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4 Comparison and Analysis of Productivity Growth and R&D Investment in the Electrical Machinery Industries of the United States and Japan

M. Ishaq Nadiri and Ingmar R. Prucha

4.1 Introduction

During the 1970s 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 Japanese industries is a key competitor to the U.S. high-technology industries in both the 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 United States and Japan. Also, a substantial amount of research and development (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 exports in electrical machinery from 22% in 1971 to 48% in 1981 and has also dramatically increased its share of U.S. imports of electrical machinery products over the same period (Grossman 1985).

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Because of these characteristics, we have chosen to examine the productivity performance of this industry in the United States 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 forgone 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 United States 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 4.2 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 United States and Japan. Section 4.3 describes the basic features of the analytical model. In section 4.4 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 run, the intermediate run, and the long run, and we calculate the speeds of adjustment of the quasi-fixed factors—physical and R&D capital. Section 4.5 is devoted to examining the sources of output and factor productivity growth rates. Summary and conclusions are offered in section 4.6. Mathematical details of the analytic model are given in appendix A. Appendix B contains the data description. Explicit formulas for expressions used in the decomposition of total factor productivity growth are given in appendix C.

4.2 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 4.1. For the pre-Opec period, the growth rates were extremely high for Japan in comparison to the United States. However, in the

Table 4.1 Growth of Output and Inputs and Input Shares in the U.S. and Japanese Electrical Machinery Industries, 1968–73 and 1974–79.

Period	Output		Labor		Materials		Capital		R&D	
	United States	Japan	United States	Japan	United States	Japan	United States	Japan	United States	Japan
Average annual rates of growth (%):										
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

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 United States. Still, the level of output growth 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 United States 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 inputs grew much faster in Japan than in the United States 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 4.1 the R&D stock grew at a much more rapid rate in Japan than in the United States in both periods, reflecting the very high rate of growth in R&D investment in Japan. In both the U.S. 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 4.1 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 United States 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 United States, 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 United States experienced increases in employment in most industries (Griliches and Mairesse, in this volume; Norsworthy and Malmquist 1983).

As demonstrated by table 4.2, 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.

Total and partial productivity growth rates based on a gross output measurement framework are shown in table 4.3. Both total and labor-productivity growth rates were much higher in the Japanese electrical machinery industry than in the United States.¹ This was particularly true in the pre-OPEC period. Unlike the aggregate manufacturing sector (Norsworthy and Malmquist 1983), total factor productivity growth 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 United

Table 4.2 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	
	United States	Japan	United States	Japan	United States	Japan	United States	Japan
Total manufacturing:								
1970	7.4	30.0	5.8	2.9	3.5	9.8	2.7	.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

Table 4.3 Average Annual Rates of Growth of Total and Partial Factor Productivity in the U.S. and Japanese Electrical Machinery Industries (in percentages)

	Total Factor Productivity		Labor Productivity		Materials Productivity		Capital Productivity		R&D Productivity	
	United States	Japan	United States	Japan	United States	Japan	United States	Japan	United States	Japan
1968-73	1.8	4.1	4.7	12.6	.9	2.1	-1.2	5.5	-1.1	-2.3
1974-79	2.9	4.5	3.6	8.9	2.8	3.9	.6	-.1	3.2	-7.0

States, labor productivity grew about 4.7% in 1968-73 and declined to 3.6% 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.

Thus, the elements of the 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 falloff 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.

4.3 Model Specification

The model specified below generates a set of factor demand equations for both variable inputs (materials and labor) and the quasi-fixed inputs (capital and R&D). Each demand equation allows for the effect of changes in output,

changes in relative prices, and technological change. Also, the model allows for the interaction (i.e., nonseparability) 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 U.S. 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:

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

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} . We assume that the normalized restricted cost function satisfies standard properties. In particular $G(\cdot)$ is assumed to be convex in X_{t-1} and ΔX_t and concave in W_t ; compare, for example, Lau (1976).²

Given the presence of large firms in the electrical machinery industries of both the United States and Japan, we do not impose a priori constant returns to scale. Rather, we allow the technology to be homogeneous of (constant) degree and determine the returns to scale parameter ρ from the data.³ Given that $F(\cdot)$ is homogeneous of degree ρ , the corresponding normalized restricted cost function is of the following general form:⁴

