Productivity Growth in the Electric Power Industry: A Comparative Study of Japan, the United States, and Korea

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Abstract

The purpose of this paper is to provide empirical estimates of total factor productivity (TFP) growth rates in the electric utility industry for the United States, Japan, and Korea. In this paper, the conventional Divisia index number approach and two cost function approaches are used to assess TFP growth rates during the 1972-1996 period. The TFP growth rates in the United States, where regulatory reform has been progressing gradually since 1978, did not show much difference from those in Japan, and were considerably lower than those achieved by Korea, where little reform has taken place. Decomposition analysis based on the total cost function shows that the major sources of TFP growth were the scale economies effect in Japan, the capacity utilization and scale economies effects in Korea, and technical change in the United States. Since the mid-80s, the increases in TFP growth were due to improvements in the capacity utilization effect in all three countries.

Introduction

There is a growing interest in the analysis of the electric power industry stemming from the increasingly competitive energy market structure in many countries, including the United Kingdom, Norway, and the United States. The inception of deregulation in the U.S. electric power industry was marked by the Public Utility Regulatory Policies Act (PURPA) of 1978. The Act was designed primarily to encourage utilities to use resources more efficiently and to direct investments towards renewable resources. However, the Act implicitly introduced competition into the wholesale market by allowing nonutility facilities that were using renewable energy sources to enter the market, and by requiring utilities to buy power from them.

The move towards a more competitive wholesale market was further promoted by the Energy Policy Act (EPACT) of 1992.(1) The Act expanded nonutility markets by creating a new category of electricity producers, the exempt wholesale generators (EWGs).(2) Since EPACT, the wholesale energy market in the United States has progressed towards complete deregulation.(3)

In the Japanese and Korean electric power industries, reforms have been lagging and deregulation remains in the early stages. In Japan, the electricity industry is dominated by 10 regulated, investor -owned, regional, and vertically integrated utilities. Competition had not been introduced even in the wholesale market of the Japanese electric power industry until recently. The Electric Utilities Industry Law was amended in 1995. A key part of the amendments included the introduction of a competitive bidding system in the wholesale electricity sector.(4) In the Korean electric power industry, until very recently there had been little regulatory change. The Korean electricity market had long been dominated by a state-run monopoly, Korea Electric Power Corporation (KEPCO).(5)

Since the process and outcome of reform are quite different from country to country, differences resulting from these reforms should appear in productivity growth. In principle, an international comparison can identify these differences. Furthermore, such an investigation into the sources of productivity growth in the electricity industry provides an important elaboration on the raw differences in productivity.

The purpose of this study is to provide empirical estimates of total and partial factor productivity growth in the electric power industry and to examine the sources of productivity growth in Japan, the United States, and Korea. I first estimate total factor productivity (TFP) using the conventional Divisia index number approach. I then provide two alternative TFP measures based upon estimation of the total cost function and the variable cost function. In addition, TFP growth is decomposed into contributions arising from scale economies, technology, and capacity utilization and so forth. Several approaches are used in this paper to compare and examine the sensitivity of the three alternative TFP growth estimates in the electric power industry.

The remainder of the paper is organized as follows. The next section provides a brief explanation of the methodology of total factor productivity measurements. The third section presents empirical results for the 1972-1996 period for the three countries, and conclusions are discussed in the final section.

Productivity Measurement

The Conventional Divisia Index Number Approach

Assuming a single output and multiple inputs, total factor productivity (TFP) is defined as:(6)

$$TFP = Q / F, \tag{1}$$

where Q is output, and F is aggregate input. The growth rate of TFP is given by

$$T\dot{F}P = \frac{d(TFP)}{dt} / TFP = \dot{Q} - \dot{F}. \tag{2}$$

The growth rate of aggregate input $\dot{F}$ can be defined as the Divisia index:

$$\dot{F} = \sum_k \frac{w_k X_k}{C} \dot{X}_k, \tag{3}$$

where w_k and X_k are the price and quantity of the k th input, respectively and $C = \sum_k w_k X_k$ is the total cost.

