b), Mori and Sawa (1985), and McRae (1985) has focused on the possibility that an important adjustment mechanism for the effects of unexpected energy price changes has been overlooked in traditional productivity measurement. Specifically, firms are able to adjust utilization rates for capital vintages embodying different energy efficiencies, thereby partially mitigating the effects of the unexpected energy price changes. If this utilization effect could be measured and properly incorporated into multifactor productivity accounting procedures, then energy price shocks could conceivably have a more substantial impact on productivity and still be consistent with the two facts noted above.

The empirical significance of this utilization adjustment mechanism in accounting for changes in productivity growth coincident with unexpected energy price changes will depend of course on technical possibilities for adjusting the energy efficiency of capital, and the vintage structure and the energy efficiency embodied in long-lived capital, the latter depending on the history of expectations about relative energy/capital prices. One major problem in evaluating the potential importance of the energy-price induced aggregate capital utilization effect upon productivity growth, however, is that both capital vintage energy efficiency and utilization rates are generally unobserved variables; hence evaluation requires measurement models based on economic theory and plausible assumptions regarding firm behavior.

In this paper we examine utilization responses to energy price shocks in the manufacturing sectors of the United States and Japan. We employ a consistent data base of output and input factor accounts for Japan and U.S. manufacturing, 1958–81, and then evaluate the potential importance of the utilization adjustment mechanism in aggregate capital stock and multifactor productivity measurement. The study employs simulation methods based on historical data on real investment and relative energy/capital prices, together with a range of values for the key parameter of the model—the *ex ante* energy-capital substitution elasticity—in calculating utilization adjusted measures of aggregate capital stock and of multifactor productivity growth. We find that even for relatively low values of this parameter, utilization adjustment effects make an important contribution in accounting for the productivity slowdown in the Japanese and U.S. manufacturing industries beginning in 1973, especially for Japan in the 1973–75 period.

The outline of the paper is as follows. In section 6.2 we present and compare real energy prices, investment patterns, and multifactor productivity growth in Japanese and U.S. manufacturing, with special attention to the post-1973 period. Section 6.3 presents a model by which energy price shocks affect productivity growth through their impact on the economic measure of aggregate utilized capital services, and section 6.4 presents and interprets the simulation results. We then conclude with remarks on directions for future econometric research and data development.

6.2 Energy Prices, Investment, and Productivity Growth in the Japanese and U.S. Manufacturing Industries

We begin by comparing basic information on energy prices, investment, and multifactor productivity performance for Japanese and U.S. manufacturing. Overall, the data suggest that Japan and U.S. manufacturing industries (*a*) sustained similar real energy price patterns for the first price shock, with Japan experiencing a much smaller real price increase in the second shock; (*b*) had quite different investment levels and patterns throughout the 1947–81 period; and (*c*) had dissimilar, traditionally measured multifactor productivity growth rates, with Japan generally having higher growth rates and experiencing a much greater productivity growth reduction coincident with the first price shock, and a much smaller reduction coincident with the second shock.

We first consider two measures of energy prices: nominal energy prices deflated by the manufacturing output price (an indicator of the overall rate of inflation), and the nominal energy price relative to the price of investment goods—a measure reflecting the operating versus fixed costs faced by the firm in choosing energy efficiency characteristics of new capital goods. Table 6.1 presents growth rates for these two energy-price measures for selected periods. Several features should be noted. First, for the preembargo period 1947–73, nominal energy prices, deflated by the gross output price deflator, decreased 1.3% per year in Japan and increased 0.7% per year in the United States, indicating that for this measure of real energy prices, Japanese and U.S. manufacturing firms faced quite different real energy prices. The second real energy price measure—equipment price-deflated energy prices—indicates, however, that real energy prices on average decreased more in the United States than in Japan in that period (−0.6% per year vs. −0.2% per year). Choice of end points matters most for the first real energy price measure; if we ignore the post–World War II and post–Korean War adjustments, for the period 1952–73 average output price-deflated energy prices increased 0.8% per year in Japan and 0.3% per year in the United States, while the corresponding equipment price-deflated energy prices increased 0.6% per year in the United States. This change in end points reduces the country disparity in the output price deflated measure and increases it for the investment price deflated measure.

Second, the average percentage increase was greatest in Japan for both measures of real energy prices for the period 1973–81, with the equipment price deflated energy price increasing more than the output price-detailed measure. This suggests that Japanese firms have had a somewhat greater relative incentive than U.S. firms to increase the energy efficiency of their equipment capital during the postembargo period

Table 6.1 Japanese and U.S. Manufacturing Industries' Real Energy Price Growth Rates for Selected Periods

	Deflator			
	Output Price		Equipment Price	
Period	Japan	United States	Japan	United States
1947–81	3.7	4.6	5.6	4.5
1947–73	−1.3	.7	−.2	−.6
1952–73	.9	.3	.6	−.6
1958–73	−1.4	.1	−.6	−.2
1973–81	19.9	17.2	24.7	20.8
1973–78	25.2	18.5	29.9	21.1
1978–81	14.7	16.0	19.4	20.6

Finally, it should be noted that for both deflation methods, although the two energy price shocks were roughly of equal magnitude in the United States, the second price shock in Japan was much less severe than the first.

Next, we consider the data on Japanese and U.S. manufacturing industry investment in equipment and structures. Figures 6.1 and 6.2 present real total and equipment investment divided by real gross output (constant 1975 yen and dollars) for the Japanese and U.S. manufacturing industries, respectively, while figure 3 presents the equipment investment/gross output ratios for both countries. Dividing by real gross output is intended, in part, to adjust for cyclical effects and for increases in scale.

A striking feature of these graphs is the consistently higher and more volatile investment/gross output ratios in Japan relative to those in the United States. Further, as can best be seen in figure 6.3, from 1955–78 the pattern of change in investment/gross output ratios in the two countries moves in opposite directions; that is, the peak-to-peak periods for Japan correspond almost exactly to a trough-to-trough period for the United States, a relation that appears to be coincidental. This pattern changes for the 1978–81 period when the investment/gross output ratios move in the same direction, with the United States ratios finally beginning to approach those of Japan.

Two additional points should be noted. First, the average overall investment/gross output ratios for the two countries move differently for the period 1947–73 versus 1974–81, with the ratio dropping slightly in Japan (.072 to .068) and rising in the United States (0.36 to .042). Within these periods, there is considerable volatility; for example, for the subperiods 1947–55 (1974–77) and 1956–73 (1978–81), the ratios increase 35.3% (decrease 8.8%) and decrease 9.2% (increase 23.7%) in Japan and the United States,

