ECONOMIC RESEARCH REPORTS

COMPARISON AND ANALYSIS OF PRODUCTIVITY GROWTH AND R&D INVESTMENT IN THE ELECTRICAL MACHINERY INDUSTRIES OF THE UNITED STATES AND JAPAN

by

M. Ishaq Nadiri

and

Ingmar R. Prucha

R.R. #88-22 June 1988

C. V. STARR CENTER FOR APPLIED ECONOMICS

NEW YORK UNIVERSITY
FACULTY OF ARTS AND SCIENCE
DEPARTMENT OF ECONOMICS
WASHINGTON SQUARE
NEW YORK, N.Y. 10003

COMPARISON AND ANALYSIS OF PRODUCTIVITY GROWTH AND R&D INVESTMENT IN THE ELECTRICAL MACHINERY INDUSTRIES OF THE UNITED STATES AND JAPAN

M. Ishaq Nadiri*

Ingmar R. Prucha**

March 1988

* New York University and National Bureau of Economic Research

** University of Maryland and National Bureau of Economic Research

ABSTRACT

This paper presents a comparative analysis of productivity growth in the U.S. and Japanese electrical machinery industries in the postwar period. This industry has experienced rapid growth in output and productivity and high rates of capital formation in both countries. A substantial amount of R&D resources of the total manufacturing sectors in both countries is concentrated in the electrical machinery industry. Also, this industry has an active export orientation in both countries.

The analysis of the paper is based on a dynamic factor demand model. This model is used to explore the production structure and the behavior of factor inputs as well as the determinants of productivity growth in the U.S. and Japanese electrical machinery industry. The analysis shows that the production structure of the industry in both countries is characterized by increasing returns to scale; the factors of production do respond to changes in factor prices qualitatively similar in both countries. The main sources of labor productivity growth are growth in materials, technical change and capital accumulation. R&D expenditures have also contributed significantly to growth of labor productivity while the most important source of total factor productivity growth in this industry for both countries has been the scale effect followed by changes in technical progress.

1. Introduction[1]

During the 1970's the growth rates of labor productivity in the Japanese manufacturing sector dramatically exceeded those of the United States, particularly in such key industries as primary metals, chemicals, electrical machinery, and transportation equipment. This enabled the Japanese to reach and eventually surpass levels of U.S. labor productivity in these industries (Grossman (1985)). Although each of these industries is a key competitor to the U.S. high technology industries in both the U.S. domestic and in the world market, the electrical machinery industry stands out in certain respects. It has experienced very rapid growth in output and productivity and high rates of capital formation both in the U.S. and Japan. Also, a substantial amount of R&D resources - over 20% of total R&D expenditures in total manufacturing - is concentrated in this industry in both countries. Furthermore, Japan has increased its share of free world export in electrical machinery from 22% in 1971 to 48% in 1981 as well as dramatically increased its share of U.S. imports of electrical machinery products over the same period (Grossman (1985)).

Because of these characteristics, we have chosen to examine the productivity performance of this industry in the U.S. and Japan. The analysis is based on a dynamic factor demand model. The model links intertemporal production decisions by explicitly recognizing that the level of certain factors of production cannot be changed without incurring some costs. These costs are often referred to as "adjustment costs" and are defined here in terms of foregone output from current production. Not all inputs are subject to adjustment costs; some inputs, like materials, which can be adjusted very easily are called variable factors while others, like capital and R&D,

which are subject to adjustment cost (and only adjust partially in the first period) are referred to as quasi-fixed inputs. Since output growth has been fairly high in the electrical machinery industry both in the U.S. and Japan, we have not imposed a priori constant returns to scale. Rather, returns to scale are estimated from the data. Since the rate of R&D investment in the electrical machinery industry has been very rapid, we have also incorporated R&D explicitly as one of the inputs. The stocks of physical capital and R&D are considered to be quasi-fixed inputs while labor (hours worked) and materials are considered to be variable factors in the production process. Using the structural parameter estimates, we analyze the sources of growth in output, labor productivity and total factor productivity.

The paper is organized as follows: In Section II we provide a brief description of the behavior of productivity growth as well as input and output growth in the electrical machinery industries of the U.S. and Japan. Section III describes the properties and structure of our analytical model. In Section IV we describe the results obtained by estimating the model using annual data. We report output and price elasticities of the variable and quasi-fixed factors of production in the short, intermediate and long run and calculate the speeds of adjustment of the quasi-fixed factors - physical and R&D capital. Section V is devoted to examining the sources of output and factor productivity growth rates. Summary and conclusions are offered in Section VI. The data description is contained in an appendix.

II. Some Descriptive Characteristics

In this section, we provide a brief description of total and partial factor productivity growth and the growth of gross output, labor, materials, capital, and R&D in the electrical machinery industry for the periods 1968-73 and 1974-79. We refer to these periods as the pre-OPEC and the post-OPEC periods respectively.

Average growth rates for gross output and factor inputs for the two periods are given in Table 1. For the pre-OPEC period the growth rates were extremely high for Japan in comparison to the U.S. However, in the post-OPEC period, the Japanese electrical machinery industry experienced a substantial drop in rates of growth of output and of most inputs. For example, the average output growth rate declined from 16.9% to 6.4% for Japan while increasing from 4.2% to 4.9% in the U.S. Still, the level of output growth

TABLE 1: Average Annual Rates of Growth of Output and Inputs and Input Shares in the US and Japanese Electrical Machinery Industries for Periods 1968-73 and 1974-79.

	Output		Labor		Materials		Capital		R&D	
Period	US	Japan	US	Japan	US	Japan	US	Japan	US	Japan
			Annual Rates of Growth (in percentages)							
1968-73	4.2	16.9	-0.5	4.3	3.3	14.8	5.4	11.4	5.3	19.2
1974-79	4.9	6.4	1.4	-2.5	2.1	2.5	4.3	6.5	1.7	11.4
			Input Shares in Total Cost							
1968-73			.35	.16	.47	.74	.07	.08	.11	.02
1974-79			.33	.20	.48	.68	.08	.09	.11	.03

rates for the Japanese industry remained high compared to the U.S. industry. The average growth rate of capital over the period 1968 - 73 was twice as high in Japan as in the U.S. even though the U.S. industry experienced a healthy 5.4% per annum growth rate over this period. However, Japan's rate of growth in capital formation decelerated by more than 40% after 1973. Materials input grew much faster in Japan than in the U.S. in the pre-OPEC period, but again Japan experienced a dramatic slowdown in the growth rate of this input during the second period.

As indicated in Table 1 the R&D stock grew at a much more rapid rate in Japan than in the US in both periods, reflecting the very high rate of growth in R&D investment in Japan. In both the US and Japanese electrical machinery industries the growth in the stock of R&D slowed down in the 1974-79 period. The input shares in total cost shown in the lower panel of Table 1 indicate for Japan a tendency toward increase in the labor share and a decline in the share of materials in the two periods. The cost shares in the US are generally very stable in this industry over the two periods.

