VERTICAL RELATIONSHIP, EFFICIENCY AND PRODUCTIVITY
IN THE KOREAN AND JAPANESE RAILWAY INDUSTRIES:
A STOCHASTIC FRONTIER APPROACH

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Abstract: This paper investigates the vertical relationship between infrastructure provision and railway operations and evaluates the effects of privatization and deregulation on the firm-specific efficiency and total factor productivity (TFP) growth in the Korean and Japanese railways. Using a stochastic frontier approach and a generalized translog functional form, the paper specifies the equation system consisting of a multiproduct variable cost function and input share equations which is estimated with the Zellner’s iterative seemingly unrelated regression and the corrected least squares method. The empirical results indicate that there are cost complementarities between infrastructure provision and overall railway operations and cost anticomplementarities between incumbent passenger and freight outputs in the Korean railways, and between Shinkansen and incumbent passenger outputs in the Japanese railways. They also indicate that the firm-specific efficiencies and TFP growth rates of the privately-owned JRs are higher than those of the government-owned KNR and JNR.

Key Words: railways, vertical separation/integration, efficiency, productivity

1. INTRODUCTION

The reform of the European railway industries has adopted for a scenario of vertical separation mostly after Sweden totally separated the ownership of infrastructure from operation services in 1988. Meanwhile, the Japan National Railway (JNR) was not only privatized but also separated into two non-operator sectors which were JNR Settlement Corporation (JNRSC) and Shinkansen Holing Corporation (SHC), and manageable sectors maintaining the vertical integration. The manageable sectors were divided into six regional passenger railway firms¹ and one freight railway firm, JR Freight, which uses the other six JRs’ (Japan Railways) tracks and pays usage fees to them². As far as the reform of the Korea National Railroad (KNR) concerned, Korea established a structure of vertical separation.

¹ Three larger firms (JR East, JR Central and JR West) are operating on the main island of Japan, Honshu, while three smaller firms (JR Hokkaido, JR Shikoku and JR Kyushu) are operating on the three smaller islands of Hokkaido, Shikoku and Kyushu. Shinkansen is operated only by the three Honshu JRs. See Ida and Suda (2004).
² Yardstick competition induces competition among rail operators. See Mizutani (1999), pp. 121-122.
KNR was divided into an infrastructure firm, Korea Rail Network Authority and an operation firm, Korea Railroad, which were established in 2005 and 2004, respectively. The separation of passenger and freight transport into two different firms will be undertaken sooner or later.

This paper, thus, aims to investigate vertical relationships between infrastructure provision and railway operations by estimating cost complementarities between them and to analyze the effects of the privatization and deregulation on the firm-specific efficiencies and total factor productivity (TFP) growth rates in the Korean and Japanese railways. The paper assumes the cost structure of the vertically-separated industry and estimates a multiproduct variable cost function with the generalized translog form using a stochastic frontier approach. The Korean and Japanese railway firms are then assumed to produce three outputs (Shinkansen passenger-kilometers, incumbent railway passenger-kilometers, ton-kilometers of freight) using three input factors (labor, fuel, maintenance and rolling stock). A monetary value of the ways and fixed installations held by the railroad firm is also included as a quasi-fixed input.

A few recent studies analyzed the cost structure (economies of density, scale, and scope) and productivity of railway industries using a traditional cost function\(^3\). The only two studies to analyze vertical relationships between infrastructure provision and railway operations are Cantos (2001) and Ivaldi and McCullough (2001). Cantos (2001) found that costs derived from freight service and infrastructure were complementary, while those derived from passenger service and infrastructure were substitutive in the European railways. He also showed that the costs derived from passenger and freight services were not complementary. Ivaldi and McCullough (2001) found strong cost complementarities among operational outputs, but cost anticomplementarities between infrastructure provision and railway operations in the U.S. freight railways. However, there were few applications of a stochastic frontier approach to estimate the efficiency and productivity in railway industries. Kumbhakar (1988) and Cantos and Maudos (2001) estimated the efficiency levels of the U. S. Class I railroads and the European railways, respectively. Cantos and Maudos (2000) is the only study to estimate the levels of productivity, efficiency and technical change for the railway firms using a stochastic frontier cost function. They found that the TFP growth rate of the European railways took place at an annual average rate of 0.81%, due to technical change (0.45%), cost efficiency change (0.19%), and scale efficiency change (0.16%).

This paper is structured as follows. Chapter 2 specifies a generalized translog multiproduct cost function using a stochastic frontier approach, and provides methods to analyze the vertical relationship between infrastructure provision and railway operations and the firm-specific efficiencies and TFP growth rates. Chapter 3 describes data and estimation methods and Chapter 4 represents estimation results. The final chapter summarizes main estimation results and emphasizes the most relevant weaknesses of the paper.