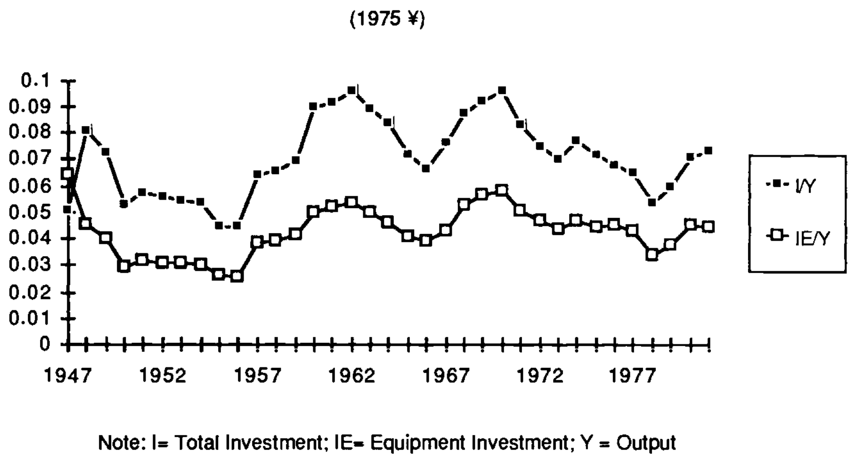

Fig. 6.1 Japan investment/output ratios

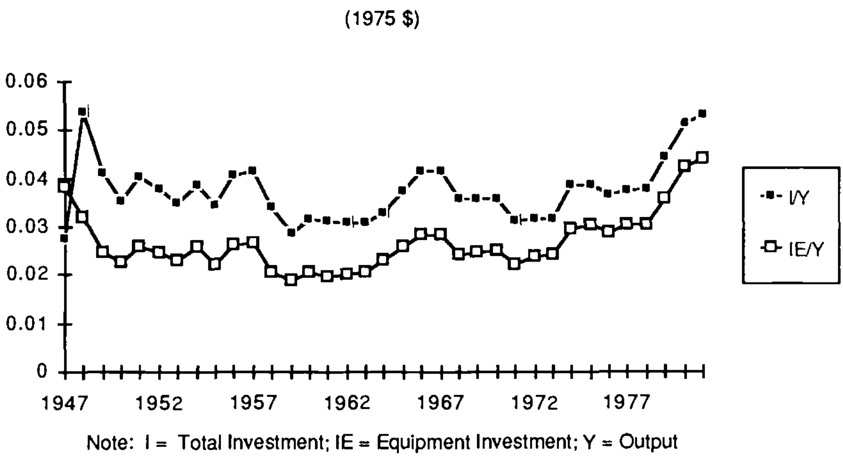

Fig. 6.2 U.S. investment/output ratio

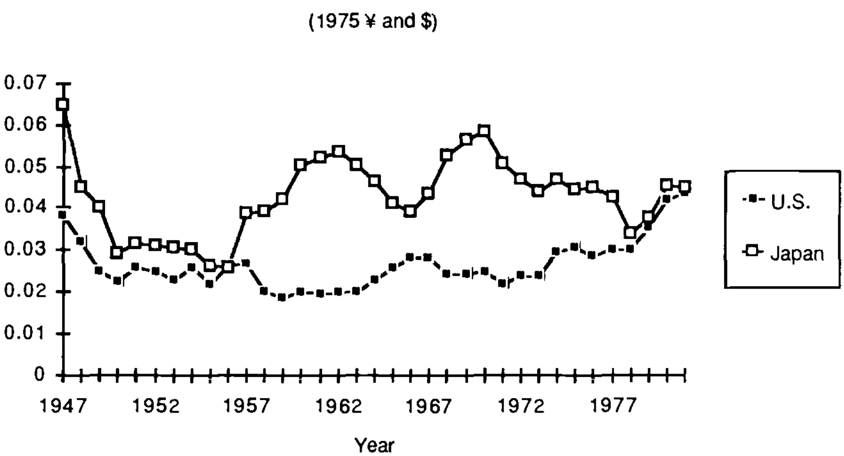

Fig. 6.3 Japan and U.S. equipment investment/output ratio

respectively. Japan shows greater volatility between the pre- and postembargo periods, while the United States shows greater volatility during the postembargo period.

Second, and of considerable interest for our present purposes, the share of equipment investment in total investment differs considerably between the two countries for the pre- and postembargo periods. For Japan, the equipment investment share in total investment increases slightly between 1947–73 and 1974–81 (61% to 64%), with the share relatively constant over the postembargo period. In contrast, the equipment investments share in total investment for the United States increases from 68% to 80% between the pre- and postembargo periods. Similar to Japan, however, U.S. equipment investment is a relatively constant share of total investment over the postembargo period.

We conclude this brief survey of significant pre- and postembargo developments in the Japanese and U.S. manufacturing industries with a comparison of multifactor productivity (MFP) growth in the two countries. MFP growth rates for selected periods are presented in table 6.2.[4] Several features should be noted. First, while there is some year-to-year variability, on average Japanese MFP growth rates have exceeded U.S. rates for all periods except 1973–75. The average Japanese and U.S. MFP growth rates for the period 1958–73 (1975–81) are 1.58% (1.39%) and 1.11% (0.92%), respectively.

Second, comparison of 1958–73 and 1973–81 periods suggests that there has been a slowdown in MFP growth rates in both the Japanese and U.S. manufacturing industries. The slowdown has been greater in Japan (1.58% vs. 0.42%) than in the United States (1.11% vs. 0.52%).

Third, the greatest contribution to the slowdown in productivity growth rates occurs in the period 1973–75—coincident with the first OPEC-induced energy price shock (OPEC-1)—in both Japan and the United States. The decrease in MFP growth rates in that period is much greater in Japan (−2.43%) than in the United States (−0.69%).

Finally, a comparison of the 1975–78 and 1978–81 periods indicates virtually no change in the Japanese MFP growth rate (1.42% vs. 1.37%) and a significant reduction for the United States (1.16% versus 0.70%). Hence, the second OPEC-induced energy price shock is again coincident with some slowdown in U.S. productivity growth—although not nearly as large as the first price shock—but it does not coincide with any change in Japanese MFP growth experiences.

6.3 Energy Price Shocks, Induced Variations in Capital Utilization, and the Measurement of Productivity

We now develop more formally the notion of how energy price changes may affect the relationship between aggregate utilized capital services and

Table 6.2 Japanese and U.S. Manufacturing Industries' Multifactor Productivity Growth Rates for Selected Periods

Period	Japan	United States
1958–81	1.172	.900
1958–73	1.575	1.105
1973–81	.419	.516
1973–75	−2.430	−.702
1975–81	1.387	.924
1975–78	1.415	1.120
1978–81	1.358	.681

aggregate capital stock, which in turn may have important implications for productivity measurement. As noted above, the analysis of the influence of energy price changes on productivity is greatly complicated by the fact that vintage specific utilization and energy efficiency information are not generally observed for most assets comprising the manufacturing industry investment and capital stock data.

Following the ancient econometric proverb, "If you don't have data, think," we will make use of two plausible assumptions.

1. Firms choose the energy efficiency characteristics of new capital goods consistent with minimizing expected life-cycle costs.
2. Firms choose relative utilization rates between old and new capital so as to minimize current period variable costs.

We now appeal to economic theory regarding firm behavior in order to develop the economic structure necessary to identify and evaluate the potential significance of a "utilization adjustment" effect for such economic measures as multifactor productivity.