The growth rate of labor measured in hours worked shows a dramatically different pattern in the two countries. It increased from -0.5% in 1968-73 to 1.4% in 1974-79 in the U.S. while in Japan the growth in this input declined from 4.3% to an actual reduction of -2.5%. This phenomenon is consistent with the general pattern of employment in the two countries: Japan experienced declines in employment in several industries while the U.S. experienced increases in employment in most industries (Griliches and Mairesse (1985) and Norsworthy and Malmquist (1983)).

As demonstrated by Table 2, an important characteristic of the electrical machinery industry in both countries is the high ratio of R&D investment in output. While the ratio of capital investment in value added or gross output in this industry is generally lower than in total manufacturing, the opposite is true for R&D investment. The R&D ratios in the electrical machinery industry are two to three times as large as those in total manufacturing. It is also important to note that in the U.S. electrical machinery industry the R&D investment ratios are considerably higher than the capital investment ratios while the opposite is true in Japan.

TABLE 2. Ratio of Investment Expenditures in Capital and Total R&D to Gross Output and Value Added in the U.S. and Japanese Total Manufacturing Sectors and Electrical Machinery Industries: 1970 and 1980 (in percentages).

	Investment Expenditures in Value Added				Investment Expenditures in Gross Output			
	Capital		R&D		Capital		R&D	
	US	Japan	US	Japan	US	Japan	US	Japan
Total Manufacturing								
1970	7.4	30.0	5.8	2.9	3.5	9.8	2.7	0.9
1980	9.4	18.5	5.7	4.0	3.8	5.6	2.3	1.2
Electrical machinery industry								
1970	5.5	21.1	16.9	8.0	3.1	7.4	7.5	2.8
1980	8.6	18.0	12.8	9.4	4.8	6.9	7.1	3.6

Total and partial productivity growth rates based on a gross output measurement framework are shown in Table 3. Both total and labor productivity growth rates were much higher in the Japanese electrical machinery industry than in the U.S.[2] This was particularly true in the pre-OPEC period. Unlike the aggregate manufacturing sector (Norsworthy and Malmquist (1983)), total factor productivity was rising in this industry in the two countries over the two periods. The differences in the growth of labor productivity in the industries of the two countries are substantial. In the U.S. labor productivity grew about 4.7% in 1968-73 and declined to 3.5% in 1974-79; in Japan the corresponding growth rates are 12.6 and 8.9 respectively. Substantial improvements in materials productivity in this industry in both countries in the post-OPEC period are also noted.

TABLE 3: Average Annual Rates of Growth of Total and Partial Factor Productivity for the Periods 1968-73 and 1974-79 in the US and Japanese Electrical Machinery Industries (in percentages).

	Total Factor Productivity		Labor Productivity		Materials Productivity		Capital Productivity		R&D Productivity	
	US	Japan	US	Japan	US	Japan	US	Japan	US	Japan
1968-73	1.8	4.1	4.7	12.6	0.9	2.1	-1.2	5.5	-1.1	-2.3
1974-79	2.9	4.5	3.5	8.9	2.8	3.9	0.6	-0.1	3.2	-7.0

Thus, the elements of the so-called Japanese productivity "miracle" can also be observed in the electrical machinery industry: high rates of labor productivity growth accompanied by rapid growth rates of output and other inputs such as materials, capital and R&D before 1973 and diminishing but still very high rates of labor productivity growth after 1973 accompanied by a substantial fall-off in the growth rates of output and other inputs. To explore the reasons for these productivity patterns, we proceed to estimate the production structure of the electrical machinery industry of the two countries.

III. Model Specification

The model specified below generates a set of factor demand equations for both the variable inputs, materials and labor, and the quasi-fixed inputs, capital and R&D. Each demand function allows for the effect of changes in output, changes in relative prices, and technological change. Also, the model allows for the interaction (i.e., "non-separability") of the quasi-fixed inputs capital and R&D during the adjustment process. From the structural parameters various underlying features of the technology such as the degree of economies of scale and the output and price elasticities of the inputs in the current and subsequent periods can be measured. Finally, these parameters can be used to decompose the factors that affect total and labor productivity growth rates in the Japanese and US electrical machinery industries.

Consider a firm that employs two variable inputs and two quasi-fixed inputs in producing a single output from a technology with internal adjustment costs. Specifically, assume the firm's production function takes the form:

$$(1) \qquad Y_t = F(V_t, X_{t-1}, \Delta X_t, T_t)$$

where Y_t denotes gross output, $V_t = [V_{1t}, V_{2t}]'$ is the vector of variable inputs, $X_t = [X_{1t}, X_{2t}]'$ is the vector of end-of-period stocks of the quasi-fixed inputs and T_t is an exogenous technology index. The vector

$\Delta X_t = X_t - X_{t-1}$ represents the internal adjustment costs in terms of foregone output.

The firm's input markets are assumed to be perfectly competitive. It proves convenient to describe the firm's technology in terms of the normalized restricted cost function defined as $G(W_t, X_{t-1}, \Delta X_t, Y_t, T_t) = \hat{V}_{1t} + W_t \hat{V}_{2t}$. Here, $\hat{V}_{1t}$ and $\hat{V}_{2t}$ represent the cost-minimizing amounts of variable inputs needed to produce the output Y_t conditional on X_{t-1} and ΔX_t and W_t denotes the price of V_{2t} normalized by the price of V_{1t}. The following properties of the normalized restricted cost function follow from Lau (1976): $G_{X_j} < 0$, $G_{|\Delta X_j|} > 0$, $G_Y > 0$, $G_W > 0$; furthermore, $G(\cdot)$ is convex in X_{t-1} and ΔX_t and concave in W_t.

Given the presence of large firms in the electrical machinery industries of both the US and Japan, we do not impose a priori constant returns to scale. Rather, we allow the technology to be homogeneous of (constant) degree ρ and determine ρ --the returns to scale parameter-- from the data.[3] Results from Nadiri and Prucha (1984) imply that if $F(\cdot)$ is homogeneous of degree ρ, the corresponding normalized restricted cost function is of the form:

$$(2) \qquad G(W_t, X_{t-1}, \Delta X_t, Y_t, T_t) = G[W_t, X_{t-1}/Y_t^{1/\rho}, \Delta X_t/Y_t^{1/\rho}, T_t] Y_t^{1/\rho}.$$

In the empirical analysis, we take labor (hours worked), L, and materials, M, as the variable factors and the stocks of capital, K, and research and development, R, as the quasi-fixed factors. We adopt the convention $V_1 = L$, $V_2 = M$, $X_1 = K$ and $X_2 = R$; W is the real wage rate; the price of materials is the numeraire. We specify the following functional form for the normalized restricted cost function:

$$(3) \qquad G(W_t, X_{t-1}, \Delta X_t, Y_t, T_t) = (\alpha_0 + \alpha_W W_t + \alpha_{WT} W_t T_t + \alpha_{WW} W_t^2/2) Y_t^{1/\rho}$$
$$+ a' X_{t-1} + b' X_{t-1} W_t + c' X_{t-1} T_t + X_{t-1}' A X_{t-1}/(2Y_t^{1/\rho})$$
$$+ \Delta X_t' B \Delta X_t/(2Y_t^{1/\rho}),$$

where

$$a = \begin{bmatrix} \alpha_K \\ \alpha_R \end{bmatrix}, \quad b = \begin{bmatrix} \alpha_{KW} \\ \alpha_{RW} \end{bmatrix}, \quad c = \begin{bmatrix} \alpha_{KT} \\ \alpha_{RT} \end{bmatrix}, \quad A = \begin{bmatrix} \alpha_{KK} & \alpha_{KR} \\ \alpha_{KR} & \alpha_{RR} \end{bmatrix}, \quad B = \begin{bmatrix} \alpha_{\dot{K}\dot{K}} & 0 \\ 0 & \alpha_{\dot{R}\dot{R}} \end{bmatrix}.$$