The above definition of TFP growth based on the Divisia index is given in continuous time. Empirical data typically refer to discrete points of time. For discrete data, the above formula for the growth rate of TFP is typically obtained from the Törnqvist approximation.(7)

$$\ln \frac{TFP_t}{TFP_{t-1}} = \ln \frac{Q_t}{Q_{t-1}} - \frac{1}{2} \sum_k (S_{kt} + S_{kt-1}) \ln \frac{X_{kt}}{X_{kt-1}}, \tag{4}$$

where $S_{kt} = w_{kt} X_{kt} / C_t$ is the cost share of the k th input in period t.(8)

The Total Cost Function Approach

The following two subsections present formulae for TFP growth and its decomposition based on the cost function approaches. This subsection employs the total cost function. The next subsection uses the variable cost function hypothesizing capital stock as a quasi-fixed input.(9)

The translog total cost function will be of the form

$$\ln C_{it} = G(\ln \boldsymbol{w}_{it}, \ln Q_{it}, \ln \boldsymbol{T}_{it}, \boldsymbol{D}), \tag{5}$$

where G is a quadratic function, C_{it} is the total cost of production, $\boldsymbol{w}_{it}$ is a vector of factor prices, and $\boldsymbol{T}_{it}$ is a vector of technological conditions in country i at time t, respectively. $\boldsymbol{D}$ is a vector of country-specific dummy variables: D_{ji}=1 if j=i and D_{ji}=0 otherwise.

The estimated cost function contains all relevant information regarding the production technology, so the estimated parameters of the total cost function can be used to analyze TFP growth. Following a similar analysis as in Denny et al. (1981), Fuss and Waverman (1992), Kwon (1986), TFP growth in country i between period 0 and period 1 can be expressed as follows:

$$\ln \frac{TFP_{i1}}{TFP_{i0}} = \frac{1}{2}[(1 - ECQ_{i1}) + (1 - ECQ_{i0})] \ln \frac{Q_{i1}}{Q_{i0}} - \frac{1}{2}\sum_j [ECT_{ji1} + ECT_{ji0}] \ln \frac{T_{ji1}}{T_{ji0}}, \tag{6}$$

where ECQ and ECT_j are the elasticity of cost with respect to output and the jth technological characteristic, respectively. Equation (6) provides the decomposition of TFP growth into its sources. The first term on the right hand side of (6) represents the portion of TFP growth that is due to output growth in the presence of scale economies. If production is characterized by constant returns to scale, the first term will vanish. The second term represents the portion of TFP growth caused by changes in technological conditions.

To obtain the results of TFP decomposition, it is necessary to specify the parametric form of the total cost function that is to be estimated. The translog total cost function with zero- and first-order terms that differ across countries and second-order terms that are common across countries is specified as

$$\begin{aligned}\ln C_{it} &= G(\ln \boldsymbol{w}_{it}, \ln Q_{it}, \ln \boldsymbol{T}_{it}, \boldsymbol{D}) \\ &= \alpha_0 + \alpha_{0i} D_i + \sum_k (\alpha_k + \alpha_{ki} D_{ii}) \ln w_{kit} \\ &\quad + (\beta_1 + \beta_{1i} D_{ii}) \ln Q_{it} + \sum_j (\theta_j + \theta_{ji} D_{ii}) \ln T_{jit}\end{aligned}$$

$$+\frac{1}{2}[\sum_{k}\delta_{kk}(\ln w_{kit})^2 + \mu_{11}(\ln Q_{it})^2 + \phi_{22}(\ln T_{2it})^2]$$
$$+\sum_{\substack{k \\ k<}}\sum_{\substack{m \\ m}}\delta_{km}\ln w_{kit}\ln w_{mit} + \sum_{k}\lambda_{k1}\ln w_{kit}\ln Q_{it}$$
$$+\sum_{k}\Lambda_{k2}\ln w_{kit}\ln T_{2it} + \tau_{12}\ln Q_{it}\ln T_{2it}\ . \qquad (7)$$