2. MODEL SPECIFICATION

2.1 STOCHASTIC FRONTIER SPECIFICATION AND FUNCTIONAL FORM

This paper employs a multiproduct variable cost function with the generalized translog form due to Caves et al. (1980) using a stochastic frontier approach. The Korean and Japanese railway firms are assumed to produce three outputs (Shinkansen passenger-kilometers, incumbent railway passenger-kilometers, ton-kilometers of freight) using three input factors (labor, fuel, maintenance and rolling stock). A monetary value of the ways and fixed installations held by the railway firm is also included as a quasi-fixed input. The generalized translog multiproduct cost function using a stochastic frontier approach is the following:

\[
\ln VC_t = \ln VC^*_t + \varepsilon_t \\
= \alpha_0 + \sum_1^k \alpha_i Y_{it}^* Y_{it} + \sum_1^k \beta_q \ln P_{qit} + \gamma_N \ln N_i + \sigma_1 \ln I_i + \rho_T \ln T_i + \frac{1}{2} \sum_1^k \sum_1^k \delta_q Y_{it} Y_{jt}^*
\]

\[+ \frac{1}{2} \sum_1^k \sum_1^k \eta_q \ln P_{qit} + \frac{1}{2} \gamma_{NN} \ln N_i^2 + \frac{1}{2} \sigma_{II} \ln I_i^2 + \sum_1^k \sum_1^k \theta_q Y_{it}^* \ln P_{qit} + \sum_1^k \gamma_{q1} \ln N_i + \sum_1^k \gamma_{q2} \ln P_{qit} + \sum_1^k \gamma_{q3} \ln I_i + \sigma_{NN} \ln N_i \ln I_i + \sum_1^k \rho_{q1} \ln P_{qit} T + D_1 + D_2 + u_i + v_i
\]

Where \( t \) refers to the year and \( VC_t \) is an observed variable cost; \( Y_i \) is an output and \( P_{qit} \) is

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4 The reasons why this paper employs the generalized translog multiproduct variable cost function using a stochastic frontier approach are as follows. First, instead of production functions cost functions are widely used to model the technology of a firm operating in regulated environments such as electricity, railroad, airlines, etc. Outputs and input prices in these industries are assumed to be exogeneous, while input demands and costs are endogeneous. The behavioral assumption underlying the formulation is that the firm minimizes its costs subject to outputs, input prices, and a production function. Second, the generalized translog function is a more general form of the translog function, which allows for a Box-Cox transformation on output variables. The Box-Cox transformation is well defined for zero output levels. So railway firms with zero output levels for some products can be included into the sample. Third, a frontier approach is consistent with the underlying economic theory of optimizing the behavior of a firm because stochastic frontier models assume that firms do not fully utilize an existing technology and estimate the efficient relationships between outputs and costs. Meanwhile, the traditional approach assumes that firms fully utilize an existing technology and estimate the average relationships between outputs and costs.
an input price\(^5\). Subscripts i and j indicate outputs, h, p, f, representing Shinkansen passenger-kilometers, incumbent railway passenger-kilometers, and ton-kilometers of freight, respectively. Also subscripts q and r indicate input prices, l, e, m, representing labor, fuel, maintenance and rolling stock, respectively. \(I_t\) represents the infrastructure variable, \(N_t\) denotes track lengths to reflect network effects, and \(T\) is time trend as a proxy for technical change. \(D_h\) and \(D_p\) are dummies for the three-island JRs (JR Hokkaido, JR Shikoku and JR Kyushu) and JR Freight to reflect the cost gap between railway firms. The error term, \(\varepsilon\), is composed of two terms: a cost inefficiency term, \(u_t\), and a statistical noise term, \(v_t\).

The symmetry conditions are imposed on parameters:

\[
\begin{align*}
\delta_q &= \delta_p, & \eta_{qp} &= \eta_{pq}, & \theta_{iq} &= \theta_{qi}, & \gamma_{qi} &= \gamma_{iq}, \\
\gamma_{qN} &= \gamma_{Nq}, & \sigma_{qi} &= \sigma_{iq}, & \sigma_{Nq} &= \sigma_{qN}, & \rho_{qT} &= \rho_{Tq}.
\end{align*}
\]

A cost function should satisfy regularity conditions such as linear homogeneous, monotonically increasing and concave in input prices to well behaved production structures. The requirement of homogeneity of degree one in input prices is imposed in advance\(^6\).

\[
\sum_q \beta_q = 1, \quad \sum_q \eta_{qr} = 0 \quad \forall q, \quad \sum_i \theta_{iq} = 0 \quad \forall i, \quad \sum_q \gamma_{qN} = 0, \quad \sum_q \sigma_{qt} = 0, \quad \sum_q \rho_{qt} = 0
\]

By Shephard’s Lemma, input shares are equated to the logarithmic partial derivatives of the cost function with respect to the input prices:

\[
S_{q} = S_{q}^* + \nu_{q} = \frac{P_{q}X_{q}}{V_{q}} = \frac{\partial VC_{q}}{\partial P_{q}} \cdot \frac{P_{q}}{VC_{q}} = \frac{\partial \ln VC_{q}}{\partial P_{q}} = \beta_{q} + \sum_q \eta_{qr} \ln P_{q} + \sum_i \theta_{iq} Y_{i} + \gamma_{qN} \ln N_{q} + \sigma_{qt} I + \rho_{qt} T + v_{q}
\]

Where \(S_{q}\) and \(S_{q}^*\) are the observed share and the efficient share of variable costs allocated to an input q, respectively.

### 2.2 VERTICAL RELATIONSHIPS

It is fundamental to know the relationships between infrastructure and operating costs to verify the decision whether to choose a market structure that vertically integrates infrastructure and operations or separates them in the reform process of the railway industries.

\(^5\) The Box-Cox transformation of output, \(Y_{i}^*\) is \((Y_{i}^* - 1)/\lambda_i\) (if \(\lambda_i \neq 0\)) and \(\ln Y_{i}\) (if \(\lambda_i = 0\)).