In light of the above discussion, we can view (3) as a second order approximation to a general normalized restricted cost function that corresponds to a homogeneous technology of degree ρ. Expression (3) is a generalization of the normalized restricted cost function introduced by Denny, Fuss and Waverman (1981) and Morrison and Berndt (1981) for linear homogeneous technologies. Nadiri and Prucha (1984) have generalized that function to homothetic technologies. As in these references we impose parameter restrictions such that the marginal adjustment costs at $\Delta X_t = 0$ are zero. In the empirical analysis, we take $T_t = t$, i.e., technical change, other than that reflected by the stock of R&D, is represented by a simple time trend. The convexity of $G(\cdot)$ in X_{t-1} and ΔX_t and concavity in W_t imply the following inequality parameter restrictions:

$$(4) \qquad \alpha_{KK} > 0, \quad \alpha_{RR} > 0, \quad \alpha_{KK}\,\alpha_{RR} - \alpha_{KR}^2 > 0,$$
$$\alpha_{\dot{K}\dot{K}} > 0, \quad \alpha_{\dot{R}\dot{R}} > 0, \quad \alpha_{WW} < 0.$$

We assume that in each period t, for given initial stocks X_{t-1}, the firm derives an optimal input path such that the present value of the future cost stream is minimized and chooses the inputs in period t accordingly. We also assume static expectations on relative factor prices, output and the technology. Accordingly, the firm's optimum problem in period t can be written as:

$$(5) \qquad \min_{\{K_{t+\tau}, R_{t+\tau}\}_{\tau=0}^{\infty}} PVC_t = \sum_{\tau=0}^{\infty} \{[G_{t,\tau} + \hat{Q}_t^R(\Delta R_{t+\tau} + \delta_R R_{t+\tau-1})](1-u_t) + \hat{Q}_t^K(\Delta K_{t+\tau} + \delta_K K_{t+\tau-1})\}(1+r)^{-\tau},$$

with $G_{t,\tau} = G(\hat{W}_t, K_{t+\tau-1}, R_{t+\tau-1}, \Delta K_{t+\tau}, \Delta R_{t+\tau}, \hat{Y}_t, T_t)$. Here Q_t^K and Q_t^R denote, respectively, the acquisition price of capital and R&D, δ_K and δ_R denote, respectively, the depreciation rates of capital and R&D, u_t is the corporate tax rate and r is the constant (real) discount rate. Expectations are characterized with a carat ($\hat{}$). We maintain $\hat{W}_t = W_t$, $\hat{Q}_t^K = Q_t^K$, and $\hat{Q}_t^R = Q_t^R$. R&D expenditures are assumed to be expended immediately. The minimization problem (5) represents a standard optimal control problem. Its solution is well known and implies the following system of quasi-fixed factor demand equations in accelerator form:[4]

$$(6) \qquad \begin{aligned} \Delta K_t &= m_{KK}(K_t^* - K_{t-1}) + m_{KR}(R_t^* - R_{t-1}), \\ \Delta R_t &= m_{RK}(K_t^* - K_{t-1}) + m_{RR}(R_t^* - R_{t-1}), \end{aligned}$$

where

$$\begin{bmatrix} K_t^* \\ R_t^* \end{bmatrix} = -\begin{bmatrix} \alpha_{KK} & \alpha_{KR} \\ \alpha_{KR} & \alpha_{RR} \end{bmatrix}^{-1} \begin{bmatrix} \alpha_K + \alpha_{KW}W_t + \alpha_{KT}T_t + C_t^K \\ \alpha_R + \alpha_{RW}W_t + \alpha_{RT}T_t + C_t^R \end{bmatrix} \hat{Y}_t^{1/\rho} ,$$

with $C_t^K = Q_t^K(r+\delta_k)/(1-u_t)$ and $C_t^R = Q_t^R(r+\delta_R)$. The matrix of accelerator coefficients $M = (m_{ij})_{i,j=K,R}$ has to satisfy the following matrix equation:

$$(7) \qquad BM^2 + (A + rB)M - A = 0;$$

furthermore, the matrix $C = (c_{ij})_{i,j=K,R} = -BM$ is symmetric and negative definite. Unless we impose separability in the quasi-fixed factors, i.e., $\alpha_{KR} = 0$, which implies $m_{KR} = 0$, (7) cannot generally be solved for M in terms of A and B. We can, however, solve (7) for A in terms of M and B: $A = BM(M+rI)(I-M)^{-1}$. Since the real discount rate r was assumed to be constant, M is constant over the sample. Hence, instead of estimating the elements of A and B, we may estimate those of M and B. Such a reparameterization was first suggested by Epstein and Yatchew (1985) for a somewhat different model with a similar algebra. Mohnen, Nadiri and Prucha (1986) used such a reparameterization within the context of a constant returns to scale model. To impose the symmetry of C we can also estimate B and C instead of B and M. Let $D = (d_{ij})_{i,j=K,R} = -MA^{-1}$ and observe that $A = C - (1+r)[B - B(C+B)^{-1}B]$ and that $D = B^{-1} + (1+r)(C-rB)^{-1}$ is symmetric. It is then readily seen that we can write (6) equivalently as:

(8) $$\Delta K_t = d_{KK}[\alpha_K + \alpha_{KW}W_t + \alpha_{KT}T_t + C_t^K]\hat{Y}_t^{1/\rho} + d_{KR}[\alpha_R + \alpha_{RW}W_t + \alpha_{RT}T_t + C_t^R]\hat{Y}_t^{1/\rho} + [c_{KK}/\alpha_{\dot{K}\dot{K}}]K_{t-1} + [c_{KR}/\alpha_{\dot{R}\dot{R}}]R_{t-1},$$

$$\Delta R_t = d_{KR}[\alpha_K + \alpha_{KW}W_t + \alpha_{KT}T_t + C_t^K]\hat{Y}_t^{1/\rho} + d_{RR}[\alpha_R + \alpha_{RW}W_t + \alpha_{RT}T_t + C_t^R]\hat{Y}_t^{1/\rho} + [c_{KR}/\alpha_{\dot{R}\dot{R}}]K_{t-1} + [c_{RR}/\alpha_{\dot{R}\dot{R}}]R_{t-1},$$

where

$$d_{KK} = 1/\alpha_{\dot{K}\dot{K}} + (1+r)[c_{RR} - r\alpha_{\dot{R}\dot{R}}]/e,$$

$$d_{RR} = 1/\alpha_{\dot{R}\dot{R}} + (1+r)[c_{KK} - r\alpha_{\dot{K}\dot{K}}]/e,$$

$$d_{KR} = -(1+r)c_{KR}/e, \quad \text{and} \quad e = (c_{KK} - r\alpha_{\dot{K}\dot{K}})(c_{RR} - r\alpha_{\dot{R}\dot{R}}) - c_{KR}^2 .$$