We begin by noting that in virtually all research involving capital input in production or cost functions, it is assumed that the flow of capital services is proportional to the capital stock and that this factor of proportionality is constant over time. With traditional capital stock aggregation over vintages, it is assumed that capital physically deteriorates or "evaporates" at the constant rate δ. The significance of this assumption is that the relative marginal product at time t of a \$1 investment in each of the two periods $t-\tau$ and $t-\tau-v$ equals $(1 - \tau)^v$. More specifically, the marginal products at time t of period t, $t-\tau$, and $t-\tau-v$ investments of \$1 are 1, $(1-\delta)^\tau$, and $(1-\delta)^{\tau+v}$. In such a case of constant geometric deterioration, and only in such a case, the rate of economic depreciation is also constant and equal to δ.[5]

Since relative prices equal relative marginal products, the implication of the "constant deterioration" assumption is that the relative prices of any surviving vintages of capital are constant over time. Further, using the fact that relative prices are fixed, one can employ the Hicksian aggregation condition to form an aggregate capital stock over vintages defined as:[6]

$$K_t \equiv \sum_{\tau=0}^{T} S_\tau I_{t-\tau} \equiv \sum_{\tau=0}^{E} K_{t,t-\tau}, \tag{1}$$

where S_τ is the physical survival rate, $S_\tau \equiv (1-\delta)^\tau$, T is the physical lifetime of equipment, $I_{t-\tau}$ is the amount of real investment put in place at time $t-\tau$, and $K_{t,t-\tau}$ is the amount of $t-\tau$ investment physically surviving to period t. Note that the S_τ are precisely the proportionality factors that reflect relative marginal products.

It is useful to generalize this traditional treatment of capital aggregation over vintages to account for energy-price-induced changes in vintage-specific rates of utilization. We now present a framework that permits us to construct an aggregate measure of utilized capital, denoted K_t^*, computed as,

$$K_t^* = \sum_{\tau=0}^{T} e_{t,t-\tau} S_\tau I_{t-\tau} = \sum_{\tau=0}^{T} e_{t,t-\tau} K_{t,t-\tau}, \tag{2}$$

where the $e_{t,t-\tau}$ are relative vintage-specific utilization rates of the physically surviving $t-\tau$ investment at time t. Notice that if $e_{t,t-\tau} = 1$ for all t, τ, then traditional (K) and "utilization-adjusted" (K^*) measures of capital coincide.

Our use of the term "utilization-adjusted" is very suggestive but obviously needs to be made more precise. When firms make investment decisions for new equipment, they recognize that equipment is durable, and thus they examine the present value of the life-cycle costs. Suppose firms first decide the amount of funds to be devoted to the sum of the capital and energy operating costs; this decision could be based on, for example, expectations concerning output demand, materials costs, wage rates, and operating rates. Second, having decided this, firms then choose the optimal split between capital and energy costs. Once the optimal energy efficiency is chosen in this second step, the capital utilization energy use relation is fixed in "clay"; hence, while flexible and "putty" *ex ante*, the amount of energy consumed per unit of capital service utilized is immutable *ex post*. Note that, in this framework, while the *ex post* energy-capital service utilization relationship is clay, *ex post* substitutability may still occur between the capital-energy bundle and labor or material inputs.

Assume further that, with the second decision noted above, the relevant production function is the familiar constant elasticity of substitution (CES) function with Hicks-neutral disembodied technical change and constant returns to scale. Using the first-order conditions for life-cycle costing, this CES production function yields the optimal *ex ante* energy intensity at time t, denoted F_t, as

$$\ln F_t = \ln\left[\frac{E}{K}\right]_t = \ln a - \sigma \ln\left[\frac{P_E^*}{P_K^*}\right]_t, \tag{3}$$

where $\ln a$ is a constant, σ is the *ex ante* substitution elasticity between energy and capital equipment, and P_E^* and P_K^* are values of discounted expected prices for energy and capital equipment, respectively, over the expected lifetime of the new equipment. A discussion of how price expectations are computed is deferred to later in this section.

If firms followed this decision criterion at all points in time—at t and $t-\tau$ for all t, τ—and if relative energy prices suddenly changed, the optimal relative utilization rates for the surviving $t-\tau$ vintages could differ significantly from those originally chosen. Specifically, denote by $u_{t,t-\tau}$ the vintage-specific utilization rates at time t for $t-\tau$ vintage surviving to time t, and then note that the total energy costs at time t equal the sum of vintage-specific energy costs. Exponentiating equation (3) over all vintages yields variable costs at time $t(VC_t)$ *as*

$$(4) \qquad VC_t \equiv P_{E,t}\sum_{\tau=0}^{T} F_{t-\tau}u_{t,t-\tau}K_{t,t-\tau} = P_{E,t}\sum_{\tau=0}^{T} a\left[\frac{P_E^*}{P_K^*}\right]_{t-\tau}^{-\sigma} u_{t,t-\tau}K_{t,t-\tau}.$$

Note that the first equality of equation (4) is an identity, relating total energy costs to the current price of energy ($P_{E,t}$), the vintage-specific energy efficiency of surviving vintages of capital ($F_{t-\tau}$), vintage-specific utilization rate ($u_{t,t-\tau}$), and the surviving amount of each vintage ($K_{t,t-\tau}$).

The shadow values of these surviving vintages, that is, their ability to reduce variable (energy) costs given their embodied energy efficiency and energy prices prevailing at time t, is given by

$$(5) \qquad -\frac{\partial\, VC_t}{\partial\, K_{t,t}} = -P_{E,t}a\left[\frac{P_E^*}{P_K^*}\right]_t^{-\sigma} u_{t,t},$$

for the most recent (period t) surviving capital, and by

$$(6) \qquad -\frac{\partial\, VC_t}{\partial\, K_{t,t-\tau}} = -P_{E,t}a\left[\frac{P_E^*}{P_K^*}\right]_{t-\tau}^{-\sigma} u_{t,t-\tau},$$

for surviving vintage $t-\tau$ capital.

Assume that the efficient firm utilizes these various surviving vintages of capital so that their shadow values in production are equal. Equating the shadow values in (5) and (6) for all t,τ and rearranging, we obtain

$$(7) \qquad \frac{u_{t,t-\tau}}{u_{t,t}} = \left[\frac{P_{EK,t}^*}{P_{EK,t-\tau}^*}\right]^{-\sigma},$$

where $P_{EK,t}^*$ and $P_{EK,t-\tau}^*$ are the relative price terms in square brackets in equations (5) and (6), respectively.

At the level of the individual manufacturing establishment, a merit ranking of utilization rates by energy efficiency could indicate that some vintages would be utilized completely and others not at all.[7] While it might be desirable to incorporate such establishment-specific utilization constraints into our framework, it appears to be exceedingly difficulty to do so. Moreover, our data is at the aggregate manufacturing level, not at that of the individual establishment. As we shall see in the empirical implementation, the values of u_t predicted by the simple model all fall within reasonable ranges, and corner solutions do not emerge at the aggregate level.

One implication of (7) is that when these shadow values are equalized, vintage-specific utilization rates will adjust, with the magnitude of the adjustment depending on the size of the *ex ante* substitution elasticity σ and the change between time $t-\tau$ and t in the relative energy prices P^*_{EK}. In particular, if relative energy prices increase between $t-\tau$ and t, and if the *ex ante* energy-capital substitution elasticity equals zero (no *ex ante* substitution possibilities available), then by (3) the optimal *ex ante* energy intensities at t and $t-\tau$ would be identical in spite of energy price increases, and thus no utilization adjustment would occur among the surviving vintages. However, if σ were substantial, that is, if significant energy-capital substitution possibilities were available *ex ante*, then according to (7) the relatively energy-inefficient $t-\tau$ vintages would be utilized less in production. On the other hand, if relative energy prices fell unexpectedly and if $\sigma > 0$, then the relatively energy-inefficient vintages would be used more in production; the ratio in (7) can be on either side of unity. In our view, this utilization adjustment response to energy price shocks is eminently plausible.