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

In the empirical analysis we take materials, M , and labor (hours worked), L , as the variable factors and the stocks of capital, K , and research and development, R , as the quasi-fixed factors. We adopt the convention $V_1 = M$, $V_2 = L$, $X_1 = K$, $X_2 = R$; W is the real wage rate; the price of materials is the numeraire. In the empirical analysis, we further take $T_t = t$, that is, technical change, other than that reflected by the stock of R&D, is represented by a simple time trend. We specify the following functional form for the normalized restricted cost function:

$$(3) \quad G(W_t, X_{t-1}, \Delta X_t, Y_t, T_t) = (\alpha_0 + \alpha_w W_t + \alpha_{wT} W_t T_t + \alpha_{wW} W_t^2 / 2) Y_t^{1/\rho} \\ + a' X_{t-1} + b' X_{t-1} W_t + c' X_{t-1} T_t \\ + X'_{t-1} A X_{t-1} / (2Y_t^{1/\rho}) + \Delta X'_t B \Delta X_t / (2Y_t^{1/\rho})$$

where

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

In light of the above discussion, we can view (3) as a second-order approximation to a generalized 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.⁵ As in these references we impose parameter restrictions such that the marginal adjustment costs at $\Delta X_t = 0$ are zero. The convexity of $G(\cdot)$ in X_{t-1} and ΔX_t , and concavity in W_t , implies the following inequality parameter restrictions: $\alpha_{KK} > 0$, $\alpha_{RR} > 0$, $\alpha_{KK}\alpha_{RR} - \alpha_{KR}^2 > 0$, $\alpha_{\dot{K}\dot{K}} > 0$, $\alpha_{\dot{R}\dot{R}} > 0$, $\alpha_{wW} < 0$.

We assume that in each period t (for given initial stocks X_{t-1} and static expectations on relative factor prices, output, and the technology) the firm derives an optimal plan for inputs in period $t, t+1, \dots$ such that the present value of the future cost stream is minimized, and that the firm chooses its inputs in period t accordingly. In each period, the firm revises its expectations and the optimal plan for its inputs, based on new information.

A mathematical formulation and analysis of the firm's optimization problem is given in appendix A. It is shown there that the implied demand equations for the quasi-fixed factors, capital and R&D, are in the form of an accelerator model. We denote the accelerator matrix with $M = (m_{ij})_{i,j=K,R}$. The firm's demand equations for the variable factors, labor and materials, can be derived from the restricted cost function via Shephard's lemma. Instead of estimating the parameter matrices A and B , it proves advantageous to estimate the matrices $C = (c_{ij})_{i,j=K,R} = -BM$ and B (and to express A as a function of C and B). The matrix C is found to be symmetric and negative definite. Explicit expressions for the resulting demand equations for labor, materials, capital, and R&D are given in equations (A4) and (A5) of appendix A.

4.4 Empirical Results

In this section, we report the structural parameter estimates for the U.S. and Japanese electrical machinery industries as well as implied estimates for short-run, intermediate-run, and long-run price and output elasticities.

A detailed description of the data sources and the variables of the model is given in the appendix B. 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. The model parameters were estimated by full-information maximum likelihood from the demand equations (A4) and (A5); for further details see appendix A.

4.4.1 Parameter Estimates

The structural parameter estimates are given in table 4.4. 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). The parameter estimates are, in general, statistically significant. For both the United States 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 $\alpha_{\dot{K}\dot{K}}$, and $\alpha_{\dot{R}\dot{R}}$, and $(c_{KK}c_{RR} - c^2_{KR})$ are positive. The variables underlying the estimates for the U.S. and Japanese electrical machinery industries are, as explained above, measured in

Table 4.4 Full Information Maximum-Likelihood Estimates of the Parameters of the Dynamic Factor Demand Model for the U.S. and Japanese Electrical Machinery Industries