The firm's demand equations for the variable factors can be derived from the normalized restricted cost function via Shephard's lemma as $L_t = \partial G_{t,0}/\partial W_t$ and $M_t = G_{t,0} - W_t L_t$:

(9) $$L_t = [\alpha_W + \alpha_{WW}W_t + a_{WT}T_t]\hat{Y}_t^{1/\rho} + \alpha_{KW}K_{t-1} + \alpha_{RW}R_{t-1},$$

$$M_t = [\alpha_0 - \alpha_{WW}W_t^2/2]\hat{Y}_t^{1/\rho} + \alpha_K K_{t-1} + \alpha_R R_{t-1} + \alpha_{KT}K_{t-1}T_t + \alpha_{RT}R_{t-1}T_t + [\alpha_{KK}K_{t-1}^2/2 + \alpha_{KR}K_{t-1}R_{t-1} + \alpha_{RR}R_{t-1}^2/2 + \alpha_{\dot{K}\dot{K}}\Delta K_t^2/2 + \alpha_{\dot{R}\dot{R}}\Delta R_t^2/2]/\hat{Y}_t^{1/\rho},$$

where

$$\alpha_{KK} = c_{KK} - (1+r)[\alpha_{\dot{K}\dot{K}} - (\alpha_{\dot{K}\dot{K}})^2(\alpha_{\dot{R}\dot{R}} + c_{RR})/f],$$

$$\alpha_{RR} = c_{RR} - (1+r)[\alpha_{\dot{R}\dot{R}} - (\alpha_{\dot{R}\dot{R}})^2(\alpha_{\dot{K}\dot{K}} + c_{KK})/f],$$

$$\alpha_{KR} = c_{KR} - (1+r)(\alpha_{\dot{K}\dot{K}}\,\alpha_{\dot{R}\dot{R}}\,c_{KR})/f, \quad \text{and} \quad f = (\alpha_{\dot{K}\dot{K}} + c_{KK})(\alpha_{\dot{R}\dot{R}} + c_{RR}) - c_{KR}^2 .$$

The complete system of factor demand equations consists of (8) for the quasi-fixed factors and (9) for the variable factors.

IV. Empirical Results

In this section, we report the structural parameter estimates for the electrical machinery industry in the US and Japan as well as estimates for the short, intermediate and long-run price and output elasticities.

IV.1 Parameter Estimates

We note that system (8) and (9) is nonlinear in parameters and variables and many of the parameters appear in more than one equation. For the empirical estimation, we have added a stochastic disturbance term to each of the factor demand equations.

A detailed description of the data sources and the variables of the model is given in the appendix. The data on gross output, materials, labor, capital and R&D are in constant 1972 dollars and yen and have been normalized by their respective sample means. Prices were constructed conformably. Expectations on gross output were calculated as follows. We first estimate a first order autoregressive model for output which is then used to predict Y_t rationally. We employed the full information maximum likelihood estimation method and, when necessary, corrected for first order autocorrelation of the disturbances.

Table 4 exhibits the parameter estimates. As indicated by the squared correlation coefficients between actual and fitted data, the estimated factor demand equations seem to fit the data quite well. (Fitted values are calculated from the reduced form). For both the US and Japan the squared correlation coefficient is somewhat low for the labor demand

TABLE 4: Full Information Maximum Likelihood Estimates of the Parameters of the Dynamic Factor Demand Model for the US and Japanese Electrical Machinery Industries: 1960-1980 and 1968-1980.*

Parameters	United States		Japan	
α_0	1.83	(7.40)	1.45	(18.14)
ρ	1.21	(17.23)	1.39	(13.20)
α_K	-0.95	(3.13)	-0.47	((2.89)
α_R	-0.65	(1.85)	-0.67	(7.82)
α_{KT}	-0.19	(4.47)	-0.05	(0.75)
α_{RT}	0.22	(3.03)	-0.02	(5.66)
c_{KK}	-2.05	(3.07)	-0.58	(8.77)
c_{RR}	-2.10	(1.90)	-0.14	(7.99)
c_{RK}	0.15	(0.74)	0.01	(1.54)
α_{KK}	8.70	(3.06)	2.57	(4.92)
α_{RR}	13.80	(1.63)	1.11	(5.15)
α_W	1.91	(25.41)	1.33	(10.01)
α_{WW}	-0.48	(3.66)	-0.81	(3.13)
α_{WK}	0.29	(2.59)	0.39	(4.65)
α_{WR}	-0.52	(4.62)	0.02	(1.47)
α_{WT}	-0.28	(6.89)	-0.42	(4.43)
Log of Likelihood	222.1		147.4	
M-Equation: R^2	0.87		0.94	
L-Equation: R^2	0.65		0.75	
K-Equation: R^2	0.99		0.99	
R-Equation: R^2	0.99		0.99	

* Absolute values of the asymptotic "t"-ratios are given in parentheses. The R^2 values correspond to the squared correlation coefficients between the actual M, L, K, R variables and their fitted values calculated from the reduced form.

equation. The parameter estimates are, in general, statistically significant. For both the US and Japan, the parameter estimates satisfy the theoretical restrictions. In particular, the estimates for c_{KK}, c_{RR} and α_{WW} are negative and those for $\alpha_{\dot{K}\dot{K}}$, $\alpha_{\dot{R}\dot{R}}$ and $(c_{KK} c_{RR} - c_{KR}^2)$ are positive. The variables underlying the estimates for the US and Japanese electrical machinery industry are, as explained above, measured in different units. Hence, a direct comparison of individual parameter estimates is difficult. However, we do calculate various unit-free characteristics that allow a meaningful comparison.

In general the adjustment cost coefficients $\alpha_{\dot{K}\dot{K}}$ and $\alpha_{\dot{R}\dot{R}}$ are significantly different from zero. They determine crucially the investment patterns of the quasi-fixed factors via the accelerator coefficients. Omitting those terms would not only have resulted in a misspecification of the investment patterns but also (in general) in inconsistent estimates of the

TABLE 5: Full Information Maximum Likelihood Estimates of the Accelerator Coefficients for Capital and R&D in the US and Japanese Electrical Machinery Industries.*

	Accelerator Coefficient			
	m_{KK}	m_{KR}	m_{RK}	m_{RR}
United States	0.236	-0.017	-0.011	0.152
	(8.55)	(0.66)	(0.68)	(6.82)
Japan	0.227	-0.003	-0.006	0.125
	(4.41)	(1.47)	(1.47)	(7.47)

*Absolute values of the asymptotic "t"-ratios are given in parentheses.

other technology parameters. Table 5 shows the estimates for the accelerator coefficients m_{KK}, m_{KR}, m_{RK}, and m_{RR}. These coefficients have been calculated from the estimates in Table 4 observing that $M = -B^{-1}C$. For both the US and Japanese electrical machinery industry we find that the cross-adjustment coefficients m_{KR} and m_{RK} (as well as c_{KR}) are very small in absolute magnitude and are not significantly different from zero at the 95 percent level. In describing the adjustment speed, we can therefore concentrate on the own-adjustment coefficients m_{KK} and m_{RR}. As a first observation, we note that the obtained estimates are quite similar across countries. For both the US and Japan capital adjusts faster than R&D. While capital closes approximately one fourth of the gap between the initial and the desired stock in the first period, R&D only closes approximately one seventh of its gap. We note that those adjustment speeds are consistent with earlier results obtained by Mohnen, Nadiri and Prucha (1986) for the total manufacturing sectors of the two countries.