\(^6\) These two restrictions reduce the number of parameters to be estimated.
To evaluate these relationships, the multiproduct variable cost function with three outputs (Shinkansen, incumbent railway passenger and freight) and one infrastructure variable measured by the value of ways and fixed installations are considered. The cross marginal cost elasticities of each output relative to infrastructure to analyze the relevance of vertical separation between infrastructure provisions and railway operations are calculated as follows:

\[
\varepsilon_{MC_i} = \frac{\partial \ln MC_i}{\partial \ln Y_i} = \frac{\sigma_{q_i} Y_{i}^{p_i} + \varepsilon_{CY_i} \varepsilon_{CY_j}}{\varepsilon_{CY_i}} \quad (5)
\]

Where \( MC_i \) is the marginal cost of the \( i \)th output.

Note that negative (positive) cross marginal cost elasticities imply the existence of cost complematarities (anticomplematarities) between each output and infrastructure. The existence of cost complematarities between infrastructure and railway operations indicates that a proportional increase of infrastructure reduces the marginal cost elasticities of \( i \)th output.

The cost elasticity of the \( i \)th output, \( \varepsilon_{CY_i} \), obtained from the generalized translog multiproduct cost function can be written as follows:

\[
\varepsilon_{CY_i} = \frac{\partial \ln VC_i}{\partial Y_i} = [\alpha_i + \sum_j \delta_{ij} Y_j^* + \sum_q \theta_{q_i} \ln P_q + \gamma_{N_i} \ln N + \sigma_{q_i} \ln I] \cdot Y_i^{\lambda}
\]

The cost elasticity of infrastructure can be expressed as follows:

\[
\varepsilon_{CI} = \frac{\partial \ln VC}{\partial \ln I} = \sigma_I + \sigma_{II} \ln I + \sum_i \sigma_{q_i} Y_i^* + \sum_q \sigma_{q_i} \ln P_q + \sigma_{N} \ln N \quad (7)
\]

Next, the cross marginal cost elasticities of each output relative to the other output to analyze the relevance of the separation of operation services are also calculated as follows:

\[
\varepsilon_{MC_{ij}} = \frac{\partial \ln MC_i}{\partial \ln Y_j} = \frac{\delta_{ij} Y_j^{\lambda} Y_i^{\lambda} + \varepsilon_{CY_i} \varepsilon_{CY_j}}{\varepsilon_{CY_j}} \quad (8)
\]

In the presence of negative cross marginal cost elasticities of each output relative to the other

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7 Cost complematarities, when \( C_{ij} = \partial^2 VC / \partial Y_i \partial Y_j \) (for \( i \neq j \)) is negative, imply that the marginal cost of producing any one product decreases with an increase in the quantities of all other products. See Baumol et al. (1982).
output, railway firms with diversified operation output mixes could have variable costs lower than the variable costs of firms with specialized product mixes. Positive cross marginal cost elasticities of each output relative to the other output indicate that multiproduct railway firms can be broken up into several specialized firms without any increase in cost\textsuperscript{8}.

2.3 EFFICIENCY

The stochastic cost frontier model given in equation (1) can be rewritten as:

\[ VC_i = V^* - \exp(u_i + \varepsilon_i) \]

The composite error term, \( \varepsilon_i \), is composed of two independent terms. The first term, \( u_i \), represents the railway firm’s cost inefficiency\textsuperscript{9}. The second term, \( v_i \), represents statistical noise such as white noise, specification error, measurement error, and unpredicted error, etc. Note that \( V^* - \exp(v_i) \) is the minimum cost for given level of outputs and input prices excluding the cost of inefficiency (which defines the cost frontier). It can be made stochastic by adding the component \( \exp(v_i) \). The following distributional assumptions are made:

\begin{align*}
(i) & \quad v_i \sim iid \ N(0, \sigma_v^2) \\
(ii) & \quad u_i \sim iid \ [N(0, \sigma_u^2)], \text{ that is as nonnegative halfnormal} \\
(iii) & \quad u_i \perp v_i
\end{align*}

Since \( \varepsilon_i = u_i + v_i \) and \( u_i \perp v_i \), the joint density function for \( u_i \) and \( \varepsilon_i \) is:

\[ f(u, \varepsilon_i) = \frac{2}{2\pi\sigma_u\sigma_v} \exp\left\{-\frac{u_i^2}{2\sigma_u^2} - \frac{(\varepsilon_i - u_i)^2}{2\sigma_v^2}\right\} 
\]

The conditional distribution of \( u_i \) given \( \varepsilon_i \) is:

\[ f(u_i | \varepsilon_i) = \frac{f(u_i, \varepsilon_i)}{f(\varepsilon_i)} = \frac{1}{\sqrt{2\pi\sigma_u}} \exp\left\{-\frac{(u_i - \mu_u)^2}{2\sigma_u^2}\right\} f\left\{1 - \Phi\left(-\frac{\mu_u - \sigma_v^2 u_i}{\sigma_v}\right)\right\} \]

Where \( u_i = \varepsilon_i \sigma_u^2 / \sigma^2 \), \( \sigma_v^2 = \sigma_u^2 \sigma_v^2 / \sigma^2 \) and \( \Phi(\cdot) \) is the cumulative distribution functions.