Factor prices $\boldsymbol{w}_{it}$ include capital (k=K), labor (k=L) and fuel (k=M). Technological condition $\boldsymbol{T}_{it}$ includes the time trend T_{1it} (j=1) and capacity utilization T_{2it} (j=2). The time trend is used as an indicator of technical change and is introduced in first-order term.(10) The dummy variable D_{ii}=0 when i=Japan, because Japan is chosen as the reference country. Linear homogeneity in factor prices is assumed to be

$$\sum_{k}\alpha_k = 1, \sum_{k}\alpha_{ki} = 0, \sum_{m}\delta_{mk} = 0, \delta_{mk} = \delta_{km},$$
$$\sum_{k}\lambda_{k1} = 0, \sum_{k}\Lambda_{k2} = 0. \qquad (8)$$

Using Shephard's lemma,

$$S_{kit} = \alpha_k + \alpha_{ki}D_{ii} + \delta_{kk}\ln w_{kit} + \sum_{m\neq k}\delta_{km}\ln w_{mit} + \lambda_{k1}\ln Q_{it}$$
$$+\Lambda_{k2}\ln T_{2it}. \qquad (9)$$

The cost share equations which form a part of the system of equations are used to estimate the parameters of the total cost function. Equations (7) and (9), each with an appended additive disturbance term, constitute a set of equations and are jointly estimated. Since cost shares sum up to unity, one of the cost share equations is deleted. Resulting estimates are invariant to which cost share equations is deleted (Barten (1969)). Applying estimated parameters of the total cost function (7) to equation (6) yields the results of TFP decomposition.

The Variable Cost Function Approach

This subsection presents the TFP growth formula based on the variable cost function. Capital is treated as a quasi-fixed input while labor and fuel are assumed to be the variable inputs. The translog variable cost function is given by

$$\ln VC_{it} = \alpha_0 + \alpha_{0i}D_i + \sum_{k}(\alpha_k + \alpha_{ki}D_{ii})\ln w_{kit}$$

$$+(\beta_1+\beta_{1i}D_{ii})\ln Q_{it}+(\alpha_K+\alpha_{Ki}D_{ii})\ln K_{it}+(\theta_1+\theta_{1i}D_{ii})T_{it}$$
$$+\frac{1}{2}[\sum_k \delta_{kk}(\ln w_{kit})^2+\mu_{11}(\ln Q_{it})^2+\delta_{KK}(\ln K_{it})^2+\phi_{11}(T_{it})^2]$$
$$+\sum_{\substack{k\\k<}}\sum_{\substack{m\\m}}\delta_{km}\ln w_{kit}\ln w_{mit}+\sum_k \lambda_{k1}\ln w_{kit}\ln Q_{it}+\lambda_{K1}\ln K_{it}\ln Q_{it}$$
$$+\sum_k \delta_{Kk}\ln w_{kit}\ln K_{it}+\sum_k \Lambda_{k1}(\ln w_{kit})T_{it}+\Lambda_{K1}(\ln K_{it})T_{it}$$
$$+\tau_{11}(\ln Q_{it})T_{it}, \tag{10}$$

where k, $m = L, M$, VC is the variable cost of production, K is capital and T is the time trend, respectively.