Having derived vintage-specific rates of utilization that depend on relative energy prices and the *ex ante* substitution elasticity, we now employ them in constructing an aggregate measure of utilized capital over vintages. Since equating shadow values preserves relative service prices of capital vintages, the Hicksian aggregation condition can again be employed in aggregating these vintages. Specifically, we set the relative vintage-specific utilization rates $e_{t,t-\tau}$ equal to the left-hand side of (7), that is, set

$$(8) \qquad e_{t,t-\tau} = \frac{u_{t,t-\tau}}{u_{t,t}},$$

normalize by setting $u_{t,t} = 1$ for all t. Using (7) and (8) and substituting into (2) yields,

$$(9) \qquad K^*_t = \sum_{\tau=0}^{T} \left[\frac{P^*_{EK,t}}{P^*_{EK,t-\tau}} \right]^{-\sigma} S_\tau I_{t-\tau}.$$

As noted above, the expression for $e_{t,t-\tau}$ provides constant valuation weights for aggregating surviving capital vintages, given relative price expectations, precisely the condition required for Hicksian aggregation of the surviving vintages.

We interpret the result of equation (9) as the utilization-adjusted aggregate capital stock, and the ratio of this measure to the traditional capital stock measure of (1),

$$B_{K,t} = \frac{K_t^*}{K_t}, \tag{10}$$

as the aggregate capital utilization adjustment coefficient. Note that this coefficient, $B_{K,t}$, can be less than, equal to, or greater than unity.

The aggregate utilization adjustment coefficient, $B_{K,t}$, should obviously be affected by energy price shocks. From equations (9) and (10) we can derive an elasticity relation between the aggregate capital utilization adjustment coefficient, $B_{K,t}$, and the relative expected life-cycle price, $P^*_{EK,t}$, as,

$$\frac{\partial \ln K_t^*}{\partial \ln P^*_{EK,t}} = \frac{\partial \ln B_{K,t}}{\partial \ln P^*_{EK,t}} = -\sigma. \tag{11}$$

Equation (11) reflects the intuition that the extent to which the aggregate capital stock is adjusted downward for an unexpected increase in relative expected life-cycle costs depends upon the extent to which the firm has opportunities to choose increased energy efficiency in new capital goods, relative to the efficiency decisions it made prior to the change in energy prices.

Finally, we must consider how the expected life-cycle–relative price function, $P^*_{EK,t}$, is evaluated by the firm. We assume that in making energy efficiency choices, firms discount expected future prices, $\hat{P}_{E,t+1}$ and $\hat{P}_{K,t+1}$, by a real discount rate, r. Recalling that equipment put in place at the beginning of a period deteriorates at the constant geometric rate δ, we define the expected relative life-cycle price as

$$P^*_{EK,t} = \sum_{l=0}^{T} \hat{P}_{EK,t+l+1}\left(\frac{(1-\delta)^l}{(1+r)^{l+1}}\right), \tag{12}$$

where now $\hat{P}_{EK,t+l+1}$ is the expected future price of energy relative to capital, and T is the physical service life of a new capital good.

But how do firms form expectations regarding future energy/capital relative prices? We consider the following two plausible possibilities: (1) relative energy/capital prices are expected to change at a constant rate of growth, g; (2) expected energy/capital prices are based on time-dependent forecasts, which are updated as new information becomes available to the firm.

In the first case, we can represent the expected relative price as

$$\mathrm{P}_{\mathrm{EK},t+l} = (1+\mathrm{g})^l\, \mathrm{P}_{\mathrm{EK},t}, \tag{13}$$

where g is the constant rate of growth. Substituting equation (13) into (11) gives

$$P^*_{EK,t} = \Gamma\, \mathrm{P}_{EK,t}, \tag{14}$$

where, after some tedious algebra, it can be shown that $\Gamma = (1-\lambda^T)$ and $\lambda = (1-\delta)(1+g)/(1+r)$. Note, however, that substituting (14) into (3) involves only an adjustment to the intercept term, $\ln a^* = \ln a - \sigma \ln \Gamma$. Since this term cancels out in evaluating $e_{t,t-T}$, the use of current prices as estimates of expected relative life-cycle prices is appropriate if we believe that a constant growth rate satisfactorily represents the firm's expectations about future relative energy/capital prices.

An alternative approach as to how firms form expected energy/capital prices is to assume that they employ historical information in making time-dependent forecasts that are then updated as new information becomes available. Such forecasts could be based on time-series techniques and may seem preferable to estimates based on constant growth rate assumptions. We are sympathetic with this view, but note that a constant growth rate can, in part, be justified by appeal to Hotelling's Law in resource economics, where g is interpreted as the real rate of interest minus the rate of technical progress in the discovery, extraction, and processing of energy resources. Then, according to Hotelling's Law, g is equivalent to the real rate of change in the energy resource price. We will examine time-series and rational expectation formulations of energy/capital price expectations in future research.

In the previous paragraphs we have developed a utilization-adjusted measure of capital input and compared it to the traditional measure. We now consider the implications of vintage utilization adjustment for multifactor productivity measurement. Growth accountants and productivity analysts typically measure the rate of multifactor productivity growth (r_{MFP}) as the growth rate in output (r_y) minus the growth rate of aggregate input (r_x), where the latter is computed as cost-share weighted growth in each of the N component inputs, that is

$$(15) \qquad r_{\mathrm{MFP}_t} = r_{y,t} - r_{x,t} = r_{y,t} - \sum_{i=1}^{N} w_{i,t}\, r_{x_i,t},$$

and where $w_{i,t}$ is the arithmetic mean of the cost share of the i^{th} input in the total costs of all N inputs for periods t and $t-1$.[8] Since (15) is the basic relation employed in most growth accounting analyses, improvements in data construction, as well as controversies among researchers, can often be described in terms of measurement issues involving output and input quantities (affecting the r_i), or involving value measurements (affecting the w_i).[9]

To highlight the effect on MFP measurement of accounting for energy-price-induced changes in capital utilization, we note first that any two measures of a given input may be related by a scalar, that is

$$(16) \qquad \beta_{i,t} \equiv \frac{x^*_{i,t}}{x_{i,t}}.$$

The growth rate in one measure of an input may be written as the sum of the growth rates of the other measure and the ratio of the two measures, that is,

$$(17) \qquad r^*_{x_{i,t}} = r_{\beta_{i,t}} + r_{x_{i,t}}.$$

Substituting (17) into (15) and denoting the alternative measure of MFP growth as MFP*, we have

$$r^*_{\mathrm{MFP}_t} = r_{y,t} - \sum_{i=1}^{N} w_{i,t}(r_{\beta_{i,t}} + r_{x_{i,t}}). \tag{18}$$

Subtracting equation (15) from (18), we obtain the difference in MFP measures associated with the difference in input measures:

$$r^*_{\mathrm{MFP}_t} - r_{\mathrm{MFP}_t} = -\sum_{i=1}^{N} w_{i,t}\, r_{\beta_{i,t}}. \tag{19}$$

As is seen in (19), the effect on the multifactor productivity growth rate of the alternative measure is given by the negative of the sum of the cost-share weighted differences in growth rates of the scalar relating the alternative measures. Note that this interpretation applies regardless of the source of the differences in the two input measures.