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	-.95	(3.13)	-.47	(2.89)
α_R	-.65	(1.85)	-.67	(7.82)
α_{KT}	-.19	(4.47)	-.05	(.75)
α_{RT}	.22	(3.03)	-.02	(5.66)
c_{KK}	-2.05	(3.07)	-.58	(8.77)
c_{RR}	-2.10	(1.90)	-.14	(7.99)
c_{RK}	.15	(.74)	.01	(1.54)
$\alpha_{\dot{K}\dot{K}}$	8.70	(3.06)	2.57	(4.92)
$\alpha_{\dot{R}\dot{R}}$	13.80	(1.63)	1.11	(5.15)
α_w	1.91	(25.41)	1.33	(10.01)
α_{ww}	-.48	(3.66)	-.81	(3.13)
α_{wK}	.29	(2.59)	.39	(4.65)
α_{wR}	-.52	(4.62)	.02	(1.47)
α_{wT}	-.28	(6.89)	-.42	(4.43)
Sample Period	1960-80		1968-80	
Log of Likelihood	222.1		147.4	
M-equation: R^2	.87		.94	
L-equation: R^2	.65		.75	
K-equation: R^2	.99		.99	
R-equation: R^2	.99		.99	

Note: 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.

Table 4.5 Full Information Maximum-Likelihood Estimates of the Accelerator Coefficients for Capital and R&D in the U.S. and Japanese Electrical Machinery Industries

	Accelerator Coefficient			
	m_{KK}	m_{KR}	m_{RK}	m_{RR}
United States	.236 (8.55)	-.017 (.66)	-.011 (.68)	.152 (6.82)
Japan	.227 (4.41)	.003 (1.47)	-.006 (1.47)	.125 (7.47)

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

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 are crucial in determining 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 other technology parameters.

Table 4.5 shows the estimates for the accelerator coefficients m_{KK} , m_{KR} , m_{RK} , and m_{RR} .⁶ For both the U.S. and Japanese electrical machinery industries 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% 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 United States 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.⁷

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 United States, 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 4.5, 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 (in this volume) find decreasing returns to scale in the U.S. and Japanese total manufacturing sectors at the firm level.

4.4.2 Price and Output Elasticities

The own- and cross-price elasticities of labor, materials, capital, and R&D for 1976 are reported in table 4.6. The elasticities are calculated for the short run (SR), intermediate run (IR), and long run (LR) for each input for the electrical machinery industry in both the United States and Japan.⁸ 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 United States, 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 U.S. 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 the price of materials, are quite large

Table 4.6 Short-Run (SR), Intermediate-Run (IR), and Long-Run (LR) Price Elasticities in the U.S. and Japanese Electrical Machinery Industries, 1976

Elasticity	United States			Japan		
	SR	IR	LR	SR	IR	LR
ϵ_{Mw^M}	-.32	-.40	-.64	-.04	-.18	-.64
ϵ_{Mw^L}	.36	.41	.65	.09	.15	.36
ϵ_{Mw^K}	-.01	.02	.09	-.02	.04	.20
ϵ_{Mw^R}	-.01	-.02	-.08	-.03	-.01	.09
ϵ_{Lw^M}	.47	.55	.90	.37	.51	.85
ϵ_{Lw^L}	-.48	-.58	-1.12	-.38	-.44	-.57
ϵ_{Lw^K}		-.02	-.06		-.06	-.23
ϵ_{Lw^R}		.04	.27		-.01	-.05
ϵ_{Kw^M}	.10	.17	.38	.27	.46	.99
ϵ_{Kw^L}	-.05	-.09	-.17	-.13	-.23	-.48
ϵ_{Kw^K}	-.04	-.08	-.18	-.14	-.24	-.49
ϵ_{Kw^R}	-.01	-.01	-.04	-.01	-.01	-.02
ϵ_{Rw^M}	-.05	-.09	-.27	.19	.33	.91
ϵ_{Rw^L}	.11	.20	.65	-.05	-.08	-.23
ϵ_{Rw^K}	-.01	-.01	-.03	-.01	-.01	-.04
ϵ_{Rw^R}	-.06	-.10	-.34	-.14	-.24	-.65

Note: 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).