As remarked earlier, our specification does not impose a priori constant returns to scale. Rather, we estimate the scale elasticity (represented by ρ) from the data. For both countries, we find substantial and significant scale effects in the industry. For the US, our estimate for the scale elasticity is 1.21; for Japan we obtained a considerably higher estimate of 1.39. As we explain in more detail in section V, this difference in scale elasticities will translate into substantial differences in productivity growth. It is also interesting to note that, contrary to our finding of increasing returns to scale at the industry level, Griliches and

Mairesse (1985) find decreasing returns to scale in the US and Japanese total manufacturing sectors at the firm level.

IV.2 Price and Output Elasticities

The own- and cross-price elasticities of labor, materials, capital and R&D for 1976 are reported in Table 6. The elasticities are calculated for the short (SR), intermediate (IR) and long-run (LR) for each input for the electrical machinery industry in both Japan and the US.[5] All of the own-price elasticities have the expected negative sign. The magnitudes of the elasticities are fairly similar between the two countries. In the US, the own-price elasticity of labor is the largest among the inputs followed by materials, R&D stock and capital stock. In Japan, with minor exceptions, the same pattern holds; the quasi-fixed inputs, capital and R&D, seem to have a higher own-price elasticity in the Japanese than in the US electrical machinery industry. These results are similar to those reported for the total manufacturing sectors of the United States and Japan in Mohnen, Nadiri and Prucha (1986).

Although the cross-price elasticities are generally small in comparison to own-price elasticities, some of the elasticities are sizable. The elasticities of materials and R&D with respect to the wage rate, and the elasticities of labor, R&D, and capital inputs with respect to materials prices are quite large in both countries. Materials are substitutes for other inputs, except for R&D in the US. Labor and R&D are substitutes in the US and weak complements in the Japanese electrical machinery industry. Labor and capital and R&D and capital are complements in both countries.

TABLE 6: Short-Run, Intermediate-Run, and Long-Run Price Elasticities in the US and Japanese Electrical Machinery Industries: 1976.*

Elasticity	United States			Japan		
	SR	IR	LR	SR	IR	LR
ϵ_{Mw^M}	-0.32	-0.40	-0.64	-0.04	-0.18	-0.64
ϵ_{Mw^L}	0.36	0.41	0.65	0.09	0.15	0.36
ϵ_{Mc^K}	-0.01	0.02	0.09	-0.02	0.04	0.20
ϵ_{Mc^R}	-0.01	-0.02	-0.08	-0.03	-0.01	0.09
ϵ_{Lw^M}	0.47	0.55	0.90	0.37	0.51	0.85
ϵ_{Lw^L}	-0.48	-0.58	-1.12	-0.38	-0.44	-0.57
ϵ_{Lc^K}		-0.02	-0.06		-0.06	-0.23
ϵ_{Lc^R}		0.04	0.27		-0.01	-0.05
ϵ_{Kw^M}	0.10	0.17	0.38	0.27	0.46	0.99
ϵ_{Kw^L}	-0.05	-0.09	-0.17	-0.13	-0.23	-0.48
ϵ_{Kc^K}	-0.04	-0.08	-0.18	-0.14	-0.24	-0.49
ϵ_{Kc^R}	-0.01	-0.01	-0.04	-0.01	-0.01	-0.02
ϵ_{Rw^M}	-0.05	-0.09	-0.27	0.19	0.33	0.91
ϵ_{Rw^L}	0.11	0.20	0.65	-0.05	-0.08	-0.23
ϵ_{Rc^K}	-0.01	-0.01	-0.03	-0.01	-0.01	-0.04
ϵ_{Rc^R}	-0.06	-0.10	-0.34	-0.14	-0.24	-0.65

* ϵ_{Zs} is the elasticity of factor Z = materials (M), labor (L), capital (K) and R&D (R) with respect to s = price of materials (w^M), labor (w^L), capital (c^K), and R&D (c^R). The symbols SR, IR and LR refer to the short, intermediate and long run.

The output elasticities of the inputs for 1976 are shown in Table 7. The long-run elasticities of the inputs are .8 and .7, respectively, for the US and Japan, implying fairly sizable economies of scale. The results are consistent with Fuss and Waverman (1985), Nadiri and Prucha (1984) and Nadiri and Schankerman (1981). The patterns of the output elasticities, particularly in the US, indicate that the variable factors of production, labor, and materials, respond strongly in the short run to changes in output. The reason is that both labor and materials in the US and materials in Japan overshoot their long-run equilibrium values in the short run to compensate for the sluggish adjustment of the quasi-fixed factors. They

TABLE 7: Short-Run, Intermediate-Run, and Long-Run Output Elasticities in the US and Japanese Electrical Machinery Industries: 1976.*

Elasticity	United States			Japan		
	SR	IR	LR	SR	IR	LR
ϵ_{MY}	1.19	1.07	0.82	1.06	0.99	0.72
ϵ_{LY}	1.07	1.06	0.82	0.39	0.45	0.72
ϵ_{KY}	0.20	0.34	0.82	0.20	0.34	0.72
ϵ_{RY}	0.14	0.24	0.82	0.15	0.26	0.72

* ϵ_{ZY} is the elasticity of factor Z = materials (M), labor (L), capital (K) and R&D (R) with respect to output (Y). The symbols SR, IR and LR refer to the short, intermediate and long run.

slowly adjust toward their long-run equilibrium values as capital and R&D adjust. The output elasticities of capital and R&D are small in the short run but increase over time and are quite similar. At least in the short and intermediate runs the output elasticities of both the variable and quasi-fixed factors substantially exceed their own-price elasticities. Surprisingly, except for the labor input, the patterns of input responses are similar in both countries.

Thus, the production structure of the electrical machinery industry in the two countries, characterized by the patterns of factor input substitution and complementarity as well as the degree of scale, is qualitatively similar . Quantitatively, there are some differences in scale and in the responses of inputs to changes in prices and output in the two industries. Both industries are characterized by increasing returns to scale. However, the Japanese industry has a higher scale which substantially influences its productivity growth and is a major source of divergence between the productivity growth rates in this industry in the two countries.