Since \( f(u_i | \varepsilon_i) \) is distributed as \( \mathcal{N}(\mu_u, \sigma_v^2) \), the expectation of this distribution is given by:

\textsuperscript{8} See Kim (1987), p. 735.

\textsuperscript{9} Cost inefficiency will contain the combined effects of technical and allocative inefficiency.
\[ E(u_i \mid \varepsilon_i) = \frac{\sigma_{\varepsilon_i} \sigma_T}{\sigma} \left\{ \frac{\phi(\varepsilon_i, \lambda \mid \sigma)}{1 - \Phi(-\varepsilon_i, \lambda \mid \sigma)} + \frac{\varepsilon_i \lambda}{\sigma} \right\} \] 

(13)

Where \( \sigma = \sqrt{\sigma^2 + \sigma^2} \), \( \lambda = \sigma / \sigma \), \( \phi(\cdot) \) is the standard normal density functions.

From the conditional expectation of \( u_i \), The cost efficiency measure, \( CE_i \) can be calculated as follows:

\[ CE_i = \exp \{E(u_i \mid \varepsilon_i)\} \] 

(14)

The conditional expectation of \( u_i \) measures a mean of the difference between the observed actual variable cost and the minimum attained variable cost, \( VC_i - (VC_i^* + v_i) \). \( CE_i \) takes a value between 1 and infinity, with a value of 1 indicating cost efficiency. Cost inefficiency (\%) is calculated by \( CE_i - 1 \).

### 2.4 TFP GROWTH

The TFP growth measures derived from the cost frontier function in the equation (1) can be decomposed into three components: cost efficiency change (CEC), technical change (TC), and scale efficiency change (SEC). Following Coelli et al. (2003), the log of the TFP growth between period t=0 and t=1 for the n-th firm can be defined to as follows:

\[ \ln \left( \frac{TFP_{s1}}{TFP_{s0}} \right) = \ln \left( \frac{CE_{s0}}{CE_{s1}} \right) - 0.5 \left( \frac{\partial VC_{s0}}{\partial T} + \frac{\partial VC_{s1}}{\partial T} \right) + 0.5 \sum_{j=1} \left( SF_{s0} e_{CY_{s0}} + SF_{s1} e_{CY_{s1}} \right) \cdot (Y_{s1} - Y_{s0}) \] 

(15)

Where the three terms on the right-hand-side of equation (15) are CEC, TC, SEC, respectively.

TC is calculated by the partial derivative with respect to time as follows:

\[ \varepsilon_{CT} = \frac{\partial \ln VC}{\partial T} = \rho_T + \rho_{TT} T + \sum_{q} \rho_{Tq} \ln P_q \] 

(16)

SEC measures the change in scale efficiency and is calculated by the cost elasticity of the \( i \)th output in equation (6). The scale factor, \( SF_{si} = (e_{si} - 1)/e_{si} \) is calculated, where \( e_{si} = \sum_{i} e_{CY_{si}} \).

In addition, with information on input quantities and output prices, the allocative inefficiency measure can be calculated as follows:
\[
AEC = \sum_{q=1}^{n} \left( \frac{\ln P_{q1} - \ln P_{q0}}{2} \right) \left( S_{q1} - W_{q1} + S_{q0} - W_{q0} \right) + \sum_{i=1}^{l} \left( \frac{\ln P_{i1} - \ln P_{i0}}{2} \right) \left( \Pi_{i1} - R_{i1} + \Pi_{i0} - R_{i0} \right) \left( Y_{i1} - Y_{i0} \right)
\]  

(17)

Where the two terms on the right-hand-side of equation (17) are input mix allocative inefficiency and output mix allocative inefficiency, respectively.

The former is, when the observed cost share, \( S_{i} \), differs from the efficient cost share, \( S_{i}^{*} \), in equation (4) and the latter is, when the observed revenue share, \( \Pi_{i} \), differs from the efficient revenue share, \( \Pi_{i}^{*} \), that is, when the shadow price of an input deviates from its market price.

3. DATA AND METHOD OF ESTIMATION

3.1 DATA

The unbalanced panel data used in this paper, a total of 154 observations, are collected from the annual records of the Korea National Railroad (KNR) for the years 1977~2003, Japan National Railways (JNR) for the years 1977~1984, seven Japan Railways (JRs) for the years 1987~2003. Table 1 shows variables’ summary statistics in constant 2003 Korean won.