Table 4.7 Short-Run (SR), Intermediate-Run (IR), and Long-Run (LR) Output Elasticities in the U.S. and Japanese Electrical Machinery Industries, 1976

Elasticity	United States			Japan		
	SR	IR	LR	SR	IR	LR
ϵ_{MY}	1.19	1.07	.82	1.06	.99	.72
ϵ_{LY}	1.07	1.06	.82	.39	.45	.72
ϵ_{KY}	.20	.34	.82	.20	.34	.72
ϵ_{RY}	.14	.24	.82	.15	.26	.72

Note: ϵ_{ZY} is the elasticity of factor $Z =$ materials (M), labor (L), capital (K), and R&D (R) with respect to output (Y).

in both countries. Materials are substitutes for other inputs, except for R&D in the United States. Labor and R&D are substitutes in the United States and weak complements in the Japanese electrical machinery industry. Labor and capital and R&D and capital are complements in both countries.

The output elasticities of the inputs for 1976 are shown in table 4.7. The long-run elasticities of the inputs are .8 and .7, respectively, for the United States and Japan, reflecting fairly sizable economies of scale. The results are consistent with Fuss and Waverman (in this volume), Nadiri and Prucha (1983, 1990) and Nadiri and Schankerman (1981). The patterns of the output elasticities, particularly in the United States, indicate that the variable factors of production, labor and materials, respond strongly in the short run to changes in output. This is because both labor and materials in the United States 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 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-run and intermediate-run, the output elasticities of both the variable and quasi-fixed factors substantially exceed their own-price elasticities. It is surprising that, 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.

4.5 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 4.8. This decomposition is based on the approximation:

$$(4) \quad \Delta \ln Y_t = \frac{1}{2} \sum_{i=1}^6 [\varepsilon_{vZ_i}(t) + \varepsilon_{vZ_i}(t-1)] \Delta \ln Z_{it} + \frac{1}{2} [\lambda_v(t) + \lambda_v(t-1)],$$

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_{vZ_i} 's denote respective output elasticities and $\lambda_v(t) = (1/Y_t) (\partial Y_t / \partial t)$ denotes technical change.⁹

The average growth of gross output was very rapid in Japan in the period 1968–73, but growth decelerated substantially in the period 1974–79. For the United States, 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 United States, 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 United States 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 industries of both countries; second, the marginal product of R&D, because of the relatively 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 United States.

In table 4.9 we provide a decomposition of labor-productivity growth. This decomposition is based on the approximation:

$$(5) \quad \begin{aligned} \Delta \ln(Y_t/L_t) = & \frac{1}{2} \sum_{i=2}^6 [\varepsilon_{vZ_i}(t) + \varepsilon_{vZ_i}(t-1)] \Delta \ln(Z_{it}/L_t) \\ & + \frac{1}{2} [\lambda_v(t) + \lambda_v(t-1)] + (\rho - 1) \Delta \ln L_t, \end{aligned}$$

where ρ is the scale elasticity.¹⁰ The most significant contribution again stems from the growth of materials, particularly in Japan, although the contribution of physical capital is also important. In comparison to the results reported by Norsworthy and Malmquist (1983) for the total manufacturing sector, the contribution of physical capital is somewhat larger for the United States but

Table 4.8 Sources of Output Growth for the U.S. and Japanese Electrical Machinery Industries: Average Annual Rates of Growth (in %)

	Gross Output	Labor Effect ^a	Materials Effect ^a	Capital Effect ^a	R&D Effect ^a	Adjustment Cost		Technical Change	Residual
						Capital	R&D		
United States:									
1968-73	4.2	-.24	1.83	.87	1.18	.06	.12	.73	-.32
1974-79	4.9	.39	1.06	.69	.31	-.09	.04	.86	1.67
Japan:									
1968-73	16.9	.94	14.32	2.12	.7	-.26	-.34	1.55	-2.11
1974-79	6.4	-.66	2.08	1.10	.72	.09	-.12	2.55	.69

^aGrowth rate of input weighted by average output elasticity.

