THE COST STRUCTURE OF THE JAPANESE RAILWAY INDUSTRY:
THE ECONOMIES OF NETWORK DENSITY AND OF SCOPE AND THE COST GAP BETWEEN JAPAN’S REGIONAL RAILWAYS AFTER PRIVATIZATION

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ABSTRACT:
It is said that the privatization of the Japanese National Railway is a success because management, productivity, and service have improved. However, as expected, the gap of both management and productivity tends to widen between the larger main island Japan Railway services (JRs) and the three smaller island JRs. In this paper, we examine the cost structure of the six JRs after the privatization. The main conclusions we reach are as follows: first, the economies of density exist in both the incumbent railway service and the Shinkansen service; second, there is no conclusive evidence to show that the economies of scope exist between them; third, the cost gap between the main island JRs and the three island JRs is large; and fourth, the cost gaps between the three island JRs are also large.

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1. INTRODUCTION

More than ten years have passed since the Japanese National Railway (JNR) was privatized and broken up. The privatization is in general evaluated as a success because management, productivity, and service have improved following the birth of the Japan Railway (JR) group. However, a problem which has accompanied privatization is the cost gap that now exists between the larger JRs operating on the main island of Japan and the smaller JRs operating on the three smaller islands. The railway industry has been considered to be one in which the economies of network density exist. It is, therefore, a matter of concern that the large difference in the density of the market leads to a cost gap between the main island JRs and the three island JRs. Furthermore, the cost gap may increase further if the economies of scope exist because only the main island JRs are at present operating the ‘Shinkansen’ (Bullet Train) service.

The aims of this paper are, first, to estimate the cost structure of the six passenger JRs, second, to test whether the economies of density and of scope exist, and third, to compare the marginal costs of the incumbent railway service and the Shinkansen service. The main conclusions we reach are as follows. First, the economies of density exist in both the incumbent railway service and the Shinkansen

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1 It is important to differentiate between the economies of network density and the economies of scale. The former are defined in terms of the relative increase in costs as the output is changed while physical network conditions essentially remain unchanged. The latter are defined as the relative increase in costs as the size of network is changed. See, for example, Caves et al. (1984, 1985). Interestingly, Mizutani (1994) concludes that the economies of density exist in the Japanese urban railway industry, but economies of scale do not. In this paper, we will focus on the economies of density because the size of the JR group’s railway network has not been expanded after privatization and thus verification of the economies of scale is a lesser issue.
service. Second, on the other hand, there is no conclusive evidence to show that the economies of scope exist between them\(^2\). Third, as expected, the cost gap between the main island JRs and the three island JRs is large. Fourth, furthermore, the cost gaps between the three island JRs are also large. The above results will provide an empirical foundation for policy discussion in the Japanese railway industry on such issues as the complete privatization of the main island JRs, the subsidy mechanism for the three island JRs, and the construction of further Shinkansen railway lines.

The paper consists of the following six sections. Section 2 briefly surveys the privatization and liberalization of the Japanese railway industry. Section 3 explains the method used for cost estimation and presents the result, while Section 4 carries out tests of the economies of density and of scope. Section 5 analyzes the different costs in each area, and Section 6 draws a conclusion.

2. AN OVERVIEW OF THE PRIVATIZATION OF THE JAPANESE NATIONAL RAILWAY

It would be helpful for non-Japanese researchers if first we summarize the privatization of the Japanese National Railway before moving on to the main subject of

\(^2\) Several studies have been made to test the economies of scope in the railway industry. For example, Kim (1987) dealt with the American railway industry while Preston (1996) studied the British railway industry. They found that the economies of scope did not exist between the passenger transportation service and the freight service. The originality of this paper lies in the fact that the economies of scope between two passenger transportation services, the incumbent railway service and the Shinkansen service, will be tested.
this paper. The explanation in this section owes much to Mizutani and Nakamura (2000) and Takeuchi (2000).