In our case, however, there is ample reason to believe that the utilization-adjusted measure of capital input is preferable to the conventional measure, which takes no account of changes in the relationship between capital service flows and capital stock. The consequences for MFP measurement of incorrectly measuring capital input flows are clear from (19). If vintage-specific utilization rates fell after OPEC-1, then the $r_{\beta i,t}$ term in (19) would be negative, and the difference between the conventional and the new utilization-adjusted measure of MFP growth would be positive, that is, growth in MFP* would be understated using the conventional accounting procedures.

In summary, equations (9) and (12), together with a specification of expected energy/capital prices, provide a model for vintage capital aggregation that explicitly accounts for a firm's decisions regarding the (unobserved) energy efficiency of new capital vintages, as well as its decisions regarding (unobserved) relative vintage utilization rates, given realized energy prices. The model retains the Hicksian aggregation condition, namely that relative vintage-specific valuation weights are constant given relative price expectations. Hence, even though two critical data series are unobserved, we are still able to introduce the effects of energy price shocks into an economic measure of aggregate capital stock. This is accomplished by the judicious use of economic theory and by several plausible assumptions regarding the optimizing behavior of the firm. In contrast to Koopman's worries concerning measurement without theory, measurement here is possible only because of our use of theory.

It remains to consider whether the ability to introduce energy price changes into the capital aggregation procedure is of any practical empirical importance. In particular, does the conceptual possibility of such a channel linking operating cost shocks to economic measures of durable assets have any empirical significance for such derived economic measures as multifactor productivity growth? Equation (19) provides the framework for addressing this question of significance, a question we now consider for Japanese and U.S. manufacturing.

6.4 Empirical Results

Our approach to evaluating the potential empirical importance of the vintage utilization adjustment effect is based on simulation methods. Rather than embedding the capital measurement model of section 6.3 within an econometric model of production and cost involving all factors of production, at this stage of our research we concentrate on evaluating the implications of plausible values of the energy-capital *ex ante* substitution elasticity on MFP growth and on the productivity slowdown for Japan and United States manufacturing industry.[10]

More specifically, we employ equations (1), (9), and (10) together with expected relative life-cycle prices and real investment, to calculate the aggregate capital utilization adjustment coefficient, $B_{K,t}$, for three assumed values of the *ex ante* energy-capital substitution elasticity, $\sigma = (1.0, .667, .333)$.[11] We then employ the three estimates of $B_{K,t}$ for each country in evaluating the capital utilization effect upon traditional measures of productivity growth and upon the productivity slowdown that began in Japanese and U.S. manufacturing industries in 1973.

One other issue requires further discussion, namely the relation between equipment and structures in accounting for vintage utilization effects. Clearly our motivation of utilization-adjusted aggregate capital stock measures seems particularly plausible with respect to equipment capital, for firms have considerable scope in adjusting utilization between machines and other equipment within a single plant and between plants. For structures, the notion of utilization adjustment, while still meaningful, seems more problematic. Of course, the firm may reduce or increase the number of shifts being worked in a particular plant (structure) depending upon the thermal integrity of the buildings, but it seems likely that the *ex ante* substitution elasticity for structures will be significantly smaller than that for equipment.

Rather than complicate our simulations by creating a grid of *ex ante* substitution elasticities for both equipment and structures, we instead adopt the assumption that the *ex ante* substitution elasticity between structures and energy equals zero. Further we assume a Cobb-Douglas relation between equipment and structures capital goods. With these assumptions the measure of aggregate utilization-adjusted capital stock becomes

$$(20) \qquad \begin{aligned} K_t^* &= K_{E,t}^{*\alpha} K_{S,t}^{*(1-\alpha)} = (B_{E,t}^{\alpha} K_{E,t}^{\alpha} B_{S,t}^{1-\alpha} K_{S,t}^{(1-\alpha)} \\ &= B_{E,t}^{\alpha} B_{S,t}^{1-\alpha} K_{E,t}^{\alpha} B_{S,t}^{1-\alpha} K_{S,t}^{(1-\alpha)} = B_{E,t}^{\alpha} K_t , \end{aligned}$$

since $B_{S,t} = 1$. In the subsequent empirical simulations, we calculate α as the average value share of equipment services in total capital services in 1974–75.

Note that this assumption of different values for the equipment and structures *ex ante* energy-capital substitution elasticity implies a slight modification to the expression for the utilization adjustment elasticity (eq. [11]). In particular, we now have

$$(21) \qquad \frac{\partial \ln B_{K,t}}{\partial \ln P^*_{EK,t}} = \frac{\partial \ln K^*_t}{\partial \ln P^*_{EK,t}} = -\alpha\sigma.$$

Thus, the extent of the aggregate capital utilization adjustment to an unexpected energy price change depends upon the extent to which new capital equipment embodies differing energy efficiency compared with older equipment vintages, and the cost share of equipment services in total capital services.

Next we consider the formation of expected relative life-cycle costs. As was noted above, $P^*_{EK,t}$ is the value of an expected life-cycle relative price function affecting the optimal energy efficiency embodied in new equipment investment. In choosing such optimal energy efficiency, firms are assumed to discount expected energy/capital prices $\hat{P}_{EK,t+s}$ by the real discount rate r, recognizing that equipment put in place at the beginning of the next time period physically deteriorates at the annual rate δ until it is physically scrapped in T years. We therefore define $P^*_{EK,t}$ as the life-cycle discounted forecast made at time t (eq. [12]), which in turn equals the weighted sum of the expected or predicted relative future prices, say $\hat{P}_{EK,t+s}$.

We now turn to an analysis of the implications of energy price changes for measuring utilization-adjusted aggregate capital stock. As noted above, we employ equations (9) and (20)—together with historical real investment, expected relative life-cycle costs based on the constant growth assumption, and the three assumed values of the *ex ante* energy-capital substitution elasticity (σ = 1.0, .667, .333)—to calculate the traditional and utilization-adjusted aggregate capital stocks, which in turn determine three estimates of the aggregate capital utilization adjustment coefficient, $B_{K,t}$.[12] Table 6.3 and figures 6.4 and 6.5 below report the estimates of $B_{K,t}$ for the period 1958–81 for Japanese and U.S. manufacturing sectors. For Japan (fig. 6.4), the aggregate capital utilization adjustment coefficients (B_K) are slightly above 1.0 for the period 1958–71, reflecting the fact that expected relative life-cycle costs were generally falling since 1929 (see fig. 6.2). For the period 1972–73, the B_K values drop slightly below 1.0 due to energy price increases in those years, two full years before the sharp increase of the first energy price shock. The first OPEC price shock, then, significantly reduced B_K from 0.91 (σ = .33) to 0.77 (σ = 1.0) in 1974 with a slight further decline in 1975 followed by rapid improvement through 1978.

