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Analysis of Effects of Vertical Structure on Costs of Regional Railways in Japan

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Main Purpose of This Study

- **The first point** is to analyze how the type of vertical separation and the competitive situation affect costs.
- Previous research such as Mizutani and Uranishi (2013) and Mizutani et al. (2015), which used econometric methods to analyze railway company data in Europe and East Asia, have shown that the desirable type of vertical structure can be determined by the degree of train density.
- However, as the series of analyses was centered on large-scale intercity railways, it has not yet been verified whether these results will hold with urban railways.
- Specifically, we analyze: (i) whether cost-effective vertical structure types, as revealed in previous studies, can be explained in the same way by train density in the local railway market, and (ii) to what extent other factors related to the railway industry (ownership type, size of railways, regulatory policy, competitive conditions) affect costs.

Main Purpose of This Study

- **The second point** is related to one important issue in the local railway industry in Japan. In Japan, the sustainability of railway service in local areas is a critical policy issue.
- The policy proposals describe a system in which management is carried out by collaboration not only with railway operators but also with local governments along the railway lines. One option for collaboration might be selection of vertical separation and a change in ownership.
- In this study, by using the estimated cost function, we explore possibilities to resolve the management difficulties of local railways. Specifically, by using the estimated cost function, we simulate (i) how much vertical separation and an ownership change can reduce the costs of a railway organization, and (ii) whether or not the vertical separation and/or an ownership change can resolve the management problems which local railway organizations have recently faced.

Cost Models

(Cost Function):

$$lnTC = \alpha_0 + \alpha_Q lnQ_p + \sum_j \beta_j lnw_j + \gamma_N lnN + \tau_T lnT + \frac{1}{2}\alpha_{QQ}\left(lnQ_p\right)^2 + \sum_j \alpha_{Qj}\left(lnQ_p\right)\left(lnw_j\right) + \alpha_{QN}\left(lnQ_p\right)(lnN) + \alpha_{QT}\left(lnQ_p\right)(lnT) + \frac{1}{2}\sum_k \sum_j \beta_{jk}\left(lnw_j\right)(lnw_k) + \sum_j \beta_{jN}\left(lnw_j\right)(lnN) + \sum_j \beta_{jT}\left(lnw_j\right)(lnT) + \frac{1}{2}\gamma_{NN}(lnN)^2 + \gamma_{NT}(lnN)(lnT) + \frac{1}{2}\tau_{TT}(lnT)^2 + (\delta_{VS} + \delta_{VSV} lnV)D_{VS} + \delta_{MIX}D_{MIX} + \delta_m CPFC_m + \theta_{TUN} lnTUN \qquad (1)$$

where TC: total cost, Q_p: passenger output, w_j: input factor price (j (or k)) = L (labor), E (energy), M (material), K (capital)), N: total route length, TUN: tunnel ratio, T : technology index (percentage of electrified length), V: train density, D_{VS}: vertical separation dummy (vertical separation = 1, otherwise = 0), D_{MIX}: private-public ownership dummy, $CPFC_m$: competition factor ($CPFC_m = D_{COR}$ $(core\ city\ dummy)$ for $m = COR$, $lnCOMP$ $(rail\ share)$ for $m = COMP$).

(Input Share Equations)

$$S_j = \alpha_{Qj}\left(lnQ_p\right) + \sum_k \beta_{jk}(lnw_k) + \beta_{jN}(lnN) + \beta_{jT}(lnT) \qquad (2)$$

where S_j: input j's share of total cost ($j = L, E, M, K$).

Summary of Cases of Estimation

Case	Case 1	Case 2	Case 3	Case 4
Vertical Structure	Vertical Separation Dummy (D_{VS})	Vertical Separation Dummy (D_{VS})	Vertical Separation Dummy (D_{VS})	Vertical Separation Dummy (D_{VS})
Ownership	Public-private Joint Ownership Dummy (D_{MIX})	Public-private Joint Ownership Dummy (D_{MIX})	Public-private Joint Ownership Dummy (D_{MIX})	Public-private Joint Ownership Dummy (D_{MIX})
Competition Factor	Urban Dummy (D_{COR})	Share of Rail Transportation ($COMP$)	Urban Dummy (D_{COR})	Share of Rail Transportation ($COMP$)
Considering Percentage of Tunnel	With	With	Without	Without

Data

- Initially, we attempted to include all kinds of urban railways, including large private railways and public subway systems in Japan. However, in Japan vertical separation has been enacted only in small railway organizations. If we included large railway organizations, the estimation result might lead to the wrong conclusion.
- Therefore, we limited our study to railway organizations with less than 200 train density.
- We collected data on 103 railway organizations in Japan for the 17 years from 2003 to 2019, giving us 1,532 observations.