The Japanese railway service was inaugurated in 1872 and was basically nationalized in 1906. After the end of World War II, a public corporation called the Japanese National Railway (JNR) was established in 1949 and started to supply an affordable and available service in the public interest. It was in 1964 that two notable occurrences happened: the first is that JNR started the Shinkansen, or Bullet Train service; the second is that JNR began incurring operational deficits for the first time. The financial difficulties of JNR continued: the accumulated deficit reached 15.4 trillion yen while the long-term liabilities amounted to 25.5 trillion yen in 1986, just before privatization. This is because of the nature of a public corporation: fares could not be raised without approval by the Diet (Japanese Parliament) and the revisions were always delayed. In addition JNR faced intensified competition with automobiles and domestic airlines

On 1 April 1987, JNR was privatized and divided into six regional passenger railway companies, which are now collectively called the Japan Railway (JR) group. Three larger companies (JR East, JR Central, and JR West) are operating on the main

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4 Furthermore, we should point out that another reason for JNR’s financial situation was the concept of ‘Oyakata Hinomaru (Rising Sun as Patron)’, which essentially meant that the government (whose symbol is the rising sun) would take care of the company whatever the deficit became.
island of Japan (Honshu) whereas three smaller companies (JR Hokkaido, JR Shikoku, and JR Kyushu) are operating on the three smaller islands of Hokkaido, Shikoku, and Kyushu. The Shinkansen service is operated only by the main island JRs. Figure 1 displays the operating areas of the six passenger JRs and Table 1 depicts the average outputs of the incumbent railway service and the Shinkansen service since privatization, which are represented by “passenger-km”. At the same time, one freight company (JR Freight) and the JNR Settlement Corporation were established: JR Freight uses the other six JRs’ tracks and pays usage fees to them; the JNR Settlement Corporation was set up in order to supervise the handling of liabilities and redundant employees.

At present, privatization of JNR is regarded as a success for the following reasons. First, the JR group is now in the black and also operating other businesses (JNR was prohibited from operating other businesses). Second, productivity has improved drastically, the largest factor in which is thought to be the increase in labor productivity. Third, service qualities in such areas as frequency, travel time, and speed have also improved. On the other hand, some problems due to privatization have been found. To begin with, the long-term debt has not significantly decreased; it reached

\[ \text{The infrastructure was at first held by the Shinkansen Holding Corporation through the vertical separation of infrastructure from the operation of the Shinkansen. However, the assets were bought by the main island JRs and the Shinkansen Holding Corporation was dissolved in 1991.}\]
27.6 trillion yen in 1996. Nevertheless, a plan for the construction of further
Shinkansen railway services is still being proposed that would serve even lower density
areas such as Hokkaido, Tohoku, Hokuriku, and Kyushu. That this proposal is still on
the table is in part because politicians want the Shinkansen service for their
constituencies. Next, and more importantly for this paper, the cost gap between the
different regional Japanese passenger railway services has appeared to widen. It was
truly expected at the time of privatization that the main island JRs would gain
advantages and that the three island JRs would suffer from managerial problems
because their sizes and population densities were quite different. A lump-sum subsidy
scheme was established at the time of privatization by the Management Stability Fund
to solve this problem. The three island JRs have been subsidized by the interest
revenue of the Fund, but the amount of subsidy has tended to decrease because of
Japan’s low interest rate policy instituted in the 1990s.

3. ESTIMATION OF THE COST FUNCTION

This section explains the estimation model of the cost function. JR East, JR

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6 At first, most of long-term debt had been the responsibility of the JNR Settlement
Corporation, but in 1998 it was taken over by general account and the JNR Settlement
Corporation was dissolved.

7 In many cases, unprofitable incumbent railway services are abolished instead of
Shinkansen lines being constructed, or a quasi-public sector company, such as a joint
venture between local governments and private companies, is established to take over
the unprofitable services.