Japanese B_K values in 1978 are, however, still some .04 to .09 below their 1973 levels. The second energy price shock in 1979–80 had a smaller percentage effect upon B_K in Japan than did the earlier price shock, with the absolute affect being only slightly greater, for example, B_K = 0.75 (σ = 1.0) in

Table 6.3 **Japanese and U.S. Manufacturing Industry Aggregate Capital Utilization Adjustment Coefficients for Selected Values of *s***

	United States			Japan		
Period	$B_K(1.0)$	$B_K(.67)$	$B_K(.33)$	$B_K(1.0)$	$B_K(.67)$	$B_K(.33)$
1958	1.045	1.029	1.014	1.014	1.008	1.004
1959	1.070	1.046	1.022	1.024	1.016	1.007
1960	1.068	1.044	1.021	1.022	1.014	1.007
1961	1.058	1.038	1.018	1.022	1.015	1.007
1962	1.053	1.034	1.017	1.015	1.010	1.005
1963	1.052	1.034	1.016	1.004	1.002	1.001
1964	1.050	1.032	1.015	1.011	1.007	1.003
1965	1.054	1.035	1.017	1.010	1.007	1.003
1966	1.055	1.036	1.017	1.016	1.011	1.005
1967	1.055	1.036	1.017	1.023	1.015	1.007
1968	1.050	1.032	1.016	1.018	1.012	1.006
1969	1.046	1.030	1.014	1.035	1.023	1.011
1970	1.027	1.018	1.008	1.027	1.018	1.009
1971	1.010	1.006	1.003	.980	.986	.993
1972	1.003	1.002	1.000	.985	.990	.995
1973	.953	.968	.983	.995	.996	.998
1974	.751	.822	.904	.766	.833	.910
1975	.791	.849	.918	.762	.827	.905
1976	.827	.874	.931	.785	.842	.913
1977	.839	.883	.936	.824	.870	.928
1978	.868	.904	.947	.907	.929	.959
1979	.811	.863	.925	.857	.894	.941
1980	.738	.807	.892	.747	.813	.896
1981	.749	.813	.894	.770	.828	.903

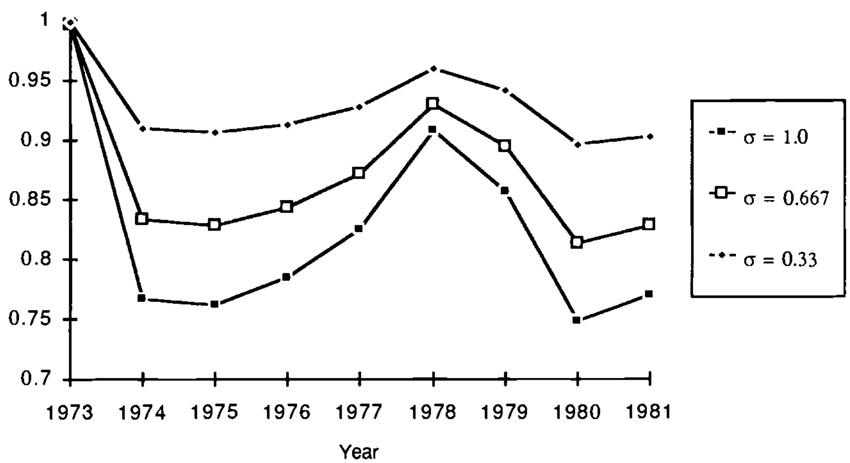

Fig. 6.4 Japan utilization adjustment coefficients B_{kt}

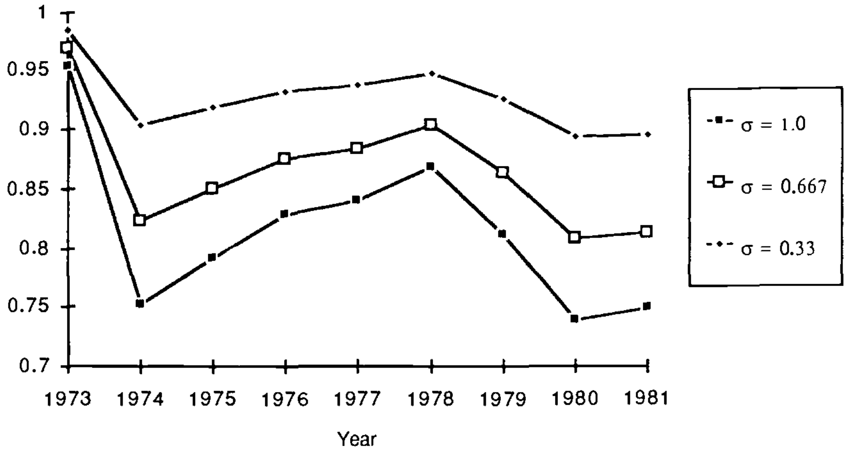

Fig. 6.5 U.S. utilization adjustment coefficients B_{kt}

1980. This is due, in part, to the smaller energy/capital price increase in the second shock in Japan (see table 6.1). Some recovery is indicated in 1981, the last year for which we are able to assemble consistent input accounts for the two countries.

A similar pattern of B_K values is obtained for United States manufacturing industry (fig. 6.5). The primary differences from the results for Japan are (*a*) a falling B_K from 1970–73 due to the fact that energy/capital prices reached their lowest sample point in 1969 and then began to rise in 1970; (*b*) slightly higher B_Ks prior to 1971, due primarily to the United States having a relatively older, more efficient, capital stock; (*c*) a quicker initial recovery for the United States from the first price shock, due primarily to having a more efficient capital stock and to a higher rate of investment in 1974 (see fig. 6.3); and (*d*) a somewhat lower recovery of B_K in the United States for the period 1973–78 due mostly, we believe, to the lower overall level of equipment investment in the United States.

The similarities and differences in the B_K measures for Japan and the United States are more clearly seen in figure 6.6, where the coefficients corresponding to $\sigma = 0.667$ are presented. Recall that the differences in B_K have been shown to depend upon a combination of the preembargo vintage structure of capital goods, relative energy/capital prices, and post-1973 investment behavior. Perhaps most striking in figure 6.6 is that 1974 and 1980 B_Ks are roughly equal in both Japan and the United States, even though the second price shock was significantly less severe in Japan than in the United States. This suggests the critical importance of the post-embargo investment, particularly in 1978–81. Both Japanese and U.S. manufacturing firms appear to have made significant progress in "insulating" themselves from advance energy price shocks.

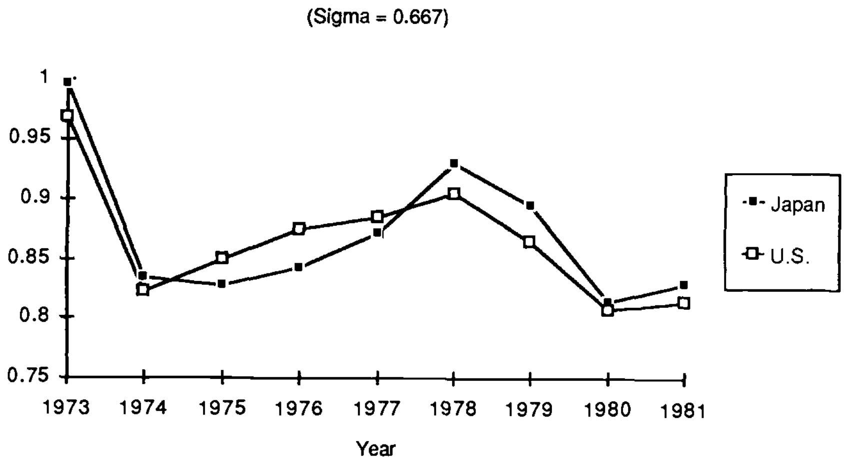

Fig. 6.6 Japan and U.S. utilization adjustment coefficient

Finally, we consider the effects of aggregate capital utilization adjustment upon MFP growth in Japan and U.S. manufacturing. In section 6.2 we noted three factors relating to the traditional MFP measures. In particular, (*a*) there was evidence of a productivity slowdown in both countries between the 1958–73 and 1973–81 periods; (*b*) the period 1973–75 made the greatest contribution to the productivity slowdown, especially in Japan; and (*c*) the second price shock is coincident with a much smaller reduction in MFP than the first price shock. We now ask, to what extent are these patterns of coincidence between price shocks and MFP growth affected by employing our new measure of utilization-adjusted aggregate capital?