V. Productivity Analysis

Using the estimates of the production structure, we can quantitatively examine the sources of output and productivity growth. The contributions of the factor inputs, technical change, and adjustment costs to output growth are shown in Table 8.

The decomposition is based on the approximation:

$$(10) \qquad \Delta \ell n Y_t = (1/2) \sum_{i=1}^{6} [\epsilon_{YZ_i}(t) + \epsilon_{YZ_i}(t-1)] \Delta \ell n Z_{it} + (1/2)[PGY_t + PGY_{t-1}]$$

with $Z_1 = L$, $Z_2 = M$, $Z_3 = K_{-1}$, $Z_4 = R_{-1}$, $Z_5 = \Delta K$ and $Z_6 = \Delta R$. The ϵ_{YZ_i}'s denote the respective output elasticities and $PGY_t = (1/Y)(\partial F/\partial t)$ denotes

TABLE 8: Sources of Output Growth for the US and Japanese Electrical Machinery Industries: Average Annual Rates of Growth (in percentages).

	Gross Output	Labor Effect	Materials Effect	Capital Effect	R&D Effect	Adjustment Cost Capital	Adjustment Cost R&D	Technical Change	Residual
United States									
1968-73	4.2	-0.24	1.83	0.87	1.18	0.06	0.12	0.73	-0.32
1974-79	4.9	0.39	1.06	0.69	0.31	-0.09	0.04	0.86	1.67
Japan									
1968-73	16.9	0.94	14.32	2.12	0.7	-0.26	-0.34	1.55	-2.11
1974-79	6.4	-0.66	2.08	1.10	0.72	0.09	-0.12	2.55	0.69

technical change. The output elasticities are computed from the structural parameter estimates of the restricted cost function using standard duality theory. For both variable and quasi-fixed factors, those output elasticities exceed long-run cost shares because of increasing returns to scale. For the quasi-fixed factors there is an additional element due to the adjustment costs. The contribution of each of the variables in (10) is calculated by multiplying the respective (average) elasticities with the growth rate of the corresponding variable. As shown in Table 8, the average growth rate of gross output was very rapid in Japan in the period 1968-73 but growth decelerated substantially in the period 1974-79. For the US, output growth rates were similar in the two periods. The contributions of various inputs to the growth of output differ considerably between the two periods and the two industries. The most significant source of gross output growth is materials growth, particularly in Japan. The contribution of capital is larger in Japan than in the US, but falls in both countries over the post-OPEC period. The R&D stock contributes significantly to the growth of output in both industries. In the post-OPEC period its contribution falls in the US but remains the same for Japan. The large contribution of R&D to the output growth may come as a surprise, but can be explained by two factors. First, the share of R&D investment in gross output, as noted earlier, is very high in the electrical machinery industry of both countries; second, the marginal product of R&D, because of the relative large adjustment costs and the considerable degree of scale, is fairly large in the two industries. The direct contributions of the adjustment costs are fairly small, as one would expect. The contribution of technical change is clearly important in explaining the growth of output in both industries. Its contribution is twice as large in Japan as in the US.

In Table 9 we provide a decomposition of labor productivity growth. The results are based on the approximation:

$$(11) \qquad \Delta \ell n(Y_t/L_t) = (1/2) \sum_{i=2}^{6} [\epsilon_{YZ_i}(t) + \epsilon_{YZ_i}(t-1)]\Delta \ell n(Z_{it}/L_t) + (1/2)(PGY_t + PGY_{t-1}) + (\rho - 1)\Delta \ell n L_t,$$

where ρ is the scale elasticity. This approximation is readily obtained from (10) by noting that the sum of the output elasticities must equal scale. In the decomposition of labor productivity, the most significant contribution again stems from the growth of materials, particularly in Japan. The contribution of physical capital is important. In comparison to

TABLE 9: Decomposition of Labor Productivity Growth in the US and Japanese Electrical Machinery Industries: Average Annual Rates of Growth (in percentages).

	Labor Productivity	Labor Effect	Materials Effect	Capital Effect	R&D Effect	Adjustment Cost		Technical Change	Residual
						Capital	R&D		
United States									
1968-73	4.68	-0.04	2.07	0.91	1.28	0.06	0.12	0.73	-0.44
1974-79	3.56	0.15	0.43	0.37	0.12	-0.07	0.04	0.86	1.66
Japan									
1968-73	12.63	0.81	10.24	1.33	0.56	-0.13	-0.26	1.55	-1.48
1974-79	8.95	-0.47	4.48	1.54	0.86	0.05	-0.16	2.55	0.10

the results reported by Norsworthy and Malmquist (1983) for the total manufacturing sector, its contribution is somewhat larger for the US but substantially smaller for Japan. The contribution of R&D is somewhat smaller and rising for Japan. For the US, the contribution of R&D is very substantial in the pre-OPEC period but only marginal in the post-OPEC period. The direct contribution of adjustment costs is again small. The contribution of technical change is very substantial (particularly in Japan) and rising in both countries. The last term on the RHS of (11) follows from the fact that scale is not equal to one. The contribution of this term to labor productivity is shown in the second column of Table 9. Its effect is positive in Japan in the pre-OPEC period and negative in the post-OPEC period. The opposite is the case for the US. This reflects the growth pattern of the labor input in the two industries over the two periods.

Denny, Fuss, Waverman (1981) have shown that if all factors are variable the traditional measure of total factor productivity (using cost shares) can be decomposed into two components, one attributable to scale and one to technical change. A similar decomposition exists for our cost of adjustment technology (Nadiri and Prucha (1984)). In particular, we can decompose the Tornquist approximation of total factor productivity as:

$$(12) \qquad \Delta TFP_t = (1-\rho^{-1})\Delta \ell n\, Y_t + (1/2)(PGX_t + PGX_{t-1}) + \phi_{1t} + \phi_{2t},$$

where $PGX = (1/\rho)PGY$. The first term on the RHS of (12) represents the scale effect and the second term the effect of technical change on the growth of total factor productivity. The term ϕ_1 is attributable to the fact that in short-run temporary equilibrium, the rate of technical substitution between the quasi-fixed and variable factors differs from the long run price ratios. We will refer to ϕ_1 as the temporary equilibrium effect. The term ϕ_2 reflects the direct adjustment cost effect in terms of foregone output due to the presence of ΔK and ΔR in the production function. We will refer to ϕ_2 as the direct adjustment cost effect. The exact expressions for ϕ_1 and ϕ_2 are given in Nadiri and Prucha (1984).

Table 10 presents the decomposition of total factor productivity based on (12) for the sample periods used in estimating the production technology of the US and Japanese electrical machinery industry. The scale effect is, by far, the most important contributor to total factor productivity growth. This is particularly the case in the Japanese industry where the output growth was very rapid and the estimated degree of scale is larger than in the US industry. The temporary equilibrium effect, ϕ_1, is fairly large in the US and about twice as big as in the Japanese electrical machinery industry. The direct effect of the adjustment costs, ϕ_2, is negligible. The combined effect of ϕ_1 and ϕ_2 due to the adjustment costs is 15 and 4 percent of the measured total factor productivity for the US and Japan, respectively, and hence not negligible, in particular for the US. Consequently, if zero adjustment costs would have been imposed, a nonnegligible portion of measure total factors productivity would have been misclassified. In addition, inconsistency of the estimates of the underlying technology

TABLE 10: Decomposition of Total Factor Productivity Growth in the US and Japanese Electrical Machinery Industries for Respective Sample Periods (in percentages).