Following a similar analysis as in Nemoto and Asai (2002), and Oniki et al. (1994), the TFP growth formula based on the variable cost function can be shown as:

$$\ln\frac{TFP_{i1}}{TFP_{i0}}=(1/2)[1-(VC_{i1}/C_{i1})EVCQ_{i1}+1-(VC_{i0}/C_{i0})EVCQ_{i0}]\ln\frac{Q_{i1}}{Q_{i0}}$$
$$-(1/2)[1-(VC_{i1}/C_{i0})(1-EVCK_{i1})+1-(VC_{i1}/C_{i0})(1-EVCK_{i0})]\ln\frac{K_{i1}}{K_{i0}}$$
$$-(1/2)[(VC_{i1}/C_{i1})EVCT_{i1}+(VC_{i0}/C_{i0})EVCT_{i0}], \tag{11}$$

where $EVCQ$ is the elasticity of variable cost with respect to output, and $EVCK$ is the elasticity of variable cost with respect to capital, and $EVCT=\partial\ln VC/\partial T$. Equation (11) implies that a change in TFP can result from changes in output scale (the first term), capital stock (the second term), and technology (the third term). The second term represents the portion of a change in TFP that is caused by a change in capital stock, when the capacity utilization rate is not at an optimal level, i.e., when the shadow price of capital stock does not equal the rental price of capital.(11) Applying estimated parameters of the variable cost function to equation (11) permits an inquiry into the determinants of TFP growth.

To get the results of TFP growth decomposition, I jointly estimate the variable cost function (10) and the variable cost share equations. Using Shephard's lemma, the cost share of the k th variable input is:

$$VS_{kit}=\alpha_k+\alpha_{ki}D_{ii}+\delta_{kk}\ln w_{kit}+\sum_{m\neq k}\delta_{km}\ln w_{mit}+\lambda_{k1}\ln Q_{it}$$
$$+\delta_{Kk}\ln K_{it}+\Lambda_{k1}T_{it}. \tag{12}$$

One of the share equations is deleted and the additive disturbance terms are appended to equations (10) and (12). Linear homogeneity, symmetry restrictions are imposed on the system of equations. They are given by

$$\sum_k \alpha_k = 1, \sum_k \alpha_{ki} = 0, \sum_m \delta_{mk} = 0, \delta_{mk} = \delta_{km},$$

$$\sum_k \delta_{Kk} = 0, \sum_k \lambda_{k1} = 0, \sum_k \Lambda_{k1} = 0. \qquad (13)$$

Empirical Results

In the first subsection, the estimated parameters of the total and variable cost functions are presented. The following subsection presents empirical estimates of productivity growth based on the conventional index number approach, and results of TFP decomposition based on the cost function approaches.

Estimation Results of the Total and Variable Cost Functions

The sample consists of panel data at the country level for Japan, the United States, and Korea for the 1972-1996 period. There are a total of 75 observations. The Japanese data come from nine private electric utilities. The U.S. data come from the major U.S. investor-owned electric utilities.(12) The Korean data come from the Korea Electric Power Corporation. Data sources and construction are provided in the Appendix. The regression results from the total and the variable cost function approaches are presented in Table 1 and Table 2 respectively.(13) The majority of the parameter estimates are statistically significant.

Empirical Estimates of Productivity Growth

The empirical estimates of TFP growth based on the conventional index number approach are presented in Table 3. TFP growth rates are computed using equation (4). During the 1972-96 period, annual TFP growth rates in Japan and the United States were very low, averaging only 0.22% and 0.12% per year respectively. From 1972 to 1984, TFP growth in Japan (the United States) occurred at the rate of –0.38% (-1.01%) per year, increasing to 0.82% (1.24%) for the 1985-1996 period.

Thus, production efficiency improved in the latter period in both Japan and the United States, but the improvement was larger in the United States than in Japan. In Korea, TFP increased substantially at the average annual rate of 2.61% during the 1972-1996 period, 1.57% for the 1972-1984 period, and 3.66% for the 1985-1996 period. Again, the improvement in productivity is particularly noticeable since the mid-1980s.

Table 3 also reports empirical estimates of partial factor productivity (PFP) growth in the three countries.(14) Labor productivity increased substantially at the average annual rate of 3.48% in Japan and 2.36% in the United States during the 1972-1996 period, while the productivity of capital and fuel declined at the average rates of –0.62% (-0.25%) and –0.43% (-0.40%) respectively. In Korea, all partial productivities increased, and labor productivity showed the highest growth rate among these three countries. Almost all partial productivities exhibited higher growth rates for the 1985-1996 period as compared to the preceding 1972-1984 period in the three countries. The partial productivity growth rates in Japan were lower than those of the United States to some extent, but much lower than those in Korea in the 1985-1996 period. In particular, labor productivity improved significantly in both the United States and Korea, but it did not improve in Japan for the same period.