Table 6.4 presents MFP indices based on the traditional measure of aggregate capital, and for the three measures of the utilization-adjusted aggregate capital for the Japanese and U.S. manufacturing sectors. Several important features are worth noting. First, it is instructive to employ equation (19) in examining the bias introduced in traditional MFP measures by ignoring the vintage utilization adjustment effect. In general, traditional MFP measures will understate (overstate) productivity growth depending on whether MFP* – MFP is positive (negative). Inspection of table 6.4, part A, reveals that MFP* – MFP is usually positive in *both* pre- and postembargo years, and that, as expected, the extent of the bias depends directly upon the size of the *ex ante* energy-capital substitution elasticity. Apparently, the traditional MFP measure has been underestimating productivity growth for quite some time, not just since 1973.

Second, while productivity growth in both the Japanese and U.S. manufacturing industries has been underestimated for some time, the extent of the bias differs between the pre- and postembargo periods. Values of the bias in per-

Table 6.4 **Japanese and U.S. Manufacturing Industries' Traditional and Utilization-Adjusted Multifactor Productivity Indices**

	Japan				United States			
Year	σ = .000	σ = 1.000	σ = .667	σ = .333	σ = .000	σ = 1.000	σ = .667	σ = .333
A. Multifactor productivity indices:								
1958	.791	.782	.783	.783	.848	.841	.842	.844
1959	.794	.784	.785	.786	.856	.847	.849	.851
1960	.836	.828	.829	.830	.870	.862	.864	.866
1961	.847	.839	.840	.841	.875	.867	.869	.871
1962	.862	.856	.856	.857	.893	.886	.888	.890
1963	.869	.863	.864	.864	.910	.903	.905	.906
1964	.871	.865	.866	.866	.938	.932	.933	.935
1965	.872	.866	.867	.867	.946	.939	.941	.943
1966	.885	.879	.880	.881	.953	.947	.949	.951
1967	.913	.907	.908	.909	.941	.935	.937	.939
1968	.939	.934	.935	.936	.951	.945	.947	.949
1969	.960	.954	.955	.957	.955	.949	.951	.952
1970	.983	.978	.980	.981	.946	.941	.942	.943
1971	.980	.981	.981	.980	.958	.954	.955	.956

1972	.990	.991	.990	.990	.978	.974	.975	.976
1973	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1974	.961	.999	.988	.975	.992	1.005	1.001	.997
1975	.952	.991	.980	.966	.986	.995	.993	.990
1976	.965	.999	.990	.979	1.002	1.009	1.008	1.006
1977	.973	1.000	.993	.984	1.015	1.021	1.020	1.018
1978	.993	1.001	1.001	.999	1.021	1.025	1.025	1.023
1979	1.009	1.028	1.024	1.018	1.027	1.035	1.034	1.031
1980	1.011	1.056	1.045	1.030	1.033	1.047	1.044	1.039
1981	1.034	1.074	1.065	1.053	1.042	1.056	1.053	1.049
B. Multifactor productivity growth rates, selected periods:								
1958–81	1.172	1.389	1.346	1.296	.900	.995	.997	.950
1958–73	1.575	1.653	1.644	1.640	1.105	1.161	1.153	1.137
1973–81	.419	.896	.790	.648	.516	.683	.648	.600
1973–75	−2.430	−.451	−1.005	−1.715	−.702	−.250	−.351	−.501
1975–78	1.414	.335	.709	1.126	1.120	.995	1.063	1.099
1978–81	1.358	2.374	2.087	1.770	.681	.998	.902	.840
C. Estimated bias in traditionally measured MFP slowdown (in %):								
1958–73		.078	.069	.065		.056	.048	.032
1973–81		.477	.371	.229		.167	.132	.084

centage points for the periods 1958–73 and 1973–81, and for each assumed value of σ, are presented in table 6.4, part C. These bias estimates are calculated as the difference between traditional and utilization-adjusted MFP growth rate estimates. Note that in both countries the bias associated with the earlier period is some three to four times smaller than that associated with the postembargo period for all three values of σ. Further, the bias associated with the U.S. manufacturing industry is consistently less than that for Japan by a factor of more than three. Hence, accounting for vintage utilization adjustment effects would seem to be significantly more important in measuring postembargo Japanese manufacturing industry productivity growth than it is for the United States.

Third, and closely related to the above, it appears that traditional productivity measures have overstated the productivity growth slowdown in both the Japanese and U.S. manufacturing sectors. Recall that the slowdown is measured as the difference between per annum growth rates in 1958–73 and 1973–81. Hence the bias in the traditional estimates of the slowdown would be the difference between the traditional and vintage utilization-adjusted estimates of the slowdown. Positive (negative) values calculated in this way indicate overstatement (understatement) of the productivity slowdown. Based on the data in table 6.4, part B, we find that the bias estimates for all values of σ for both Japan and the United States are negative, with values of 0.399%, 0.302%, and 0.164% per year for Japan and 0.111%, 0.084%, and 0.052% per year for the United States as σ = (1.0, .667, .333), respectively. Thus, ignoring the utilization adjustment effect leads to a consistent overstatement of the productivity growth slowdown, with the bias some 3.2–3.6 times greater in Japan than for the United States. Thus, not only is the vintage utilization adjustment more important in measuring productivity growth in Japan, it is also more important in measuring the extent of the productivity growth slowdown since 1973.

Fourth, the pattern of traditional and utilization-adjusted productivity growth within the 1973–81 period varies considerably, with both similarities and significant differences between the two countries. For the three subperiods—1973–75, 1975–78, and 1978–81—traditional MFP estimates understate, overstate, and understate utilization-adjusted MFP, respectively, in both Japan and the United States. Most striking is the effect of the utilization adjustment on traditional MFP measures for the period 1973–75, the period including the first energy price shock. While the traditional MFP measure decreased 2.43% per year (0.702% per year) for Japan (the United States) in that period, allowing for utilization adjustment mitigates the decrease by 81.4%, 58.6%, and 29.4% in Japan and 64.4%, 50.0%, and 28.6% in the United States for σ = (1.0, .667, .333), respectively. Hence, even for the low estimate of σ = .333, the utilization adjustment effect in both Japan and the United States accounts for almost 30% of the reduction in productivity growth rates coincident with the first energy price shock.

For the middle subperiod, 1975–78, the traditional measure overstates productivity growth in both countries, due to a combination of flat, even falling energy/capital prices plus new, more energy-efficient investment.

For the period 1978–81, which includes the second energy price shock, traditional measures again understate MFP growth in both countries. Moreover, while traditional measures decrease only slightly from 1975–78 for Japan (1.415 to 1.358), the decrease is some 64% (1.12 to 0.681) for the United States. Hence, for traditional MFP measures, it appears that the second price shock was coincident with a much greater reduction in U.S. productivity growth than in Japan.