<table>
<thead>
<tr>
<th></th>
<th>( Y_{h} )</th>
<th>( Y_{p} )</th>
<th>( Y_{f} )</th>
<th>( N )</th>
<th>( I )</th>
<th>( VC )</th>
<th>( P_{l} )</th>
<th>( P_{r} )</th>
<th>( P_{m} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNR(1977~2003)</td>
<td>28,603</td>
<td>12,165</td>
<td>6,377</td>
<td>144,079</td>
<td>14,731</td>
<td>6,427</td>
<td>472</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JNR(1977~1984)</td>
<td>44,361</td>
<td>149,839</td>
<td>34,178</td>
<td>869,301</td>
<td>375,648</td>
<td>73</td>
<td>13,745</td>
<td>1,470</td>
<td></td>
</tr>
<tr>
<td>JR East(1987~2003)</td>
<td>16,205</td>
<td>107,060</td>
<td>12,689</td>
<td>528,335</td>
<td>117,108</td>
<td>91</td>
<td>12,419</td>
<td>2,474</td>
<td></td>
</tr>
<tr>
<td>JR West(1987~2003)</td>
<td>14,656</td>
<td>37,769</td>
<td>8,198</td>
<td>163,766</td>
<td>64,091</td>
<td>79</td>
<td>16,722</td>
<td>2,198</td>
<td></td>
</tr>
<tr>
<td>JR Shikoku(1987~2003)</td>
<td>1,888</td>
<td>896</td>
<td>8,920</td>
<td>4,001</td>
<td>79</td>
<td>4,885</td>
<td>2,530</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JR Kyushu(1987~2003)</td>
<td>8,211</td>
<td>2,665</td>
<td>26,128</td>
<td>13,986</td>
<td>84</td>
<td>9,709</td>
<td>1,717</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JR freight(1987~2003)</td>
<td>14,087</td>
<td>13,057</td>
<td>16,858</td>
<td>88</td>
<td>8,248</td>
<td>577</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>10,058</td>
<td>31,448</td>
<td>6,524</td>
<td>8,375</td>
<td>52,735</td>
<td>71</td>
<td>9,641</td>
<td>1,864</td>
<td></td>
</tr>
</tbody>
</table>

\( Y_{h} \), passenger-km(in millions); \( Y_{p} \), passenger-km(in millions); \( Y_{f} \), ton-km(in millions); \( N \), length of network(km); \( I \), value of ways and fixed installations(in 100 millions of won); \( VC \), variable cost(in 100 millions of won); \( P_{l} \), labor price; \( P_{r} \), energy price; \( P_{m} \), maintenance price.

Firstly, we consider three inputs: labor, fuel, maintenance and rolling stock. Costs were allocated to the input factors divided by each input quantity to obtain unit price index of inputs. The labor costs including total wages, fringe benefits, allowances and pension payments divided by the total number of employees (\( P_{l} \)). We used the fuel costs including
total electricity, coal, and petroleum charges divided by ton of equivalent \( (P_e) \). Maintenance and rolling stock costs which were total expenses spent on maintaining infrastructure and rolling stocks plus the depreciation and opportunity cost of rolling stocks divided total car-km \( (P_m) \). All these costs were expressed in constant 2003 Korean won through the rate of exchange. Variable cost was defined as the sum of input factor costs, respectively.

Secondly, as a measurement of infrastructure we include a monetary value of the ways and fixed installation \( (I) \) held by the railway firms just as Cantos (2001). Infrastructure included land, way and structure, buildings, telecom, signal and electric facilities, etc. The monetary value of the ways and fixed installation was also expressed in constant 2003 Korean won.

3.2 METHOD OF ESTIMATION

The simultaneous equation system consisting of a cost function and the input share equations is estimated with the Zellner’s iterative seemingly unrelated regression (ITSUR)\(^{10}\). The estimation of systems of equations provides asymptotically efficient estimates to efficiency and parameters by increasing the degree of freedom and the iterative Zellner efficient procedure is known to obtain asymptotically maximum likelihood estimates. One of the input share equations will be eliminated since the three input share equations add up to unity and only two of them are linearly independent. In this case, we omit the maintenance and rolling stock share equation. Also, a key problem is how to model the relationship between the two-sided disturbances in the input share equations and the nonnegative inefficiency disturbance in the cost equation when such cost systems of equations are estimated using stochastic frontier approach (so called Greene problem). In this case, we ignore the relationship among the disturbances in the cost and input share equations like Greene (1980), that is, treats these disturbances as independent.

4. ESTIMATION RESULTS

4.1 STOCHASTIC FRONTIER COST FUNCTION

Table 2 reports the estimation results of the generalized translog variable cost function using the stochastic frontier approach. Overall, the majority of the estimates are statistically significant and \( R^2 \)’s of the cost function and the input share equations are relatively high. The estimates of the Cost function also satisfy prior conditions\(^{11}\).

\(^{10}\) The estimates of a cost equation system can be generally obtained using corrected ordinary least squares (COLS) or maximum likelihood estimation (MLE). MLE tends to outperform COLS in sample size larger than 400, whereas COLS tends to outperform MLE in sample size of less than 400. See Bauer (1990), p. 42.

\(^{11}\) Hypotheses of homotheticity, homogeneity, and Cobb-Douglas production technology are statistically tested
and Ivaldi and McCullough (2001) estimated that infrastructure coefficients had wrong (positive) signs in transport literature. Using the likelihood ratio (LR) test, all hypotheses of production technology are rejected. The positive parameters of the three outputs (\(a_p=0.260\), \(a_v=0.190\), \(a_f=0.173\)) imply that larger Shinkansen passenger-kilometers, incumbent railway passenger-kilometers, and ton-kilometers of freight increase the variable cost. The parameter of infrastructure (\(\sigma_f=-0.099\)) which is statistically significant at the 5% probability level suggests that the shadow value of infrastructure is negative\(^\text{12}\). Two dummies for the three-island JR’s (JR Hokkaido, JR Shikoku and JR Kyushu) and JR Freight (\(D_1=-0.340\), \(D_2=-0.700\)) imply that the variable costs of the three-island JRs and JR Freight are smaller than other railway firms. The estimate of time using the likelihood ratio (LR) test. All of the hypotheses of production technology are rejected at 1% level of significance since the LR test statistics for these models are 371.83, 443.16, and 759.43, respectively.