Table 4.9 **Decomposition of Labor Productivity Growth in the U.S. and Japanese Electrical Machinery Industries. Average Annual Rates of Growth (in %)**

	Labor Productivity	Labor Effect	Materials Effect ^a	Capital Effect ^a	R&D Effect ^a	Adjustment Cost		Technical Change	Residual
						Capital	R&D		
United States:									
1968-73	4.68	-.04	2.07	.91	1.28	.06	.12	.73	-.44
1974-79	3.56	.15	.43	.37	.12	-.07	.04	.86	1.66
Japan:									
1968-73	12.63	.81	10.24	1.33	.56	-.13	-.26	1.55	-1.48
1974-79	8.95	-.47	4.48	1.54	.86	.05	-.16	2.55	.10

^aGrowth rate of input per unit of labor, weighted by average output elasticity.

smaller for Japan. The contribution of R&D is somewhat smaller and rising for Japan. For the United States, 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 labor effect (given by the last term on the right-hand side of [5]) follows from the fact that scale is not equal to one. The contribution of this term to labor-productivity growth is shown in the second column of table 4.9. 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 United States. This reflects the growth pattern of the labor input in the two industries over the two periods.

Denny, Fuss, and Waverman (1981) have shown that if all factors are variable, then 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. Nadiri and Prucha (1983, 1990) extend this decomposition to technologies with adjustment costs. More specifically, consider the Törnqvist approximation of the growth rate of total factor productivity, ΔTFP_t , defined implicitly by:

$$(6) \quad \Delta \ln Y_t = \frac{1}{2} \sum_{i=1}^4 [s_{Z_i}(t) + s_{Z_i}(t-1)] \Delta \ln Z_{it} + \Delta TFP_t,$$

with $Z_1 = L$, $Z_2 = M$, $Z_3 = K_{-1}$, $Z_4 = R_{-1}$ and where the s_{Z_i} 's denote respective long-run cost shares. Given increasing returns to scale and adjustment costs we find that the output elasticities $\epsilon_{Y Z_i}$ exceed the cost shares s_{Z_i} . As a consequence, as is evident from a comparison of equations (4) and (6), total factor productivity will not equal technical change.¹¹ Prucha and Nadiri (1983, 1990) shows that total factor productivity growth can be decomposed as follows:

$$(7) \quad \Delta TFP_t = (1 - \rho^{-1}) \Delta \ln Y_t + \phi_{1t} + \phi_{2t} + \frac{1}{2} [\lambda_x(t) + \lambda_x(t-1)],$$

where $\lambda_x = (1/\rho)\lambda_y$. The first term on the right-hand side of (7) represents the scale effect and the last term the pure effect of technical change on the growth of total factor productivity. The terms 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 terms ϕ_2 reflects the direct adjustment-cost effect in terms of forgone 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. Explicit expressions for the terms ϕ_1 and ϕ_2 (and a further discussion of those terms) are given in appendix C.

Table 4.10 presents the decomposition of total factor productivity based on

Table 4.10 Decomposition of Total Factor Productivity Growth in the U.S. and Japanese Electrical Machinery Industries for Respective Sample Periods (in %)

	United States, 1960–80	Japan, 1968–80
Scale effect +	1.04	3.38
Temporary equilibrium effect +	.28	.16
Direct adjustment-cost effect +	.03	–.04
Technical change +	.60	1.49
Unexplained residual =	.10	–.24
Total factor productivity	2.04	4.74

(7) for the sample periods used in estimating the production technology of the U.S. and Japanese electrical machinery industries.¹² 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 larger than in the U.S. industry. The temporary equilibrium effect, ϕ_1 , is fairly large in the United States 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% of the measured total factor productivity growth for the United States and Japan, respectively, and hence not negligible, particularly for the United States. Consequently, if zero adjustment costs would have been imposed, a nonnegligible portion of measured total factor productivity growth would have been misclassified. In addition, inconsistency of the estimates of the underlying technology parameters would have distorted the decomposition of total factor productivity growth. 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.

4.6 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 U.S. and Japanese electrical machinery industries. 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 U.S. and world markets. Our model allows for scale effects and the quasi fixity of some of the input factors. It also incorporated R&D to capture the high-technology feature of the industry. Other inputs considered are labor, materials, 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 United States 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 run, intermediate run and long run are similar in the two industries. Materials are generally found to be substitutes for other inputs. Other inputs are generally complements except for labor and R&D in the U.S. 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 United States, 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 United States from the pre-OPEC to the post-OPEC period.

(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 United States and Japan is due to the greater contribution of economies of scale to the 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 growth.

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. However, a number of issues remain unresolved.