In Table 4, the TFP growth rate discussed above is compared with the TFP growth rates estimated using the cost function approaches. In this table, the average annual TFP growth rate in column (1) is obtained by the conventional index number approach. The average annual TFP growth rates in column (2) and (3) of Table 4 are estimated based on the total cost function and the variable cost function, respectively. One of the major findings is that empirical estimates of the TFP growth rate (1) are quite similar to those of (2) and (3). For example, over the 1972-1996 period, (1), (2) and (3) are respectively 0.22%, 0.20% and 0.39% in Japan, 0.12%, 0.14% and 0.26% in the United States, and 2.61%, 2.34% and 2.37% in Korea.

The results of this paper suggest that the United States, in which some reform programs have been introduced in the electric power industry since 1978, did not experience a large productivity improvement. Actually, comparing the results in columns (1), (2) and (3), there was not much difference in TFP growth between Japan and the United States, whereas there was a substantial difference between Korea and the other two countries.(15) It is also confirmed by the alternative approaches that although productivity growth increased in the latter period in all three of these countries, TFP improvement in the United States was greater than that in Japan, but less than that in Korea.

It is of some interest to compare our results with those presented in previous empirical studies. For example, O'Mahony and Vecchi (2001) estimated TFP growth rates in the U.S. electric power industry for the 1960-1997 period. Their estimated TFP growth rates are above ours. CAO (2001) estimated the TFP growth in the Japanese electricity industry for the 1986-99 period. One of the results suggested an average growth rate of –0.6%, which is below the estimates in the present study. Lee et al. (2002) focused on the productivity performance of the Korean electric power industry. Their estimates are on average 3.9% for the 1976-1995 period, a little bit higher than the present estimates.(16)

Table 4 also summarizes the results of TFP decomposition based on the total cost function and the variable cost function, using equation (6) and equation (11). In Table 4, (2-a)-(2-c) and (3-a)-(3-c) represent the sources of TFP growth. Empirical results based on the total cost function reveal that the major sources of TFP growth were the scale economies effect in Japan, technical change in the United States, and the capacity utilization effect and scale economies effect in Korea. It is also shown that an increase in the capacity utilization effect contributed to the increase in TFP growth in the 1985-1996 period in all three countries. Results based on the variable cost function approach suggest that the effects of each component on TFP growth rates are somewhat different from those in the total cost function approach both in signs and values.(17) Results from the variable cost function approach suggest that the major component of TFP improvement was the scale economies effect in each of the countries considered. For Japan and Korea, both the total and the variable cost function approaches point to the scale economies effect as the major contributor to TFP growth, though effects based on the variable cost function are bigger than those based on the total cost function.

Concluding Remarks

This study analyzes the electric power industry's productivity experience during the 1972-1996 period in Japan, the United States, and Korea using three alternative approaches. The following conclusions are obtained from this analysis. First, it was confirmed that almost all partial productivities showed higher growth rates for the 1985-1996 period as compared to the 1972-1984 period in the three countries. However, growth rates in Japan were somewhat lower than those in the United States and far lower than those in Korea.

Second, the TFP growth rates obtained using the conventional index number approach and the cost function approaches were substantially the same. It is also confirmed that the growth rates in the United States, where regulatory reforms have been adopted gradually since 1978, were similar to those in Japan, and considerably lower than those achieved in Korea, where little reform has taken place. The results suggest that the regulatory reforms of the United States have not, to date, delivered remarkable improvements in productivity.(18)

Third, from the decomposition analysis based on the total cost function, it is found that the increase in TFP growth since the mid-80s was due to the improvement in the capacity utilization effect in all three countries. The capacity utilization effect in Korea was much larger than that in Japan and the United States.