	United States 1960-1980	Japan 1968-1980
Total Factor Productivity	2.04	4.74
Scale Effect	1.04	3.38
Temporary Equilibrium Effect	0.28	0.16
Direct Adjustment Cost Effect	0.03	-0.04
Technical Change	0.60	1.49
Unexplained Residual	0.10	-0.24

parameters would have distorted the decomposition of total factor productivity. The contribution of technical change to the growth of total factor productivity is second only to the scale effect. For each of the sample periods, the unexplained residual is small.

VI. Conclusion and Summary

In this paper, we have modeled the production structure and the behavior of factor inputs, and have analyzed the determinants of productivity growth in the US and Japanese electrical machinery industry. These industries have experienced a very high rate of output growth, are technologically very progressive (measured by the rate of expenditures on R&D) and are highly competitive in the domestic US and in the world markets. Our model allows for scale effects and the quasi-fixity of some of the input factors. It also incorporates R&D to capture the high technology feature of the industry. Other inputs considered are: labor, material and physical capital. We have also allowed for exogenous technical change using a time trend. The model was estimated using annual data from 1960-80 and 1968-80 for the US and Japan, respectively.

The main results of this paper can be summarized as follows:

(i) The production structure of the electrical machinery industry in both countries is characterized by increasing returns to scale; the Japanese electrical machinery industry exhibits higher returns to the scale than the US industry. The responses of the factors of production to changes in factor prices and output in the short, intermediate and long run are similar in the two industries.

Materials are found to be generally substitutes for other inputs. Other inputs are generally complements except for labor and R&D in the US industry. Capital and R&D are found to be quasi-fixed and their adjustment speeds are found to be similar across countries. The stock of capital adjusts much faster than the stock of R&D.

(ii) The elements of the so-called Japanese productivity miracle noted by others are, to a large extent, present in the electrical machinery industry: high rates of labor productivity growth accompanied by rapid output growth and input growth before 1973 and diminishing but still high rates of labor productivity growth after 1973 accompanied by a substantial slowdown in the growth rates of outputs and factor inputs.

(iii) Based on the structural estimates of our model, we identify the following sources of growth of output and labor productivity:

a) The most important source of output and labor productivity growth is the growth of materials for both pre- and post-OPEC periods in both countries. Technical change and capital were found to be the next most important factors. For the US, capital's contribution exceeds that found at the total manufacturing level; the reverse is true for Japan.

b) Consistent with the high ratio of R&D expenditures to gross output in the electrical machinery industry, we find significant contributions of R&D to both output and labor productivity growth. However, the R&D contribution to both has significantly declined in the US from the pre-OPEC to post-OPEC periods.

(iv) The most important source of growth in total factor productivity for both countries is the scale effect. This is particularly true in Japan due to the higher scale elasticity and higher rate of growth of output. A significant portion of the differential of total factor productivity in the electrical machinery industry in the US and Japan is due to the greater contribution of economies of scale to growth of total factor productivity in Japan. Technical change is the second most important contributor. In the context of our dynamic model the rate of technical substitution for the quasi-fixed factors deviates in the short run from the long-run relative price ratios. This source also explains part of the traditional measure of total factor productivity.

Our model provides a richer framework for the analysis of productivity growth than some of the conventional approaches by incorporating dynamic aspects, nonconstant returns to scale, and R&D. The omission of dynamic aspects will typically result in inconsistent estimates of the technology parameters and a misallocation in the decomposition of measured total factor productivity growth for the US and Japan, respectively. However, a number of issues remain unresolved:

(i) Given the rapid expansion of the electrical machinery industries in the US and Japan, it seems important to explore the effect of non-static expectations on the input behavior and its implications for the productivity growth analysis.

(ii) It may also be of interest to explore a more general lag structure for the quasi-fixed factors and to adopt a more general formulation of the model that allows for scale to vary over the sample period.

(iii) A further area of research is the decomposition of labor into white and blue collar workers and the modelling of white collar workers as potentially quasi-fixed. The quasi-fixity of labor may be particularly important in Japan where employment is considered fairly long-term.

(iv) Finally, an important extension of the model would be to incorporate explicitly the role of demand and thereby analyze the role of the utilization rate on productivity growth.

APPENDIX: Data Sources and Construction of Variables

US Electrical Machinery Industry

Gross Output: Data on gross output in current and constant 1972 dollars were obtained from the U.S. Department of Commerce, Office of Business Analysis (OBA) database and correspond to the gross output series of the U.S. Department of Commerce, Bureau of Industrial Economics (BIE). Gross output is defined as total shipments plus the net change in work in process inventories and finished goods inventories.

Labor: Total hours worked were derived as the sum of hours worked by production workers and nonproduction workers. Hours worked by production workers were obtained directly from the OBA database. Hours worked by nonproduction workers were calculated as the number of nonproduction workers*hours worked per week*52. The number of nonproduction workers was obtained form the OBA database. Weekly hours worked of nonproduction workers were taken to be 39.7. A series of total compensation in current dollars was calculated by multiplying the total payroll series from the OBA database with the ratio of compensation of employees to wages and salaries from U.S. Department of Commerce, Bureau of Economic Analysis (1981, 1984).

Materials: Materials in current dollars were obtained from the OBA database. Materials in constant 1972 dollars were calculated using deflators provided by the U.S. Department of Commerce, Bureau of Economic Analysis.

Value Added: Value added in current and constant 1972 dollars was calculated by subtracting materials from gross output.

Capital: The net capital stock series in 1972 dollars and the current and constant 1972 dollars gross investment series were taken from the OBA database. The method by which the capital stock series is constructed is described in the US Department of Labor, Bureau of Labor Statistics (1979). The user cost of capital was constructed as $c_K = q^K(r+\delta_K)/(1-u)$, where q^K = investment deflator, δ_K = depreciation rate of the capital stock, u = corporate tax rate and r = 0.05.

R&D: The stock of total R&D is constructed by the perpetual inventory method with a depreciation rate $\delta_R = .1$. The benchmark in 1958 is obtained by dividing total R&D expenditures by the depreciation rate and the growth rate in real value added. The nominal R&D expenditures are taken from National Science Foundation (1984) and earlier issues. To avoid double counting we have subtracted the labor and material components of R&D from the labor and material inputs. The GDP deflator for total manufacturing is used as a deflator for R&D.

All constant dollars variables were normalized by respective sample means. Prices were constructed conformably.

Japanese Electrical Machinery Industry

Gross Output: For the period 1970-1980 the data series on gross output in current and constant 1975 yen were obtained from Economic Planning Agency (1984). The data for the period before 1970 were constructed by connecting these series with the corresponding series reported in Economic Planning Agency (1980) via identical growth rates.