Statistics of Variables Used for the Estimation

Variable	Definition	Unit	Mean	Standard Deviation	Minimum	Maximum
TC (total cost)	Sum of labor, energy, material and capital cost	1000 yen	1,451,513	1,964,457	51,069	14,221,700
Q_p (passenger output)	Passenger-km	1000 km	43,677	75,919	179	524,032
w_L (wage)	Labor costs per employee	1000 yen	5,239	1,329	1,826	11,572
w_E (energy price)	Energy price per 1000TOE	1000 yen	141	62	14	393
w_M (material price)	Material costs per rolling stock	1000 yen	20,358	27,242	1,592	210,875
w_K (capital price)	Capital costs per route length	1000 yen	14,252	31,900	30	252,673
N (total route length)	Total route km	km	38.3587	29.9067	2.2000	163.0000
T (technology index)	Percentage of electrified line	%	53.6321	49.2127	0.0100	100.0100
V (train density)	Train-km per route length per day	-	69.1240	44.2155	9.8793	199.5814

Statistics of Variables Used for the Estimation

Variable	Definition	Unit	Mean	Standard Deviation	Minimum	Maximum
D_{VS} (vertical separation)	Vertical separation dummy	-	0.0646	0.2459	0.0000	1.0000
D_{MIX} (private-public ownership)	Private and public joint ownership dummy	-	0.5209	0.4997	0.0000	1.0000
D_{COR} (core city)	Core city dummy	-	0.3982	0.4897	0.0000	1.0000
$COMP$ (competition)	Share of rail to all transport modes	%	6.4769	7.7969	0.0100	43.4100
TUN (tunnel ratio)	Percentage of tunnel length	%	8.0390	15.6992	0.0100	97.0233
S_L (share of labor)	Share of labor input expenditure	-	0.4354	0.1224	0.0293	0.7926
S_E (share of energy)	Share of energy expenditure	-	0.0622	0.0284	0.0027	0.1828
S_M (share of material)	Share of material expenditure	-	0.3230	0.1398	0.0097	0.8696
S_K (share of capital)	Share of capital expenditure	-	0.1794	0.1499	0.0006	0.9583