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Appendix

Data Sources and Construction

The Japanese and Korean data are obtained from *the Financial Report of Japanese Electric Utilities* (Federation of Electric Power

Corporation) and *Financial Statistics* (Korea Electric Power Corporation), respectively. The U.S. data are obtained from *Statistics of Privately Owned Electric Utilities*, *Financial Statistics of Selected Electric Utilities*, *Financial Statistics of Major U.S. Investor-Owned Electric Utilities* (Energy Information Administration) and *Overseas Electric Power Industry Statistics* (Japan Electric Power Information Center).

(1) The Conventional Index Number Approach

Data for the conventional index number approach are defined as follows. Output (Q) is the total electricity generated. Total cost (C) is computed as (total electric operating expenses – purchased power expenses – taxes + interest charges). Labor input (X_L) is the total number of employees, and capital input (X_k) is installed generating capacity. Fuel input (X_M) is obtained by summing up fuels converted to calorific value. Labor cost shares (S_L), fuel cost shares (S_M) and capital cost shares (S_K) are computed by (labor expenditures / C), (fuel expenditures / C) and (capital expenditures / C), respectively. Capital expenditures are equal to (C – labor expenditures – fuel expenditures).

(2) The Cost Function Approaches

Data for the cost function approaches are defined as follows. Output (Q), total cost (C) and capital (K) are defined the same as in (1). Variable cost (VC) is the sum of labor expenditures and fuel expenditures. The price of labor (w_L) is computed as (labor expenditures / the total number of employees). Following Hayashi, et al. (1997), the price of fuel (w_M) is found by dividing fuel expenditures by the total power generated. The price of capital service (w_K) is calculated by dividing capital expenditures by capital input. The capacity utilization rate (T_2) is computed as (total electricity generated) / (installed generating capacity $\times 365 \times 24$).

Notes

1. The electricity power industry in the U.S. has gradually been undergoing a deregulation process during the 1980s. See, for example, U.S. Department of Energy (2000).
2. This Act also authorized FERC to open up the national electricity transmission system to wholesale suppliers.
3. For further details of PURPA and EPACT, see U.S. Department of Energy (2000). In some U.S. states, retail competition began several years ago. For more detailed information on regulatory reform in the United States, see OECD (1999a), U.S. Department of Energy (2000).

4. The Revised Electric Utilities Industry Law was implemented in 2000 and the retail market was partially opened to large customers. For information on regulatory reform in Japan, see Goto and Tsutsui (1998), OECD (1999b), JEPIC (2001).
5. The 1999 Basic Plan for Restructuring the Electricity Supply Industry reflects the Korean government's commitment to market principles in reforming this sector. Major elements include a structural reform of KEPCO and the creation of a sectoral regulator. And the generation sector of KEPCO was separated into six subsidiaries in 2001. See OECD (2000), OECD (2003).
6. TFP measurements in this subsection are based on Denny et al. (1981).
7. Diewert (1976) showed that the Törnqvist index is in fact exact if the underlying potential function has the translog form.
8. The conventional Divisia index number approach has the advantage of simplicity of not requiring direct estimation of the cost or production function. As a result, the often difficult tasks of econometric specification models can be avoided. Hulten (2001) reviewed the advantages and disadvantages of the conventional index number approach and the econometric approach. He further described the added advantage of implementing the both approaches.
9. The total cost function assumes that all inputs are employed at their long-run cost-minimizing level, however the variable cost function assumes that capital is treated as fixed in the short-run. For further information about assumptions that underlie the total cost function and the variable cost function, see, for example, Nelson (1985), Callan (1991).
10. I do not take the logarithm of the time trend. Therefore, in equation (6), ECT_1 means $\partial \ln C/\partial T_1$ and the second term with regard to j=1 in the right hand side becomes $-(1/2)[ECT_{1i1}+ECT_{1i0}]$. Note also that equation (6) decomposes the growth rate of TFP into three sources due to scale economies, technical change and capacity utilization.
11. Equation (11) can be rewritten as the formula used by Nemoto and Asai (2002, p.310). Nemoto and Asai explains further details of the TFP decomposition.
12. For the U.S., because of data limitations, I use data from all investor-owned electric utilities and not just the major investor-owned electric utilities for the Output and Capital variables. There is little difference between these datasets. For example, in 1996, major investor-owned electric utilities accounted for 99.6 percent of the revenues from sales to ultimate consumers and 97.5 percent of the revenues from sales for