\(^{12}\) Oum and Zhang (1991) argued that the shadow value of a fixed capital stock is negative but most of the variable cost functions in transport literature had wrong (positive) signs for the capital stock. Also Cantos (2001) and Ivaldi and McCullough (2001) estimated that infrastructure coefficients had negative signs.
trend, T is not significant even at the 10% probability level but the estimate of $T^2$ ($\rho_{TT}=-0.001$) is statistically significant with a negative sign, showing that the cost decreases with time. Finally, this paper used a value for $\lambda$ of 0.095 to estimate box-cox transformation output following Park and Kim(2006).

### 4.2 VERTICAL RELATIONSHIPS

Table 3 shows elasticities of cost with respect to output and elasticities of marginal cost with respect to infrastructure. Elasticities of cost with respect to Shinkansen passenger-kilometers, incumbent railway passenger-kilometers, and ton-kilometers of freight for the total sample suggest that one percent increase in output on average will increase the costs by 0.19%, 0.26%, 0.17%, respectively. Incumbent passenger railway service has the highest elasticity.

<table>
<thead>
<tr>
<th>Railway firms</th>
<th>Elasticities of cost with respect to output</th>
<th>Elasticities of marginal costs with respect to infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\varepsilon_{cy}$</td>
<td>$\varepsilon_{cx}$</td>
</tr>
<tr>
<td>KNR(1977~2003)</td>
<td>0.39*** (75.12)</td>
<td>0.04 (1.00)</td>
</tr>
<tr>
<td>JR East(1987~2003)</td>
<td>0.18*** (17.08)</td>
<td>0.34*** (18.91)</td>
</tr>
<tr>
<td>JR Central(1987~2003)</td>
<td>0.12*** (15.63)</td>
<td>0.21*** (18.73)</td>
</tr>
<tr>
<td>JR West(1987~2003)</td>
<td>0.17*** (29.83)</td>
<td>0.41*** (21.32)</td>
</tr>
<tr>
<td>JR Hokkaido(1987~2003)</td>
<td>0.44*** (23.59)</td>
<td>-0.40*** (-25.78)</td>
</tr>
<tr>
<td>JR Shikoku(1987~2003)</td>
<td>0.56*** (33.81)</td>
<td>-0.42*** (-21.82)</td>
</tr>
<tr>
<td>JR Kyushu(1987~2003)</td>
<td>0.53*** (22.06)</td>
<td>-0.41*** (-14.07)</td>
</tr>
<tr>
<td>JR freight(1987~2003)</td>
<td>0.51*** (35.55)</td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>0.19*** (4.90)</td>
<td>0.26*** (5.46)</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level with t-statistics in parentheses.

The results of elasticities of marginal cost with respect to infrastructure have negative signs except to Shinkansen service of JR Central. Therefore overall, it indicates that cost complementarities derived from the joint supply infrastructure provision and railway operations will exist. Cost complementarities between infrastructure provision and railway operations can be existed when railway firms use shared inputs that are not easy to divide more efficiently than they would be used if production were performed separately. If infrastructure endowments will increase, the costs of route scheduling and designing would reduce. On the other hand an increase in infrastructure endowments of JR Central, whose incumbent passenger service is very small but Shinkansen service is large, would increase the marginal cost of Shinkansen service. It might be explained that Shinkansen trains operate at high speed and frequency on its own tracks. So increases in these types of services could
increase the marginal cost of infrastructure.

Table 4 Elasticities of marginal cost with respect to output

<table>
<thead>
<tr>
<th>Railway firms</th>
<th>Shinkansen</th>
<th>Incumbent</th>
<th>Freight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$e_p^{MC}$</td>
<td>$e_h^{MC}$</td>
<td>$e_f^{MC}$</td>
</tr>
<tr>
<td>KNR(1977~2003)</td>
<td>0.07**(4.76)</td>
<td>0.12**(4.17)</td>
<td></td>
</tr>
<tr>
<td>JNR(1977~1984)</td>
<td>0.08**(2.64)</td>
<td>0.12**(4.17)</td>
<td>0.41**(9.79)</td>
</tr>
<tr>
<td>JR East(1987~2003)</td>
<td>0.43**(23.58)</td>
<td>0.22**(21.02)</td>
<td></td>
</tr>
<tr>
<td>JR Central(1987~2003)</td>
<td>0.32**(20.83)</td>
<td>0.18**(18.94)</td>
<td></td>
</tr>
<tr>
<td>JR West(1987~2003)</td>
<td>0.49**(24.51)</td>
<td>0.20**(33.02)</td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>0.33**(2.47)</td>
<td>0.23**(10.19)</td>
<td>0.24(0.31)</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level with t-statistics in parentheses.

Table 4 represents elasticities of marginal cost with respect to output. The results indicate that cost anticomplementarities between incumbent passenger and freight output in the Korean railway\(^{13}\) and also cost anticomplementarities between Shinkansen and incumbent passenger output in the Japanese railways\(^{14}\) exist. Therefore it can not be said that the separation of the two services into different firms will not be economical. It would be explained that Shinkansen, incumbent passenger trains, and freight trains interfere with each other’s railway operations. They have the different speeds and the axle-loadings from traffic, i.e. passenger trains require relatively light in axle loadings and straighter tracks because of their high speeds and the need for passenger comfort and safety.