8 Originally, there used to be no fare differences within the JR group because it imposed
a uniform tariff policy. However, due to the decrease in interest revenue from the
Fund, the three island JRs decided to increase fares by 6-7% in 1996.
Central, and, JR West are operating Shinkansen services, whereas JR Hokkaido, JR Shikoku, and JR Kyushu are not. Accordingly, we estimate their costs separately, assuming a two-output model for the main island JRs and a one-output model for the three island JRs.

3.1. Estimation of the two-output model for the main island JRs

This section explains the estimation model for the main island JRs. The data used here are extracted from the Statement of Income and Finance Reports of the main island JRs published for each fiscal year (1987-1999). We also use the Monthly Price Index Report by the Bank of Japan for the price index of the capital goods and the Monthly Economic Statistics Report by the Bank of Japan for the interest rate of the government guaranteed bonds.

We assume here a cost function that consists of three inputs’ prices of labor force, material, and capital, and two outputs of incumbent railway and Shinkansen as follows:

\[ C = C(P_L, P_M, P_K, Y_1, Y_2), \]

The reason for separate estimations is that the three island JRs do not run a Shinkansen service but the translog cost function does not admit a zero value. One possible alternative method is to adopt the generalized translog cost function that carries out the Box-Cox transformation. The Box-Cox transformation defines output as \( Y_i = (Y_i^{\theta} - 1) / \theta \), which becomes linear in the case of \( \theta = 1 \) and logarithmic in the case of \( \theta = 0 \). At first, we tried to perform the Box-Cox transformation with the pooled data of the six JRs. However, we abandoned this approach because the value of \( \theta \) did not converge and the model was not therefore appropriate.
given $P_L$=the labor price, $P_M$=the material price, $P_K$=the capital price, $Y_1$=the incumbent railway service, and $Y_2$=the Shinkansen service.

Furthermore, we suppose the cost function to be a translog cost function, which is known as a type of flexible cost function.

\[
\ln C = \alpha_f + \sum_{i=L,M,K} \alpha_i \ln P_i + \frac{1}{2} \sum_{i=L,M,K} \sum_{j=L,M,K} \beta_{ij} \ln P_i \ln P_j + \sum_{k=1,2} Y_k \ln Y_k
\]

\[
+ \frac{1}{2} \sum_{k=1,2} \sum_{l=1,2} \delta_{kl} \ln Y_k \ln Y_l + \sum_{i=L,M,K} \sum_{k=1,2} \rho_{ik} \ln P_i \ln Y_k
\]

(2)

Note: $\alpha_f$ ($f=E, C, W$) represents the constant term of each company\(^{10}\).

The three inputs’ prices are defined as follows:

$P_L$: the labor price = the real personnel expenses / the number of employees at the end of the fiscal year;

$P_M$: the material price = the real non-personnel expenses / the number of vehicle-km;

$P_K$: the capital price = the price index of the capital goods (the interest rate of the government guaranteed bonds + the rate of depreciation),

given the rate of depreciation = the depreciation expenses / the equipment expenses at the beginning of the fiscal year.

The two outputs are defined as follows:

$Y_1$: the incumbent railway service (passenger-km);

$Y_2$: the Shinkansen service (passenger-km).

\(^{10}\) Since the fixed effect model with panel data is adopted here, the estimated coefficient $\alpha_f$ represents what is called the ‘firm-specific effect’. For further discussion, see Baltagi (1996) and Hsiao (1986).
Furthermore, we assume the following constraints of linear homogeneity with regard to input prices in advance:

$$\sum_{i=L,M,K} a_i = 1, \quad \sum_{j=L,M,K} \beta_{ij} = \sum_{j=L,M,K} \rho_{jk} = 0.$$  \hspace{1cm} (3)

At the same time, we assume the following symmetry of second-order partial derivatives with regard to input prices:

$$\beta_{ij} = \beta_{ji}.$$ \hspace{1cm} (4)

From Shepherd’s lemma, the share equations of inputs (i=L,M,K) are obtained as follows:

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{\partial \ln P_i}{\partial C} \frac{P_i X_i}{C} = \alpha_i + \sum_{j=L,M,K} \beta_{ij} \ln P_j + \sum_{k=1,2} \rho_k \ln Y_k.$$ \hspace{1cm} (5)

The total cost that is the explained variable is the sum of the real personnel expenses, the real material cost, and the real capital cost. The capital cost is defined as the product of the capital stock and the capital price, and the capital stock is defined as follows:

- the capital stock = \((1 - \text{the rate of depreciation}) \times \text{the capital stock at the previous term} + \text{the real gross investment},

- given the real gross investment = \text{the amount of annual change of the fixed assets} + \text{the depreciation expenses}.