resale of all investor-owned electric utilities.

13. The estimated total cost function is nondecreasing in input prices at each observation. It satisfies concavity in input prices for 75% of the observations in the sample. The estimated variable cost function is nondecreasing in variable input prices at each observation and concave in the prices of the variable inputs for 82% of the data points in the sample. However, many observations fail to satisfy monotonicity and convexity in capital.
14. The growth rate of PFP is given by $P\dot{F}P_k = \dot{Q} - \dot{X}_k$.
15. One explanation for the very weak gains in TFP growth in Japan and the United States may be the high levels of productivity reached in the past.
16. O'Mahony and Vecchi (2001) and CAO(2001) employed the index number approach. Lee et al. used a framework similar to that of the present study.
17. As noted in footnote13, many observations fail to satisfy monotonicity and convexity in capital. Such behaviors mean that I have less confidence in the variable cost function estimates and related results. I include these results since others may wish to choose or avoid a model based on this evidence.
18. Many reforms have been in progress since the mid-90s in the electric power industry, and as new data become available, further empirical studies will be necessary to yield definitive results.

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Table 1: Parameter Estimates of the Total Cost Function

Parameters	Estimates	Parameters	Estimates
α_{0}	8.2621(9.13)	δ_{KK}	0.2269 (50.23)
α_{0US}	-0.3617 (-0.78)	δ_{MM}	0.2195 (105.16)
α_{0KR}	-1.2158 (-3.03)	δ_{LL}	0.0868 (24.63)
α_{K}	-0.2778 (-8.26)	μ_{11}	0.0458 (4.87)
α_{KUS}	-0.0394 (-9.12)	ϕ_{22}	0.3185 (4.15)
α_{KKR}	0.0714 (14.29)	δ_{KM}	−0.1798 (-98.33)
α_{M}	0.3562 (8.70)	δ_{KL}	−0.0471 (-12.03)
α_{MUS}	-0.0286 (-5.55)	δ_{ML}	−0.0397 (-22.73)
α_{MKR}	0.0372 (5.55)	λ_{K1}	0.0387 (16.18)
α_{L}	0.9215 (21.41)	λ_{M1}	0.0203 (7.04)
α_{LUS}	0.0680 (12.57)	λ_{L1}	−0.0590 (-20.00)
α_{LKR}	-0.1085 (-15.15)	τ_{12}	−0.0846 (-4.97)
β_{1}	0.2730 (2.11)	Λ_{K2}	−0.2204 (-26.18)
β_{1US}	0.0289 (0.85)	Λ_{M2}	0.1672 (17.88)
β_{1KR}	0.0835 (2.45)	Λ_{L2}	0.0532 (4.90)
θ_{1}	-0.0002 (-0.22)		
θ_{1US}	-0.0021 (-2.05)		
θ_{1KR}	-0.0003 (-0.14)	Log-likelihood	823.396
θ_{2}	0.9071 (3.78)		
θ_{2US}	0.0176 (0.48)		
θ_{2KR}	-0.1301 (-3.85)		

Note: t-statistics are in parentheses. Parameters are reported as they appear in the total cost function. See equation (7).