### 4.3 EFFICIENCY

Table 5 Estimates of cost efficiency

<table>
<thead>
<tr>
<th>Railway firms</th>
<th>$CE_i$</th>
<th>77-86</th>
<th>87-90</th>
<th>91-95</th>
<th>96-00</th>
<th>01-02</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNR(1977~2003)</td>
<td>1.018</td>
<td>1.14</td>
<td>0.82</td>
<td>0.94</td>
<td>4.16</td>
<td>2.77</td>
<td>1.80</td>
</tr>
<tr>
<td>JNR(1977~1984)</td>
<td>1.047</td>
<td>4.73</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JR East(1987~2003)</td>
<td>1.021</td>
<td>5.43</td>
<td>1.17</td>
<td>1.10</td>
<td>1.04</td>
<td>2.13</td>
<td></td>
</tr>
<tr>
<td>JR Central(1987~2003)</td>
<td>1.028</td>
<td>1.03</td>
<td>1.89</td>
<td>3.74</td>
<td>5.26</td>
<td>2.83</td>
<td></td>
</tr>
<tr>
<td>JR West(1987~2003)</td>
<td>1.013</td>
<td>1.67</td>
<td>1.09</td>
<td>1.43</td>
<td>0.71</td>
<td>1.26</td>
<td></td>
</tr>
<tr>
<td>JR Hokkaido(1987~2003)</td>
<td>1.020</td>
<td>1.03</td>
<td>1.36</td>
<td>3.28</td>
<td>2.35</td>
<td>2.02</td>
<td></td>
</tr>
<tr>
<td>JR Shikoku(1987~2003)</td>
<td>1.023</td>
<td>3.30</td>
<td>0.97</td>
<td>1.94</td>
<td>3.53</td>
<td>2.26</td>
<td></td>
</tr>
<tr>
<td>JR Kyushu(1987~2003)</td>
<td>1.056</td>
<td>12.04</td>
<td>3.84</td>
<td>4.29</td>
<td>2.22</td>
<td>5.62</td>
<td></td>
</tr>
<tr>
<td>JR freight(1987~2003)</td>
<td>1.021</td>
<td>3.05</td>
<td>1.69</td>
<td>2.11</td>
<td>1.59</td>
<td>2.12</td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>1.026</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.57</td>
</tr>
</tbody>
</table>

Table 5 provides a descriptive summary of the estimates of cost efficiency. These estimates

\(^{13}\) These results are consistent with the empirical results found by Cantos (2001).

\(^{14}\) Ida and Suda (2004) did not conclude that the main island JR’s had cost complementarities between Shinkansen and incumbent passenger services which were not significant even at 10% level.
represent the ‘relative’ excess costs compared to a minimum level that would have been achieved if the firm had operated as efficiently as the best practice observed in the sample. The average estimate of cost inefficiency is 2.57% for the total sample. On the average, JNR and JR Kyushu are found to be worst efficient while the most efficient railway firm in the sample is JR West. The cost inefficiency levels of JNR and JR Kyushu are 4.73% and 5.62%, respectively. Empirical results show that the cost efficiency levels of seven JRs have been improved after the reform and privatization of JNR.

### 4.4 TFP GROWTH

Technical change and its determinants are reported in Table 6. As far as technical change is concerned, the paper observes technical progress as a whole. The mean annual technical change over the full sample is -0.0054%. Neutral effect (T₁) of its determinants which led to the annual overall technical change is larger than non-neutral effect (T₂).

<table>
<thead>
<tr>
<th>Railway firms</th>
<th>$\varepsilon_{ct}$</th>
<th>$T_1$(neutral effect)</th>
<th>$T_2$(non-neutral effect)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNR(1977~2003)</td>
<td>-0.0040</td>
<td>-0.0034</td>
<td>-0.0006</td>
</tr>
<tr>
<td>JNR(1977~1984)</td>
<td>0.0011</td>
<td>0.0021</td>
<td>-0.0010</td>
</tr>
<tr>
<td>JR East(1987~2003)</td>
<td>-0.0061</td>
<td>-0.0064</td>
<td>0.0003</td>
</tr>
<tr>
<td>JR Central(1987~2003)</td>
<td>-0.0049</td>
<td>-0.0064</td>
<td>0.0015</td>
</tr>
<tr>
<td>JR West(1987~2003)</td>
<td>-0.0059</td>
<td>-0.0064</td>
<td>0.0005</td>
</tr>
<tr>
<td>JR Hokkaido(1987~2003)</td>
<td>-0.0045</td>
<td>-0.0064</td>
<td>0.0019</td>
</tr>
<tr>
<td>JR Shikoku(1987~2003)</td>
<td>-0.0058</td>
<td>-0.0064</td>
<td>0.0005</td>
</tr>
<tr>
<td>JR Kyushu(1987~2003)</td>
<td>-0.0074</td>
<td>-0.0064</td>
<td>-0.0011</td>
</tr>
<tr>
<td>JR freight(1987~2003)</td>
<td>-0.0126</td>
<td>-0.0064</td>
<td>-0.0062</td>
</tr>
<tr>
<td>average</td>
<td>-0.0054</td>
<td>-0.0054</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

Table 7 represents TFP growth and its determinants. TFP growth rates are negative in KNR, JNR, and JR Central and those of the other railway firms are all positive ranging from the highest in JR Kyushu (1.20%) to the lowest in JR Hokkaido (0.04%). KNR’s average annual TFP decreases during 1977-2003. The contributions of technical change and allocative efficiency change to KNR’s TFP growth (TFPG) are positive, these are 0.41% and 0.07%, respectively. But cost efficiency change and scale efficiency change contribute negatively to the mean annual TFP growth. Technical change is shown to have the greatest impact on TFP growth.