(i) Given the rapid expansion of the electrical machinery industries in the United States and Japan, it seems important to explore the effect of nonstatic 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 modeling 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 A

Estimated System of Factor Demand Equations

Given the assumptions of section 4.3, the firm's optimum problem in period t can be written as

$$(A1) \quad \min_{\{K_{t+\tau}, R_{t+\tau}\}_{\tau=0}^{\infty}} \text{PVC}_t = \sum_{\tau=0}^{\infty} \{ [G_{t,\tau} + \hat{Q}_t^R(\Delta R_{t+\tau} + \delta_R R_{t+\tau-1})](1-u) + \hat{Q}_t^K(\Delta K_{t+\tau} + \delta_K K_{t+\tau-1}) \} (1+r)^{-\tau},$$

where the restricted cost function $G_{t,\tau} = G(\hat{W}_t, K_{t+\tau-1}, R_{t+\tau-1}, \Delta K_{t+\tau}, \Delta R_{t+\tau}, \hat{Y}_t, T_t)$ is defined by (3). With Q_t^K and Q_t^R we denote the acquisition price of capital and R&D normalized by the price of materials, respectively, δ_K and δ_R denote the depreciation rates of capital and R&D, respectively, u is the corporate tax rate, and r is the constant (real) discount rate. Expectations are characterized with a caret (^). 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 (A1) 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:¹³

$$(A2) \quad \begin{aligned} \Delta K_t &= m_{KK}(K_t^* - K_{t-1}) + m_{KR}(R_t^* - R_{t-1}), \\ \Delta R_t &= m_{RK}(K_t^* - K_{t-1}) + m_{RR}(R_t^* - R_{t-1}), \end{aligned}$$

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:

$$(A3) \quad BM^2 + (A + rB)M - A = 0;$$

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, that is, $\alpha_{KR} = 0$, which implies $m_{KR} = 0$, (A3) cannot generally be solved for M in terms of A and B . We can, however solve (A3) 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 .¹⁴ 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 we observe that $A = C - (1+r)[B - B(C+B)^{-1}B]$ and that $D = B^{-1} + (1+r)(C - rB)^{-1}$ are symmetric. It is then readily seen that we can write (A2) equivalently as:

$$(A4) \quad \begin{aligned} \Delta K_t &= d_{KK}[\alpha_K + \alpha_{KW}W_t + \alpha_{KT}T_t + C_t^K] \hat{Y}_t^{1/\rho} \\ &\quad + d_{KR}[\alpha_R + \alpha_{RW}W_t + \alpha_{RT}T_t + C_t^R] \hat{Y}_t^{1/\rho} \\ &\quad + [c_{KK}/\alpha_{KK}]K_{t-1} + [c_{KR}/\alpha_{KK}]R_{t-1}, \\ \Delta R_t &= d_{KR}[\alpha_K + \alpha_{KW}W_t + \alpha_{KT}T_t + C_t^K] \hat{Y}_t^{1/\rho} \\ &\quad + d_{RR}[\alpha_R + \alpha_{RW}W_t + \alpha_{RT}T_t + C_t^R] \hat{Y}_t^{1/\rho} \\ &\quad + [c_{KR}/\alpha_{RR}]K_{t-1} + [c_{RR}/\alpha_{RR}]R_{t-1}, \end{aligned}$$

where

$$\begin{aligned} d_{KK} &= 1/\alpha_{KK} + (1+r)[c_{RR} - r\alpha_{RR}]/e, \\ d_{RR} &= 1/\alpha_{RR} + (1+r)[c_{KK} - r\alpha_{KK}]/e, \\ d_{KR} &= -(1+r)c_{KR}/e, \end{aligned}$$

and

$$e = (c_{KK} - r\alpha_{KK})(c_{RR} - r\alpha_{RR}) - c_{KR}^2.$$

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 $M_t = G_{t,0} - W_t L_t$:

$$(A.5) \quad \begin{aligned} L_t &= [\alpha_w + \alpha_{ww}W_t + \alpha_{wT}T_t] \hat{Y}_t^{1/\rho} + \alpha_{Kw}K_{t-1} + \alpha_{Rw}R_{t-1}, \\ M_t &= [\alpha_0 - 1/2\alpha_{ww}W_t^2] \hat{Y}_t^{1/\rho} + \alpha_K K_{t-1} + \alpha_R R_{t-1} + \alpha_{KT} K_{t-1} T_t \\ &\quad + \alpha_{RT} R_{t-1} T_t + [1/2\alpha_{KK} K_{t-1}^2 + \alpha_{KR} K_{t-1} R_{t-1} + 1/2\alpha_{RR} R_{t-1}^2 \\ &\quad + 1/2\alpha_{\dot{K}\dot{K}} \Delta K_t^2 + 1/2\alpha_{\dot{R}\dot{R}} \Delta R_t^2] / \hat{Y}_t^{1/\rho}, \end{aligned}$$

where

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

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

$$\alpha_{KR} = c_{KR} - (1+r)(\alpha_{\dot{K}\dot{K}} \alpha_{\dot{R}\dot{R}} c_{KR})/f,$$

and

$$f = (\alpha_{\dot{K}\dot{K}} + c_{KK})(\alpha_{\dot{R}\dot{R}} + c_{RR}) - c_{KR}^2.$$

The complete system of factor demand equations consists of (A4) for the quasi-fixed factors and (A5) for the variable factors. This system is nonlinear in parameters and variables. For the empirical estimation, we have added stochastic disturbance terms to each of the factor demand equations. When necessary, we have corrected for first-order autocorrelation of the disturbances. Expectations on gross output were calculated as follows. We first estimated a first-order autoregressive model for output that was then used to predict Y_t rationally.

Appendix B

Data Sources and Construction of Variables

U.S. 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) data base 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 data base. Hours worked by nonproduction workers were calculated as the number of nonproduction workers times hours worked per week times 52. The number of nonproduction workers was obtained from the OBA data base. Weekly hours worked by 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 data base with the ratio of compensation of employees to wages and salaries from the U.S. Department of Commerce, Bureau of Economic Analysis (1981, 1984).

Materials: Materials in current dollars were obtained from the OBA data base. 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 dollar gross investment series were taken from the OBA data base. The method by which the capital stock series is constructed is described in the U.S. 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 $\delta_R = 0.1$. 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 the 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 gross domestic product (GDP) deflator for total manufacturing is used as a deflator for R&D.

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

Japanese Electrical Machinery Industry

Gross Output: For the period 1970–80, 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 times monthly hours worked times 12. For the period 1970–80, 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 1977–80 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 1970–80, 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 1970–80, data on value added in current and constant 1975 yen were obtained from the EPA (1984). The data for the period before 1970 were obtained by connecting these series with the corresponding series reported in the 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 the 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 United States.

R&D: Current yen R&D expenditures are taken from Organization for Economic Cooperation and Development (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 United States 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.

Appendix C

Expressions in TFP Growth Decomposition

In the following we give explicit expressions for the temporary equilibrium effect and the direct adjustment-cost effect in the decomposition (7) of total factor productivity growth. We make use of the cost-share weighted index of aggregate inputs F defined as

$$\begin{aligned}\Delta \ln F_t &= \frac{1}{2}[\Delta \ln F_t^+ + \Delta \ln F_t^{-1}], \\ \Delta \ln F_t^+ &= s_M(\tau)\Delta \ln M_t + s_L(\tau)\Delta \ln L_t + s_{K_{-j}}(\tau)\Delta \ln K_{t-j} \\ &\quad + s_{R_{-j}}(\tau)\Delta \ln R_{t-j},\end{aligned}$$

where $\tau = t, t-1$. The cost shares are defined as $s_M(t) = M_t/TC_t$, $s_L(t) = W_t L_t/TC_t$, $s_{K_{t-1}}(t) = C_t^K K_{t-1}/TC_t$, $s_{R_{t-1}}(t) = C_t^R R_{t-1}/TC_t$, with $TC_t = M_t + W_t L_t + C_t^K K_{t-1} + C_t^R R_{t-1}$. Here C_t^K and C_t^R denote, respectively, the rental price of capital and R&D normalized by the price of materials; compare appendix A. The following expressions for the temporary equilibrium effect ϕ_1 and the direct adjustment cost effect ϕ_2 are taken from Nadiri and Prucha (1983, 1990) and can be derived by comparing equations (4) and (6):