Estimation Results: Coefficients and Standard Errors

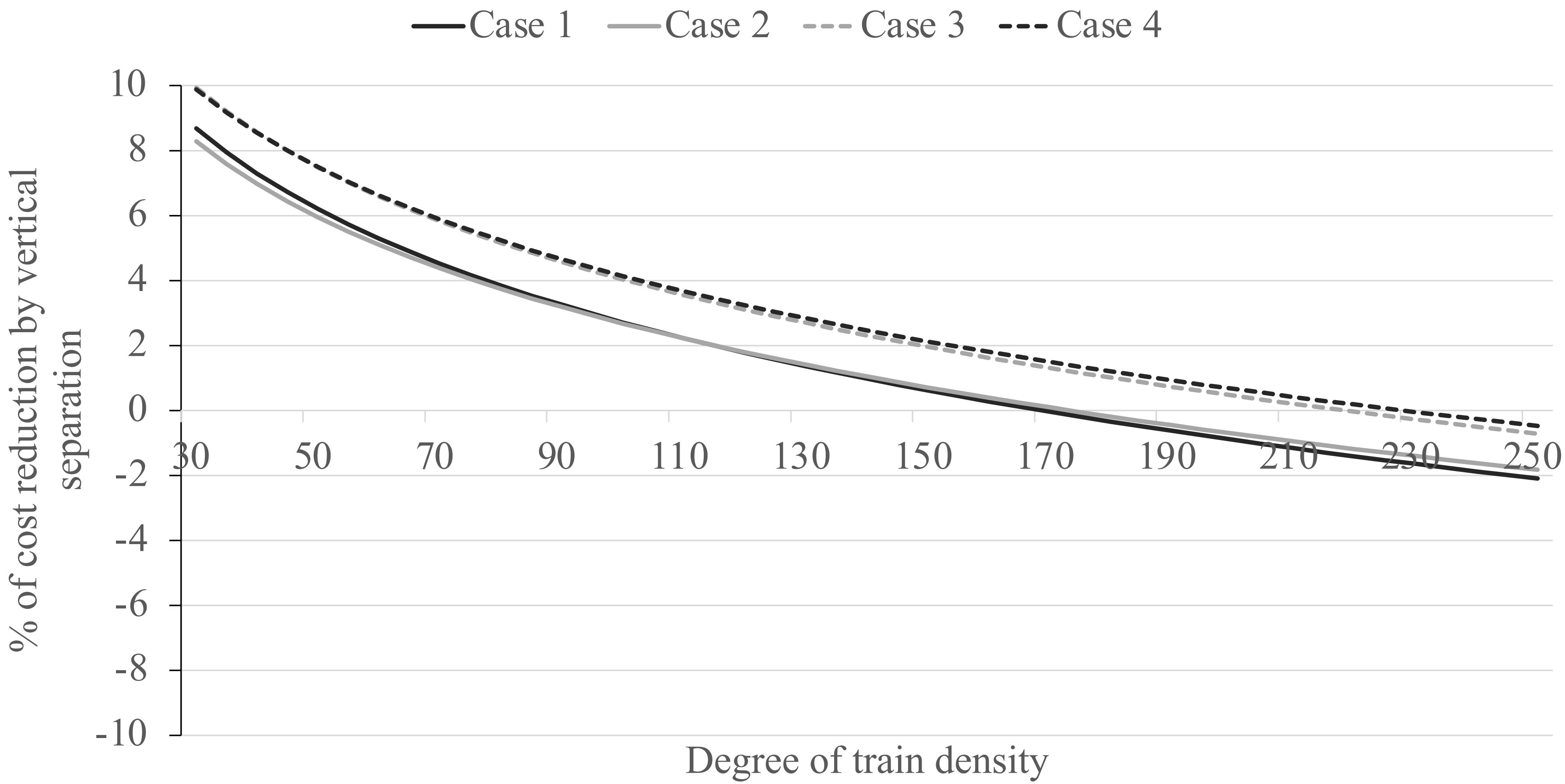
Case	Case 1	Case 2	Case 3	Case 4
C_0	14.5347^{***} (0.0256)	14.5447^{***} (0.0251)	14.5202^{***} (0.0246)	14.5304^{***} (0.0244)
α_Q	0.3520^{***} (0.0093)	0.3638^{***} (0.0093)	0.3520^{***} (0.0093)	0.3634^{***} (0.0093)
β_L	0.3450^{***} (0.0034)	0.3453^{***} (0.0034)	0.3443^{***} (0.0033)	0.3446^{***} (0.0033)
β_E	0.0669^{***} (0.0018)	0.0669^{***} (0.0018)	0.0664^{***} (0.0018)	0.0664^{***} (0.0018)
β_M	0.2941^{***} (0.0043)	0.2933^{***} (0.0043)	0.2949^{***} (0.0043)	0.2944^{***} (0.0043)
β_K	0.2941^{***} (0.0031)	0.2944^{***} (0.0031)	0.2943^{***} (0.0031)	0.2946^{***} (0.0031)
γ_N	0.4770^{***} (0.0141)	0.4629^{***} (0.0141)	0.4824^{***} (0.0139)	0.4696^{***} (0.0138)
τ_T	-0.1087^{***} (0.0330)	-0.1076^{***} (0.0331)	-0.1131^{***} (0.0331)	-0.1133^{***} (0.0331)
δ_{VS}	-0.0469^{*} (0.0269)	-0.0453^{*} (0.0269)	-0.0606^{**} (0.0263)	-0.0612^{**} (0.0264)
δ_{VSV}	0.0526 (0.0371)	0.0493 (0.0375)	0.0527 (0.0372)	0.0513 (0.0376)

Case	Case 1	Case 2	Case 3	Case 4
δ_{MIX}	-0.2416^{***} (0.0138)	-0.2470^{***} (0.0139)	-0.2359^{***} (0.0135)	-0.2401^{***} (0.0136)
δ_{COR}	0.0277^{**} (0.0127)	-	0.0299^{**} (0.0127)	-
δ_{COMP}	-	-0.0078 (0.0070)	-	-0.0056 (0.0069)
θ_{TUN}	0.0038^{**} (0.0019)	0.0045^{**} (0.0019)	-	-
Log of likelihood	7.569	6.962	5.675	4.711
Pseudo R^2	0.951	0.952	0.952	0.952
Concavity condition	55.09%	55.16%	54.96%	54.96%
Numbers of observations	1532	1532	1532	1532