We can now estimate the simultaneous equations of the translog cost function, with the constraints of linear homogeneity and second-order symmetry, and the share
equations of labor and material by the maximum likelihood (ML) method\(^\text{11}\).

### 3.2. Estimation of the one-output model for the three island JR\(\)s

This section explains the estimation model for the three island JR\(\)s. The data used here are extracted from the Statement of Income and Finance Reports of the three island JR\(\)s published for each fiscal year (1987-1999). We assume here a cost function that consists of three inputs’ prices of labor force, material, and capital and one output of the incumbent railway service as follows:

\[
C = C(P_L, P_M, P_K, Y_1), \quad (6)
\]

given \(P_L = \)the labor price, \(P_M = \)the material price, \(P_K = \)the capital price, and \(Y_1 = \)the incumbent railway service.

The cost function to be estimated is given as follows:

\[
\ln C = f + \sum_{i=L,M,K} \alpha_i \ln P_i + \frac{1}{2} \sum_{i=L,M,K} \sum_{j=L,M,K} \beta_{ij} \ln P_i \ln P_j \\
+ \gamma \ln Y_1 + \frac{1}{2} \delta \ln Y_1^2 + \sum_{i=L,M,K} \rho_i \ln P_i \ln Y_1. \quad (7)
\]

Note: \(\alpha_i (i=H, S, K)\) represents the constant term of each company.

From Shepherd’s lemma, the share equations of inputs \((i=L,M,K)\) are obtained as follows:

\[
\frac{\partial \ln C}{\partial \ln P_i} = \frac{\partial C}{\partial P_i} \frac{P_i}{C} = \frac{P_i X_i}{C} = \alpha_i + \sum_{j=L,M,K} \beta_{ij} \ln P_j + \rho_i \ln Y_1. \quad (8)
\]

We can now estimate the simultaneous equations in the same way as in the previous section 3.1 by the maximum likelihood (ML) method.

\(^{11}\) Since the sum of the three share equations must be one, one of them can be dropped.
3.3. Results of the estimations

This section presents the results of the estimations. Tables 2 and 3 display the results of the estimations of the cost functions of the main island JRs and the three island JRs, respectively. The standard errors are parenthetically represented. The results are quite good12.

< Tables 2 and 3>

4. TEST OF THE ECONOMIES OF DENSITY AND OF SCOPE

In this section we move on to verify the economies of density and of scope, based on the above results of the estimations.

4.1. Definitions of the economies of density and of scope

First, the product-specific economies of density are originally defined as follows:

\[
\frac{\partial C(Y_1, Y_2)}{\partial Y_1} \times \frac{Y_1}{(C(Y_1, Y_2) - C(0, Y_2))} \\
\frac{\partial C(Y_1, Y_2)}{\partial Y_2} \times \frac{Y_2}{(C(Y_1, Y_2) - C(Y_1, 0))}.
\]

(9)

If these figures are lower (higher) than 1, the product-specific economies

12 It must be noted that since the panel data covers a large number of years, the problem of auto-correlation might occur.
(diseconomies) of density exist. However, as previously stated in this paper, since the translog functional form does not admit $C(0, Y_2)$ and $C(Y_1, 0)$, the economies of density cannot be verified directly\(^{13}\). Hereafter, the following indices will be used:

$$DENSITY(Y_1) = \frac{\partial \ln C(Y_1, Y_2)}{\partial \ln Y_1}$$
$$DENSITY(Y_2) = \frac{\partial \ln C(Y_1, Y_2)}{\partial \ln Y_2}. \quad (10)$$

In the cases of $DENSITY(Y_1)<1(>1)$ and $DENSITY(Y_2)<1(>1)$, it can be said that the product-specific economies (diseconomies) of density exist\(^{14}\).