However, a very different picture emerges when we compare the utilization-adjusted MFP. In particular, the Japan utilization-adjusted productivity growth rates increase between 1975–78 and 1978–81 by 608.7%, 194.4%, and 57.2%, while U.S. MFP growth changes by 0.3%, −15.1%, and −23.6%, for σ = (1.0, .667, .333), respectively. For Japan, the energy/capital price reduction in the earlier period, coupled with the dramatic increase in investment/output ratios beginning in 1978, leads to very different MFP estimates when these economic conditions are expressed via the firm's efficiency choice and vintage utilization decisions. The effects are perhaps less dramatic for the United States, given its particular energy/capital price history and the fact that increasing investment/output ratios began earlier in 1974.

In summary, we find that our simple model accounting for the unobservable effects of efficiency choice and vintage utilization decisions has significant implications for productivity growth measurement. Our simulation results suggest that these effects differ substantially for the two countries considered here, depending critically upon the history of energy/capital prices, the vintage structure of surviving capital goods, and historical investment patterns, particularly in the postembargo period. Variation is also a function of the value assumed for a critical parameter in the model, the *ex ante* energy-capital substitution elasticity. Most important, we find that even for low values of σ, vintage utilization adjustment is an important factor in measuring both productivity growth and the so-called productivity growth slowdown in the Japanese and U.S. manufacturing sectors. These simulation results suggest the importance of further econometric research focused on estimation of this key parameter.

6.5 Concluding Remarks

Our purpose in this paper has been to employ a model accounting for the unobserved effects of vintage efficiency and utilization choice in measuring aggregate utilized capital services and multifactor productivity growth in Japanese and U.S. manufacturing. The approach has been exploratory, employing simulations in which historical data are combined with assumptions about expected energy/capital prices and the *ex ante* energy-capital substitution elasticity to estimate ranges for aggregate capital utilization adjustment effects on capital and MFP growth measures. The results suggest that accounting for these unobserved effects is in fact important; even low values of σ result in nontrivial impacts upon capital and productivity measures, especially in the Japanese manufacturing sector. Clearly, more systematic econometric research is warranted on this important issue.

Several modeling and measurement issues must also be considered in future research. These include (i) the formation of expected relative life-cycle prices; (ii) the possibility of alternative adjustment mechanisms that account for changing expected utilization over the remaining life of the asset, not just the current period utilization adjustments considered in this paper; and (iii) consideration of nonenergy factors contributing to utilization effects, in particular environmental regulations.

With respect to (ii), it is worth noting that utilization adjustments should affect expected present values of quasi rents, and thus should ultimately affect depreciation patterns of durable assets. In this context, it is of interest to note that the study by Hulten, Robertson, and Wykoff (1987) suggests that large energy-price-shock-induced depreciation effects did not occur. Research that reconciles these findings should receive high priority.

Finally, this paper highlights the fact that energy-price-induced productivity growth effects vary significantly between the Japanese and U.S. manufacturing industries. It is likely that adding other countries to the data set would increase the diversity of results and would provide a richer collection of analyses and evidence for obtaining better understanding of the economic consequences of the key economic event of the 1970s—the OPEC-induced energy price shocks.

Notes

1. Other leading students of productivity growth analysis also arrive at this conclusion. See, e.g., Kendrick (1983).

2. The pattern of annual energy price and productivity changes for the years 1947–81 in Japanese and U.S. manufacturing are discussed below; see tables 6.1–6.3 for details.

3. In addition to these two facts, Denison (1979) has pointed out that at the level of the aggregate economy, energy is both an input and an output, and thus energy effects tend to cancel out. In our context of the manufacturing sector, this point is, of course, irrelevant.

4. These measures are calculated as growth in output minus the sum of value-share weighted growth in capital, labor, energy, and nonenergy intermediate material inputs.

5. While economists are attracted to the geometric decay assumption, in part because of its analytical convenience, economic statisticians have often tended to employ other assumptions about deterioration profiles. Empirical evidence is mixed, but the

important recent study of Hulten and Wykoff (1981) tends to support the geometric decay form for a wide variety of durable goods.

6. See Diewert (1978) for a discussion of Hicksian aggregation.

7. Incidentally, the most recent vintage would not necessarily be used the most intensively.

8. Because r_{MFP} is computed as a residual, it can capture the effects of all types of errors and omissions. This has led Abramovitz (1956, p. 11) to call it a "measure of our ignorance."

9. See, e.g., the debate among Jorgenson-Griliches (1967, 1972) and Denison (1969).

10. The simulation approach adopted here is similar to that of Mori and Sawa (1985) for the total Japanese manufacturing industry, and to Berndt and Wood (1987) for two-digit SIC U.S. manufacturing industries.

11. Berndt and Wood (1984) have estimated this elasticity for U.S. manufacturing industries employing four alternative specifications of expected life-cycle costs and measurement error. Their estimates range from 0.390 to 0.935, and so are contained in the [0,1] interval. Recall that $\sigma = 0.0$ is equivalent to $B_{K,t} = 1.0$.

12. As will become clear, we require a series on energy/equipment prices roughly one investment cycle prior to the first year of analysis. Since our estimates of equipment depreciation rates are .133 and .135 for Japan and the United States, respectively, and since the starting year for analysis is 1958, the 29-year interval from 1929 to 1958 implies that, in 1958, approximately 1.6% of Japanese and 1.5% of U.S. manufacturing sector equipment investment made in 1929 is still surviving in 1958.

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Comment
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Berndt, Mori, Sawa, and Wood present a simple but useful ex ante, ex post model of production in which the vintage-specific utilization rate of production equipment is endogenized. It then analyzes the slowdown in productivity observed in Japan and the United States in light of two important facts. First, it is known that investment in new, energy-efficient plants and equipment tends to be gradual and does not occur instantaneously. Second, it is also well-known that the cost share of energy is rather small.

Although their method is pioneering and suggestive, I believe that more development is needed before it is applicable to the measurement of multifactor productivity during the productivity slowdown. First, before 1973 the energy-relative price had decreased in the United States and had slightly decreased or fluctuated in Japan. Therefore, just after the oil embargo, we would expect to find that the utilization rate of relatively new equipment invested in

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the early 1970s was less than that of old equipment invested in the early 1960s. This does not seem to have happened. Also, it has been said that firms in Japan tried to adapt to the embargo by adding energy-saving investment or by changing only the parts of equipment, and that the utilization rate of new capital equipment was greater than that of the old. If this is so, disaggregation of the assets by energy intensity might be desirable.

As an alternative approach, a model of technical progress with an energy-saving bias in the ex ante aggregator function of energy and capital might be able to explain this "reverse utilization" problem. According to the Japanese experience, the input coefficient of the energy in the energy-using manufacturing industries (like aluminum, pig iron, and flat glass) has been almost constantly decreasing even before 1973, while the input coefficient of the capital input has been increasing (see Economic Planning Agency's *White Book of Economy* [Keizai Hakusho, 1979]).

Although these facts are not conclusive, they suggest that technical progress (including energy-saving bias or capital-embodied technical change) might have been dominant in these industries. To insert this technical progress term into the ex ante aggregator function would be one solution to the above-mentioned problem.

As a second general point, it should be noted that the authors' definition of utilization rate is somewhat ambiguous. The key equation for endogenizing the utilization rate is the short-run variable cost expressed in equation (4). In this equation, the utilization rates are the only variables, and cost is linear in them. Therefore, if utilization rates fall sufficiently, the most efficient vintage-specific capital equipment alone will be used, and if they are defined to have an upper bound like 1, the short-run cost minimization is in the corner equilibrium. This will be an undesirable property of their model.