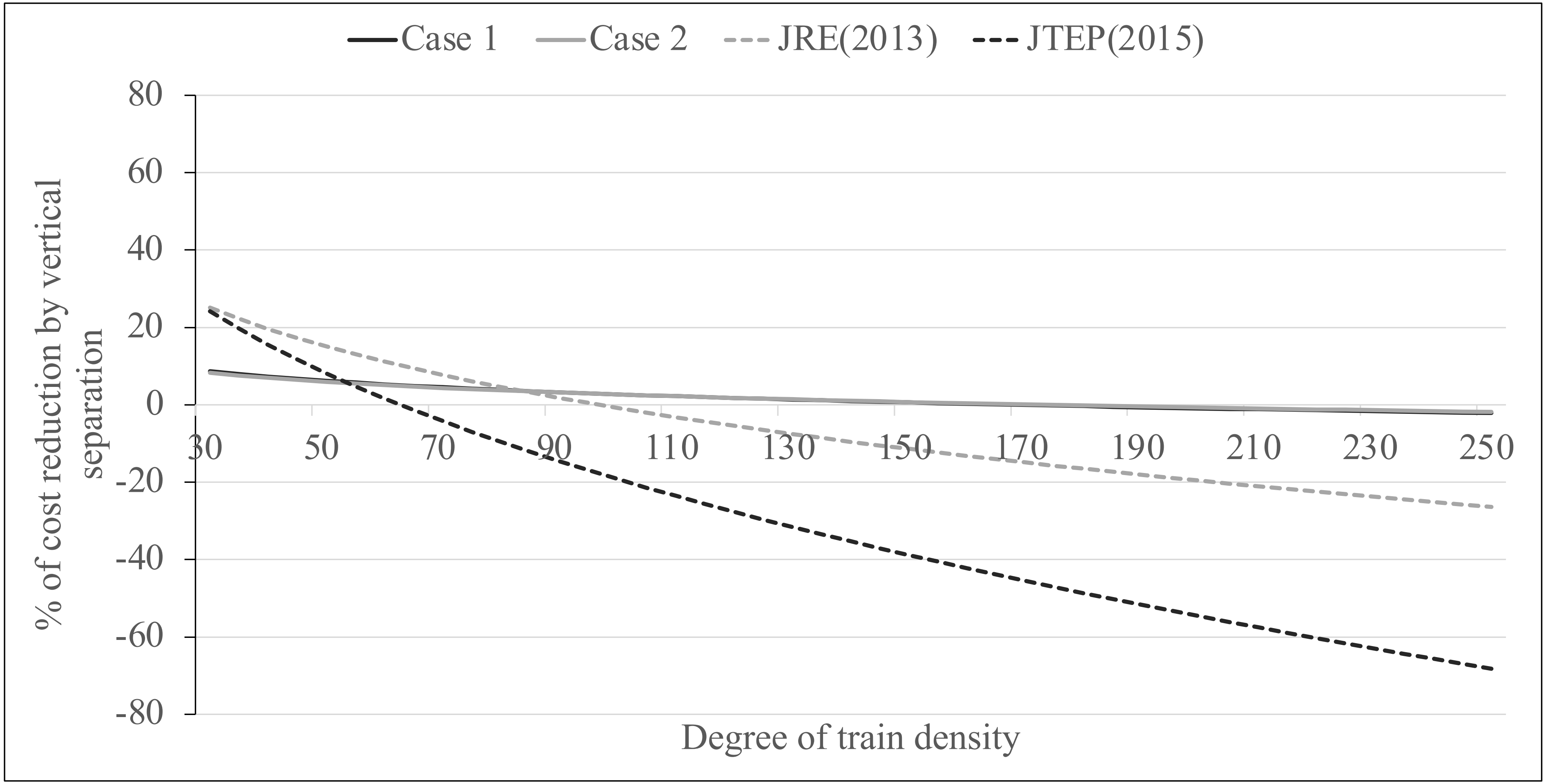
Major Results of Empirical Analysis

- **Vertical Separation**: Vertical separation effects with lower train density tend to reduce the total costs of a railway organization. But as train density increases, vertical separation causes a weak increase in a railway's total costs.
- **Competition Effects**: As for the competition factor, the results are not conclusive. Although competition tends to reduce total costs, the competition factor measure by the share of rail transportation does not have an effect. A more populated city tends to be monopolistic, and as a result the total cost of its railway company becomes higher.
- **Ownership Effects**: A private-public ownership shows negative effects on the total cost.