Second, the economies of scope are originally defined as follows:

$$\frac{[C(Y_1, 0) + C(0, Y_2) - C(Y_1, Y_2)]}{C(Y_1, Y_2)}. \quad (11)$$

If this figure is positive (negative), the economies (diseconomies) of scope exist. However, since the translog functional form does not admit $C(0, Y_2)$ and $C(Y_1, 0)$, the economies of scope cannot be verified directly. Hereafter, the following index, which is called the weak complementarities of cost, will be used:

$$SCOPE = \frac{\partial^2 C(Y_1, Y_2)}{(\partial Y_1 \partial Y_2)}. \quad (12)$$

In the case of $SCOPE<0(>0)$, the weak complementarities of cost exist (do not exist). This nature of cost is a sufficient condition for the existence of the economies of scope.

4.2. Results of the test of the economies of density and of scope

To begin with, we investigate the economies of density of the main island JRs.

\(^{13}\) See Baumol, Panzar and Willig (1982) for further discussions of the economies of density and of scope.

\(^{14}\) Note $\frac{\partial \ln C(Y_1, Y_2)}{\partial \ln Y_k} = [\frac{\partial C(Y_1, Y_2)}{\partial Y_k}] \times [\frac{Y_k}{C(Y_1, Y_2)}]$. 

12
Table 4 shows the result of the test. First, the economies of density exist in the incumbent railway service for the average value of the main island JRs (1987-1999) in that DENSITY(Y₁)<1 holds. Second, the economies of density exist in the Shinkansen service for the average value of the main island JRs (1987-1999) because DENSITY(Y₂)<1 holds. Standard errors of DENSITY(Y₁) and DENSITY(Y₂) are both small, therefore the result of the test is reliable. As we verify the null hypotheses that DENSITY(Y₁) and DENSITY(Y₂) are 1 for the average value of the main island JRs (1987-1999) with the Wald test, we can reject these null hypotheses at the 1% statistically significant level, because the values of $\chi^2$ are 96.766 (the p-value is 0.000) and 8.470 (the p-value is 0.004) respectively. Consequently, the main island JRs have the economies of density for both the incumbent railway service and the Shinkansen service on the average values (1987-1999).

<Table 4>

However, it may be that the average values are not important because the cost structures are very different between JR East and JR West, whose incumbent services are large but whose Shinkansen services are small, and JR Central, whose incumbent service is small but whose Shinkansen service is large. At this point, we investigate the characteristic of each company. For JR East, as we carry out the Wald test concerning the null hypotheses that DENSITY(Y₁) and DENSITY(Y₂) are 1, we can reject these null hypotheses at the 1% statistically significant level because the values of $\chi^2$ are 8.915 (the p-value is 0.003) and 50.567 (the p-value is 0.000), respectively. Similarly, for JR West, we can reject the null hypotheses at the 1% statistically
significant level because the values of $\chi^2$ are 167.101 (the p-value is 0.000) and 50.034 (the p-value is 0.000), respectively. On the other hand, for JR Central, we can reject the null hypotheses for the incumbent service at the 1% statistically significant level because the value of $\chi^2$ is 39.516 (the p-value is 0.000), but we cannot reject the null hypotheses for the Shinkansen service even at the 10% statistically significant level because the value of $\chi^2$ is 0.965 (the p-value is 0.326). Thus, we can conclude that the economies of density have disappeared in the case of the Shinkansen service of JR Central.