On 1 April 1987, JNR was privatized and divided into six regional passenger railways and one freight railway. TFP growth rates of JRs (except for JR Central) which are private enterprises are more productive than those of KNR and JNR, which are state-owned enterprises or public enterprises. Also, three-island JRs and JR Freight have slightly higher TFP growth than
Honshu JRs. TFP measure which is one of the key indicators of a business’s success reports how well railway firms perform at turning inputs into outputs. Thus, the results suggest that managerial autonomy and increased competition via deregulation have improved efficiency and TFP growth.

Table 7 TFP growth and its determinants

<table>
<thead>
<tr>
<th>Railway firms</th>
<th>CEC(%)</th>
<th>TC(%)</th>
<th>SEC(%)</th>
<th>AEC(%)</th>
<th>TFPG(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNR(1977~2003)</td>
<td>-0.02</td>
<td>0.41</td>
<td>-1.01</td>
<td>0.07</td>
<td>-0.54</td>
</tr>
<tr>
<td>JNR(1977~1984)</td>
<td>0.09</td>
<td>-0.11</td>
<td>0.65</td>
<td>-1.97</td>
<td>-1.34</td>
</tr>
<tr>
<td>JR East(1987~2003)</td>
<td>0.45</td>
<td>0.62</td>
<td>-0.82</td>
<td>0.15</td>
<td>0.40</td>
</tr>
<tr>
<td>JR Central(1987~2003)</td>
<td>-0.30</td>
<td>0.50</td>
<td>-0.24</td>
<td>-1.03</td>
<td>-1.07</td>
</tr>
<tr>
<td>JR West(1987~2003)</td>
<td>0.03</td>
<td>0.60</td>
<td>-0.36</td>
<td>0.09</td>
<td>0.36</td>
</tr>
<tr>
<td>JR Hokkaido(1987~2003)</td>
<td>-0.06</td>
<td>0.45</td>
<td>-0.37</td>
<td>0.01</td>
<td>0.04</td>
</tr>
<tr>
<td>JR Shikoku(1987~2003)</td>
<td>0.19</td>
<td>0.59</td>
<td>0.12</td>
<td>0.09</td>
<td>0.99</td>
</tr>
<tr>
<td>JR Kyushu(1987~2003)</td>
<td>0.57</td>
<td>0.76</td>
<td>-0.11</td>
<td>-0.01</td>
<td>1.20</td>
</tr>
<tr>
<td>JR freight(1987~2003)</td>
<td>0.00</td>
<td>1.26</td>
<td>-0.32</td>
<td>0.04</td>
<td>0.99</td>
</tr>
<tr>
<td>average</td>
<td>0.10</td>
<td>0.60</td>
<td>-0.38</td>
<td>-0.16</td>
<td>0.16</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

This paper investigated the vertical relationships between infrastructure provision and railway operations and analyzed the effects of privatization and deregulation on the firm-specific efficiency and TFP growth rates in the Korean and Japanese railways by estimating a generalized translog multiproduct variable cost function using a stochastic frontier approach. The paper then assumed that the Korean and Japanese railway firms produced three outputs (Shinkansen passenger-kilometers, incumbent railway passenger-kilometers, ton-kilometers of freight) using three input factors (labor, fuel, maintenance and rolling stock). A monetary value of the ways and fixed installations held by the railway firm was also included as quasi-fixed input.

The empirical results of this study indicate that there are cost complementarities between infrastructure provision and railway operations, but cost anticomplementarities between infrastructure and Shinkansen operation of JR Central. In addition, cost anticomplementarities between incumbent passenger-kilometers and freight ton-kilometers in the Korean railways and between Shinkansen and incumbent passenger passenger-kilometers in the Japanese railways exist. The findings also indicate that the firm-specific efficiency and TFP growth of the privately-owned JRs are higher than those of the government-owned KNR and JNR. Three-island JRs and JR Freight have slightly higher TFP growth than Honshu JRs as well.
There are some relevant weaknesses or subjects to take into account for future research. Firstly, infrastructure output is required to evaluate the relevance of the policy decision of whether infrastructure provision and railway operations should be separated directly. But this paper can not assess whether the transactions costs associated with vertical separation would be higher (or lower) than those of vertical integration directly since our sample included only vertically integrated firms. Secondly, one of the approaches to deal with the multiproduct nature of railway firms is generally to increase the number of outputs in a cost function since railway networks are characterized by a high level of output heterogeneity. KNR, JR East, JR West, and JR Central operate rail transit of the Seoul and Tokyo, Osaka, Nagoya metropolitan areas, respectively. So it is preferred to consider four outputs including rail transit passenger-kilometers separately in the cost function. Thirdly, unobserved firm-specific heterogeneity can be taken into account as an additional disturbance term in the stochastic frontier cost function. Finally, this paper needs to take profitability or the rate of return on assets into consideration overall to analyze the effects of the privatization or deregulation in addition to the productivity perspective.

REFERENCES


15 See Farsi et al. (2005) and Greene (2005).