Cost Reduction Effect of the Vertical Separation



Comparison of Cost Reduction Effect of the Vertical Separation



Comparison on Boundary Point and Slope of the Curve

	This study		Previous studies	
	Case 1	Case 2	Mizutani and Uranishi (2013)	Mizutani et al. (2015)
Boundary point in train density	168.7	173.1	96.8	62.7
Slope of the curve	-0.035	-0.033	-0.153	-0.284

(Note):

(1) The boundary point in the train density is obtained by the following equation.

$\delta_{VS} + \delta_{VSV} \cdot \ln V^* = 0$ where $V^* = V_i/\overline{V}$, $\overline{V}$ is a sample mean.

(2) The slope of the curve in Figure 2 is obtained by the following equation.

$$\frac{\partial CR_{VS}}{\partial V^*} = -\frac{\delta_{VSV} \cdot e^{\delta_{VS} + \delta_{VSV} \cdot \ln V^*}}{V^*}.$$

In this case, CR_{VS} is the cost reduction rate by vertical separation, which is as follows.

$CR_{VS} = 1 - e^{\delta_{VS} + \delta_{VSV} \cdot \ln V^*}$.

Comparison of the Boundary Point and Slope of Train Density Curve for Vertical Structure

- Two points become clear from this figure.
- First, the boundary point of the train density where the cost advantage between the vertical separation type and the vertical integration type is larger than shown in previous studies.
- Second, the slope of this curve is gentler than in previous studies.

Cost Reduction Effects by Vertical Separation and Ownership Change

Items of Effects	Change of percent (%)	Amount of money per company (thousand yen)	Total number of railways converted
Vertical integration to vertical separation	7.2	51,423	46
Private ownership to private-public ownership	21.5	165,618	16

(Note):
(1) Cost reduction effects by vertical separation are calculated as follows.
(a) Change of percent: $\left(1 - e^{\delta_{VS} + \delta_{VSV} \cdot lnV^*}\right) * 100$
(b) Amount of money per company: $\left(1 - e^{\delta_{VS} + \delta_{VSV} \cdot lnV^*}\right) \cdot TC$
(2) Cost reduction effects by ownership change are calculated as follows.
(a) Change of percent: $\left(1 - e^{\delta_{MIX}}\right) * 100$
(b) Amount of money per company: $\left(1 - e^{\delta_{MIX}}\right) \cdot TC$

Cost Reduction Effects

- **Vertical Separation**: By converting to vertical separation from vertical integration, the cost of a railway organization can be reduced by 7.2%, which produces savings of about 51 million yen per company.
- **Ownership Change**: On the other hand, the ownership change effect is larger than the vertical separation effects. By converting from vertical integration to private-public ownership, the cost of a railway organization can be reduced by 21.5%, which produces savings of about 166 million yen per company.
- Although an ownership change can be expected to create large cost savings for a railway company, it is a necessary condition that local governments agree to participate in the management of railway organizations.

Effects of Managerial Situation by Vertical Separation and Ownership Change

	Case 1: Present situation	Case 2: Taking vertical separation	Case 3: Taking vertical separation plus converting private-public ownership
Average	0.445	0.477	0.531
Improvement ratio to Case 1	1.000	1.070	1.191
Improvement ratio to Case 2	-	1.000	1.113

(Note):
(1) "Average" means the sample average of 50 railways in terms of the revenue-cost ratio.
(2) "Improvement ratio to Case 1" means the revenue-cost ratio of Case 2 and Case 3 to Case 1.
(3) "Improvement ratio to Case 2" means the revenue-cost ratio of Case 3 to Case 2.

Effects of Managerial Situation

- The following points can be made from this table.
- First, we found that the management situation will improve as a result of taking the vertical separation policy and converting to private-public ownership.
- Second, however, the effect of improvement is not very large. In particular, adopting vertical separation will result in an improvement of only around 7% compared to the present situation.
- Third, when combined with private-public ownership, a 19% improvement can be expected. This suggests that cost reductions are expected to occur through the public sector's participation in management, rather than through the vertical separation policy only.
- Thus, as the ratio is still below one, no rail company has yet reached the point of self-independent management, in which revenues cover rail costs.

Thank you very much.