Next, we investigate the economies of scope of the main island JRs, as shown in Table 4. The economies of scope appear to exist for the average values of the main island JRs (1987-1999) in that $\text{SCOPE}<0$ holds. However, this figure is quite small in comparison with the standard error. As we carry out the Wald test concerning the null hypotheses that SCOPE is 0, we cannot reject the null hypotheses even at the 10% statistically significant level, because the value of $\chi^2$ is 0.283 (the p-value is 0.594). Thus we do not have conclusive evidence to show that the main island JRs have the economies of scope on the average values (1987-1999).

Again, it may be that the average values are not important because the cost structures are very different between JR East, JR West, and JR Central. In fact, SCOPE is negative only for JR Central, while they are positive for JR East and JR West. As we carry out the Wald test concerning the null hypotheses that SCOPE is 0, we cannot reject the null hypotheses even at the 10% statistically significant level because the value of $\chi^2$ is 0.437 (the p-value is 0.509) for JR Central, 0.124 (the p-value is
0.724) for JR East, and 0.605 (the p-value is 0.437) for JR West. Consequently, we cannot say whether the economies of scope or the diseconomies of scope exist.

Finally, we look at the economies of density of the three island JRs. Table 5 shows the result of the test. The economies of density exist for the incumbent railway service in that $DENSITY(Y_i) < 1$ holds for all three, JR Hokkaido, JR Shikoku, and JR Kyushu after privatization. We can confirm all these conclusions by carrying out the Wald test.

<Table 5>

To sum up, on the one hand, the economies of density exist for both the incumbent railway service and the Shinkansen service, which presumably leads to the different costs in each region. The only exception is the Shinkansen service of JR Central, whose economies of density have almost disappeared. On the other hand, since there is no conclusive proof to show that the economies of scope exist, we cannot be absolutely certain that the additional provision of the Shinkansen service would decrease the cost of providing the incumbent railway service.

5. THE COST GAP BETWEEN THE SIX REGIONAL JRS

In this section, based on the results of the estimation, the marginal costs of each output, $\partial C(P_L, P_M, P_K, Y_1, Y_2)/\partial Y_i$, are calculated to compare the six JRs. First, the upper row of Table 6 shows the marginal costs of the incumbent railway service of five
JRs, excluding JR Central for which a reliable estimate cannot be obtained\textsuperscript{15}. The marginal costs of the incumbent railway service of JR East and JR West, which both own Shinkansen, are about 6-7 yen. On the other hand, the marginal costs of JR Hokkaido, JR Shikoku and JR Kyushu, which do not own Shinkansen services, are considerably different. The marginal cost of JR Shikoku is very high (about 11 yen), while that of JR Kyushu is very low (about 5 yen, which is in fact lower than the figures of JR East and JR West). At any rate, we can see that there is a large cost gap according to region for the incumbent service because of the different densities of the six JRs at the time of privatization. It is noteworthy that JR East, which is by far and away the largest company in terms of the incumbent service, is not necessarily operating at the least cost level. One reason for this is that JR East has to cover low-density areas such as Tohoku as well as the Tokyo metropolitan area. Another reason is probably that the economies of scope are not strong between the incumbent railway and the Shinkansen services. In addition, our new observation is that the difference in the cost gap between the three island JRs is large. This means that we cannot discuss their management problems in the same way because their cost structures are so different.

Next, the lower row of Table 6 shows the marginal costs of the Shinkansen service of the main island JRs. The marginal costs of the Shinkansen service of JR East and JR West are similar; about 10-11 yen, respectively. A noteworthy fact is that

\textsuperscript{15} The value of JR Central is negative because the monotonicity condition with regard to the output of the incumbent railway service is not satisfied. This is probably because the output of the incumbent railway service of JR Central is so small that the estimated model is not suitable for this area. However, it should be noted that such an anomaly is not observed in other samples.
the marginal cost of the Shinkansen service of JR Central, which connects the three metropolises of Tokyo, Nagoya, and Osaka, is low (about 9 yen), as compared with those of JR East and JR West. This still means that there is a cost gap for the Shinkansen service between high-density and low-density areas.