Table 2: Parameter Estimates of the Variable Cost Function

Parameters	Estimates	Parameters	Estimates
α_{0}	1.4389 (0.20)	δ_{KK}	0.1715 (0.90)
α_{0US}	-8.1697 (-5.14)	δ_{MM}	0.1632 (41.01)
α_{0KR}	7.8985 (3.25)	δ_{LL}	0.1632 (41.01)
α_{K}	5.5790 (3.91)	μ_{11}	0.2661 (1.65)
α_{KUS}	0.4116 (3.41)	ϕ_{11}	−0.0019 (-6.60)
α_{KKR}	-1.0696 (-5.17)	δ_{KM}	0.0080 (0.43)
α_{M}	-0.5471(-4.48)	δ_{KL}	−0.0080 (-0.43)
α_{MUS}	-0.1137 (-9.19)	δ_{ML}	−0.1632 (-41.01)
α_{MKR}	0.1933(10.17)	λ_{K1}	−0.5005 (-2.96)
α_{L}	1.5471 (12.66)	λ_{M1}	0.1014 (6.65)
α_{LUS}	0.1137 (9.19)	λ_{L1}	−0.1014 (-6.65)
α_{LKR}	-0.1933 (-10.17)	τ_{11}	0.0053 (0.66)
β_{1}	-0.4684 (-0.32)	Λ_{K1}	0.0374 (6.16)
β_{1US}	0.4740 (3.16)	Λ_{M1}	−0.0005 (-0.93)
β_{1KR}	-0.4707 (-2.04)	Λ_{L1}	0.0005 (0.93)
θ_{1}	-0.2314 (-2.78)		
θ_{1US}	-0.0569 (-8.77)		
θ_{1KR}	0.1147 (7.44)	Log-likelihood	468.922

Note: t-statistics are in parentheses. Parameters are reported as they appear in the variable cost function. See equation (10).

Table 3: Average Annual Growth Rates of TFP and PFP (%)

	TFP	PFP		
		Labor	Capital	Fuel
Japan				
1972-96	0.22	3.48	-0.62	-0.43
1972-84	–0.38	3.80	-1.82	-0.77
1985-96	0.82	3.16	0.58	-0.09
US				
1972-96	0.12	2.36	-0.25	-0.40
1972-84	-1.01	0.41	-1.55	-0.88
1985-96	1.24	4.31	1.06	0.09
Korea				
1972-96	2.61	7.80	2.86	0.42
1972-84	1.57	6.91	1.68	-0.14
1985-96	3.66	8.69	4.05	0.99

Table 4: Decomposition of TFP Growth (Average Annual Rate of Change (%))

	TFP growth (1)	TFP growth (2)	Sources of productivity growth			TFP growth (3)	Sources of productivity growth		
			Capacity utilization (2-a)	Scale economies (2-b)	Technical change (2-c)		Capital adjustment (3-a)	Scale economies (3-b)	Technical change (3-c)
Japan									
1972-96	0.22	0.20	-0.16	0.33	0.02	0.39	-2.77	2.78	0.39
1972-84	-0.38	-0.34	-0.72	0.36	0.02	-0.04	-3.05	2.59	0.42
1985-96	0.82	0.73	0.40	0.30	0.02	0.82	-2.50	2.97	0.35
US									
1972-96	0.12	0.14	-0.08	-0.02	0.23	0.26	-1.36	1.43	0.19
1972-84	-1.01	-0.64	-0.87	-0.01	0.23	-0.60	-1.99	1.48	-0.09
1985-96	1.24	0.93	0.71	-0.02	0.23	1.11	-0.73	1.39	0.46
Korea									
1972-96	2.61	2.34	1.48	0.81	0.05	2.37	-3.85	6.63	-0.41
1972-84	1.57	1.57	0.63	0.89	0.05	1.43	-3.59	4.76	0.25
1985-96	3.67	3.11	2.34	0.72	0.05	3.31	-4.11	8.50	-1.08

Note: TFP growth rate (1) is obtained by the conventional index number approach.
TFP growth rate (2) is obtained by estimation of the total cost function.
TFP growth rate (3) is obtained by estimation of the variable cost function

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