$$\begin{aligned}\phi_{1t} &= \frac{1}{2\rho} \sum_{\tau=t, t-1} \left\{ \frac{(-\partial G_\tau / \partial K_{\tau-1} - C_\tau^K) K_{\tau-1}}{(\partial G_\tau / \partial Y_\tau) Y_\tau} [\Delta \ln K_{t-1} - \Delta \ln F_t^\tau] \right. \\ &\quad \left. + \frac{1}{2\rho} \sum_{\tau=t, t-1} \left\{ \frac{(-\partial G_\tau / \partial R_{\tau-1} - C_\tau^R) R_{\tau-1}}{(\partial G_\tau / \partial Y_\tau) Y_\tau} [\Delta \ln R_{t-1} - \Delta \ln F_t^\tau] \right\}, \right. \\ \phi_{2t} &= \frac{1}{2\rho} \sum_{\tau=t, t-1} \left\{ \frac{(-\partial G_\tau / \partial \Delta K_\tau) \Delta K_\tau}{(\partial G_\tau / \partial Y_\tau) Y_\tau} [\Delta \ln \Delta K_t - \Delta \ln F_t^\tau] \right. \\ &\quad \left. + \frac{1}{2\rho} \sum_{\tau=t, t-1} \left\{ \frac{(-\partial G_\tau / \partial \Delta R_\tau) \Delta R_\tau}{(\partial G_\tau / \partial Y_\tau) Y_\tau} [\Delta \ln \Delta R_t - \Delta \ln F_t^\tau] \right\} \right.\end{aligned}$$

where ($\tau = t, t-1$). In long-run equilibrium both the temporary equilibrium effect and the direct adjustment-cost effect are zero since $\partial G / \partial K + C^K = \partial G / \partial R + C^R = \partial G / \Delta K = \partial G / \Delta R = 0$. Furthermore both effects are zero if all factors (and hence the aggregate input index) grow at the same rate.

Notes

1. The total factor productivity growth rates are calculated from the Törnqvist approximation formula (using long-run 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.

2. The restricted cost function $G(\cdot)$ is furthermore assumed to satisfy

$$G_{X_i} < 0, G_{|\Delta X_i|} > 0, G_Y > 0, G_W > 0.$$

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

4. Compare, e.g., Nadiri and Prucha (1983, 1990).

5. For a generalization to homothetic technologies see Nadiri and Prucha (1983, 1990).

6. These coefficients have been calculated from the estimates in table 4 observing that $M = -B^{-1}C$.

7. 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.

8. Let $\{X_{i,\tau}, V_{i,\tau}\}_{\tau=0}^{\infty}$ denote the optimal plan values of the inputs in periods $t, t+1, \dots$, corresponding to the firm's optimization problem in period t . Short-run, intermediate-run, and long-run elasticities then refer to the elasticities of $X_{i,\tau}$ and $V_{i,\tau}$ in periods $\tau = 0, 1$, and ∞ , respectively ($X_t^* = X_{i,\infty}$).

9. The contribution of each of the variables is calculated by multiplying the respective (average) elasticities with the growth rate of the corresponding variable. The output elasticities are computed from the estimated 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 the output elasticities also differ from long-run cost shares because of adjustment costs.

10. This approximation is readily obtained from the decomposition of output growth by noting that the sum of the output elasticities must equal scale.

11. For an excellent discussion of problems in measuring technical change see Griliches (1988).

12. Note that in this table technical change corresponds to $\lambda_x = \lambda^y/\rho$ while in tables 4.8 and 4.9 technical change corresponds to λ_y . Furthermore, note that the decomposition of output growth and labor productivity growth in tables 8 and 9 only gives the direct effect of adjustment costs. The "indirect" temporary equilibrium effect in those decompositions is accounted for by using (estimated) output elasticities rather than cost shares as weights.

13. Compare, e.g., Epstein and Yatchew (1985), Madan and Prucha (1989), and Prucha and Nadiri (1986).

14. Such a reparametrization 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 reparametrization within the context of a constant returns to scale model. Recently Madan and Prucha (1989) generalized this approach to the case where B may be nonsymmetric.

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