6. CONCLUSION

This paper has examined the cost structure of the six regional passenger JRs after privatization. As a result, we have found that the economies of density exist while the economies of scope do not always exist. Furthermore, as expected, there are cost gaps not only between the main island JRs and the three island JRs, but also between the three island JRs. Thus, we have empirically observed cost gap between the regional divisions of the JR group after privatization. Some problems have been left unanswered. First, this paper focused on the aspect of cost structure. We also need to take account of the aspects of demand and revenue. Furthermore, we should consider the competition of the JR group with other railway companies. Finally, the competition between railway, motorcar, and airplane must be taken into consideration. We are fully aware of the questions stated above and consider them to be subjects for future research.

REFERENCES

of Industrial Structure, Harcourt Brace and Jovanovich.


Mizutani, F. and K. Nakamura, 1997, “Privatization of the Japan National Railway:


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<tr>
<th></th>
<th>Hokkaido</th>
<th>East</th>
<th>Central</th>
<th>West</th>
<th>Shikoku</th>
<th>Kyushu</th>
<th>Average</th>
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<tr>
<td>Incumbent railway</td>
<td>4595.23</td>
<td>107034.49</td>
<td>9597.85</td>
<td>37572.31</td>
<td>1968.69</td>
<td>8277.92</td>
<td>28174.42</td>
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<td>15604.58</td>
<td>39172.23</td>
<td>14904.46</td>
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<td>23227.09</td>
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Note. output: $10^6$ passenger-km
### TABLE 2  The result of the estimation of the main-island JRs

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<th>Coefficient</th>
<th>$\alpha_i$</th>
<th>$\alpha_m$</th>
<th>$\beta_{1k}$</th>
<th>$\beta_{1m}$</th>
<th>$\beta_{2k}$</th>
<th>$\beta_{2m}$</th>
<th>$\gamma_i$</th>
<th>$\gamma_m$</th>
<th>$\delta_{11}$</th>
<th>$\delta_{12}$</th>
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<tr>
<td>Estimate</td>
<td>0.39617</td>
<td>0.04906</td>
<td>-0.14923</td>
<td>-0.00684</td>
<td>-0.01202</td>
<td>0.50915</td>
<td>0.38728</td>
<td>0.32550</td>
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<tr>
<td>Standard error</td>
<td>0.01159 **</td>
<td>0.00142 **</td>
<td>0.02588 **</td>
<td>0.00335 **</td>
<td>0.00354 **</td>
<td>0.04990 **</td>
<td>0.21053 *</td>
<td>0.10057 **</td>
<td>0.10141</td>
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<tr>
<th>Coefficient</th>
<th>$\delta_{22}$</th>
<th>$\rho_{1m}$</th>
<th>$\rho_{1k}$</th>
<th>$\rho_{2m}$</th>
<th>$\rho_{2k}$</th>
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<th>$\alpha_t$</th>
<th>$\alpha_w$</th>
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<tbody>
<tr>
<td>Estimate</td>
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<td>-0.01298</td>
<td>0.04241</td>
<td>-0.04846</td>
<td>0.42154</td>
<td>-0.05020</td>
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<tr>
<td>Standard error</td>
<td>0.48049</td>
<td>0.00210 **</td>
<td>0.01717 **</td>
<td>0.00592 **</td>
<td>0.04320 **</td>
<td>0.03590</td>
<td>0.06436</td>
<td>0.05334</td>
</tr>
</tbody>
</table>

Note 1. the cost function $R^2=0.93705$ / the labor share $R^2=0.87614$ / the material $R^2=0.92384$