Labor: Total hours worked were calculated as total numbers of employees*monthly hours worked*12. For the period 1970-1980, the number of employees was taken from Economic Planning Agency (1984). For the period before 1970 the number of employees was calculated by connecting this series with the employment index provided by the Economic Planning Agency (EPA). Monthly hours worked for the period 1977-1980 were obtained from the Statistics Bureau (1985). For previous years monthly hours worked were calculated by using the monthly hours work index provided by the EPA. For the period 1970-1980, total compensation is reported in the EPA (1984). For the period before 1970, total compensation was calculated by connecting this series with an index on cash earnings provided by EPA.

Value Added: For the period 1970-1980, data on value added in current and constant 1975 yen were obtained from EPA (1984). The data for the period before 1970 were obtained by connecting these series with the corresponding series reported in EPA (1975) via identical growth rates.

Materials: Materials in current and constant 1975 yen were calculated as the differences between gross output and value added.

Capital Stock: Data for the stock of capital and gross investment in 1975 yen were taken from EPA (1985). A series for current dollar gross investment was obtained from the Japanese Ministry of Finance. This series was adjusted in such a way that it coincided with the constant yen EPA series in 1975. The user cost of capital was constructed analogously to that for the US.

R&D: Current yen R&D expenditures are taken from OECD (1983) and earlier issues. To avoid double counting we have subtracted the labor and material component of R&D from the labor and material inputs. The GDP deflator for total manufacturing is used as the deflator for R&D. The stock of R&D is constructed analogously to that for the US with 1965 as the benchmark year.

All constant yen variables were transformed to a 1972 base and then normalized by respective sample means. Prices were constructed conformably.

NOTES

[1] We would like to thank Jack Triplett, Ernie Zampelli and the participants of the NBER Conference on Research in Income and Wealth for valuable comments. Yuzu Kumasaka and Yoichi Nakamura were extremely helpful in the preparation of the Japanese data. We would further like to thank Elliot Grossman for providing us with his data set and Jennifer Bond, Milo Peterson and Ken Rogers for their help with the US data. Nancy Lemrow provided very able research assistance. We gratefully acknowledge the assistance of Kristofer Hogg of the C.V. Starr Center for Applied Economics at New York University in the preparation of this manuscript. The research was supported in part by NSF grant PRA-8108635 and by the C.V. Starr Center's Focal Program for Capital Formation, Technological Change, Financial Structure and Tax Policy. We would also like to acknowledge the support with computer time from the Computer Science Center of the University of Maryland.

[2] The total factor productivity growth rates are calculated from the Tornquist approximation formula (using cost shares). The divergence in total factor productivity growth rates is much more pronounced in a value added measurement framework. However, Norsworthy and Malmquist (1983) found that such a framework is inappropriate -- at least at the total manufacturing level.

[3] Clearly the scale elasticity depends for general $F(\cdot)$ on the various factor inputs. However, to keep the model specifications reasonably parsimonious, we have assumed that $F(\cdot)$ is homogeneous of constant degree ρ.

[4] Compare e.g. Epstein and Yatchew (1985), Mohnen, Nadiri and Prucha

(1986) and Prucha and Nadiri (1986).

[5] Let $\{X_{t,\tau}, V_{t,\tau}\}_{\tau=0}^{\infty}$ denote the optimal input path corresponding to (5). Short-run, intermediate-run and long-run elasticities then refer to the elasticities of $[X_{t,\tau}, V_{t,\tau}]$ in periods $\tau=0$, 1 and ∞, respectively ($X_t^* = X_{t,\infty}$).

REFERENCES

Denny, M., M.A. Fuss and L. Waverman (1981), "Substitution possibilities for energy: Evidence from US and Canadian manufacturing industries," in E. R. Berndt and B.C. Field (eds.), *Modeling and Measuring National Resource Substitution*. MIT Press, Cambridge.

Economic Planning Agency (1985), *Private Industrial Capital Stock*, Tokyo: Government of Japan (February).

Economic Planning Agency (1984), *Annual Report on National Accounts*, Tokyo: Government of Japan (and earlier issues).

Economic Planning Agency (1980), *Supply and Disposition of Commodities*, Tokyo: Government of Japan.

Economic Planning Agency (1975), *Economic Analysis*, Tokyo: Government of Japan (August).

Epstein, L. and A. Yatchew (1985), "The empirical determination of technology and expectations: A simplified procedure," *Journal of Econometrics*, 27, 235-258.

Fuss, M. and L. Waverman (1985), "Productivity growth in the automobile industry, 1970-1980: A comparison of Canada, Japan and the United States", mimeo.

Griliches, Z. and J. Mairesse (1985), "Productivity growth and R&D: Japan - US comparisons", mimeo.

Grossman, E.S. (1985) Productivity and international competition: United States and Japanese industries," in J. Kendrick (ed.) Interindustry Differences in Productivity Growth, American Enterprise Institute (Washington, D.C.).

Lau, L.J. (1976), "A characterization of the normalized restricted profit function," *Journal of Economic Theory*, 12, 131-163.

Mohnen, P.A., M.I. Nadiri and I.R. Prucha (1986), "R&D, production structure, and rate of return in the US, Japanese and German manufacturing sectors: A nonseparable dynamic factor demand model," European Economic Review, 30, 749-771.

Morrison, C.J., and E.R. Berndt (1981), "Short-run labor productivity in a dynamic model," *Journal of Econometrics*, 15, 339-365.

Nadiri, M.I. and I.R. Prucha (1984), "Production structure, R&D and productivity growth in the US Bell system: Estimation from dynamic factor demand functions under nonstatic expectations," mimeo.

Nadiri, M.I. and M. Schankerman (1981), "The structure of production, technological change and the rate of growth of total factor productivity in the US Bell system," in T. Cowing and R. Stevenson, *Productivity Measurement in Regulated Industries*, New York: Academic Press, 219-247.

Norsworthy, J.R. and D.H. Malmquist (1983), "Input measurement and productivity growth in Japanese and US manufacturing," *American Economic Review*, 73, 947-967.

Organization for Economic Cooperation and Development (1983), *International Statistical Year, (1981), Japan*, Paris, mimeo.

Prucha, I.R. and M.I. Nadiri (1986), "A comparison of alternative methods for the estimation of dynamic factor demand models under nonstatic expectations," *Journal of Econometrics*, 33, 187-211.

Statistics Bureau, Management and Coordination Agency (1985), *Monthly Statistics of Japan*, (January).

US Department of Commerce, Bureau of Economic Analysis (1981), *The National Income and Product Accounts of the United States, 1928-76, Statistical Tables*, Washington: US Government Printing Office.

U.S. Department of Commerce, Bureau of Economic Analysis (1984), *Survey of Current Business*, (July 1984 and earlier issues), Washington: US Government Printing Office.

US Department of Labor, Bureau of Labor Statistics (1979), *Capital Stock Estimates for Input-Output Industries: Methods and Data*, Bulletin 2034, Washington: US Government Printing Office.

National Science Foundation (1984), *Research and Development in Industry, 1982*, Washington: US Government Printing Office.