Note 2. **statistical significance at the 5% level, *statistical significance at the 10% level
<table>
<thead>
<tr>
<th>Coefficient</th>
<th>$\alpha$</th>
<th>$\alpha_m$</th>
<th>$\beta_{ik}$</th>
<th>$\beta_{mk}$</th>
<th>$\beta_m$</th>
<th>$\gamma_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimate</td>
<td>0.63251</td>
<td>0.09000</td>
<td>-0.18495</td>
<td>-0.01293</td>
<td>-0.01012</td>
<td>0.40290</td>
</tr>
<tr>
<td>Standard error</td>
<td>0.00597 **</td>
<td>0.00102 **</td>
<td>0.01024 **</td>
<td>0.00176 **</td>
<td>0.00144 **</td>
<td>0.09350 **</td>
</tr>
<tr>
<td>Coefficient</td>
<td>$\delta_{11}$</td>
<td>$\rho_{1m}$</td>
<td>$\rho_{1k}$</td>
<td>$\alpha_1$</td>
<td>$\alpha_5$</td>
<td>$\alpha_k$</td>
</tr>
<tr>
<td>Estimate</td>
<td>-0.16732</td>
<td>0.01093</td>
<td>-0.03535</td>
<td>0.18253</td>
<td>-0.42373</td>
<td>0.18405</td>
</tr>
<tr>
<td>Standard error</td>
<td>0.26065</td>
<td>0.00130 **</td>
<td>0.00799 **</td>
<td>0.01518 **</td>
<td>0.11497 **</td>
<td>0.07227 **</td>
</tr>
</tbody>
</table>

Note 1. the cost function $R^2=0.972401$ the labor share $R^2=0.77567$ the raw material $R^2=0.87667$

Note 2. **statistical significance at the 5% level, *statistical significance at the 10% level
<table>
<thead>
<tr>
<th></th>
<th>East</th>
<th>Central</th>
<th>West</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Density economies of Incumbent railway</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.76613</td>
<td>-0.06795</td>
<td>0.43825</td>
<td>0.50915</td>
</tr>
<tr>
<td><strong>Standard error</strong></td>
<td>0.07833 **</td>
<td>0.16989</td>
<td>0.04346 **</td>
<td>0.04990 **</td>
</tr>
<tr>
<td><strong>Dcale economies of Shinkansen</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.15241</td>
<td>0.64242</td>
<td>0.28620</td>
<td>0.38728</td>
</tr>
<tr>
<td><strong>Standard error</strong></td>
<td>0.11919 **</td>
<td>0.36407 *</td>
<td>0.10091 **</td>
<td>0.21053 **</td>
</tr>
<tr>
<td><strong>Scope economies</strong></td>
<td>0.06282</td>
<td>-0.09760</td>
<td>0.07148</td>
<td>-0.05395</td>
</tr>
<tr>
<td><strong>Standard error</strong></td>
<td>0.17814</td>
<td>0.14765</td>
<td>0.09191</td>
<td>0.10141</td>
</tr>
</tbody>
</table>

Note. **statistical significance at the 5% level, *statistical significance at the 10% level**
<table>
<thead>
<tr>
<th>Density economies of Incumbent railway</th>
<th>Hokkaido</th>
<th>Shikoku</th>
<th>Kyushu</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.41697</td>
<td>0.55608</td>
<td>0.31461</td>
<td>0.40290</td>
</tr>
<tr>
<td>Standard error</td>
<td>0.09074 **</td>
<td>0.23499 **</td>
<td>0.18188 **</td>
<td>0.09350 **</td>
</tr>
</tbody>
</table>

Note. **statistical significance at the 5% level, *statistical significance at the 10% level
<table>
<thead>
<tr>
<th></th>
<th>Hokkaido</th>
<th>East</th>
<th>Central</th>
<th>West</th>
<th>Shikoku</th>
<th>Kyushu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incumbent railway</td>
<td>8.8536</td>
<td>7.5395</td>
<td>n.a.</td>
<td>6.6698</td>
<td>10.9870</td>
<td>4.9686</td>
</tr>
<tr>
<td>Shinkansen</td>
<td>10.288</td>
<td>9.3868</td>
<td>10.9801</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

Note. unit: yen /passenger-km
FIGURE 1 The six passenger JRs

(1) Hokkaido
(2) East (Tohoku/Jyoetsu/Ngano-Shinkansen)
(3) Central (Tokaido-Shinkansen)
(4) West (Sanyo-Shinkansen)
(5) Shikoku
(6) Kyusyu