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Operating Cost Differences between Urban Rail Modes in Japan

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Abstract

This study explores whether urban rail modes differ in operating cost. It does so by estimating a Trans-log Cost Function based on data from 46 Japanese urban rail companies from 2004 to 2015. Our findings from this study indicate that over-ground, monorail, and under-ground in Japan differ in returns to density (RTD) and returns to scale (RTS). With this understanding, we believe that the policymakers, regulators and stakeholders will be able to make more informed decisions on policies, regulations and future investments pertaining to urban rail services. For a more conclusive understanding on operating cost differences between urban rail modes, we suggest this empirical research be replicated in other regions where data are sufficient.

Keywords: urban rail, cost function, trans-log, density, scale.

1 Introduction

The cost function studies on rail services are prevalent in the North American and European regions according to a survey carried out by Catalano, et al. [1]. These studies are uncommon in the Asian region, possibly due to the scarcity of data. Japan, perhaps being a developed nation, is an exception. In Japan, Mizutani [2] used the Cobb-Douglas cost function of 34 private railway companies to evaluate the effects of yardstick regulation. Also, Mizutani and Shoji [3] compared the infrastructure maintenance costs of a vertically separated railway company against 76 vertically integrated railway companies by using Trans-log cost function. Additionally, Mizutani [2] explored the optimal size of a private urban rail company by applying Trans-log cost function on 56 railway companies.

So far, there has never been an analysis which emphasises returns to density (RTD) and returns to scale (RTS) differences between urban rail modes in Japan, especially through the application of Trans-log cost function. For this given scenario and the availability of relevant data on Japan's urban rail services, we think that it would be fruitful to conduct a Trans-log cost function study on urban rail services in Japan — with the interest of understanding RTD and RTS differences between over-ground, monorail, and under-ground. Japan's urban rail market is unique. Most operators own the rail infrastructure. A few only operate the rail infrastructure, and another few only provide rail services. The market also comprises private, public, and quasi-public operators. Moreover, unlike many others, "Japanese passenger railways are financially healthy and performing well in metropolitan areas" [4].

This study aims to understand RTD and RTS differences between over-ground, monorail, and under-ground in Japan, and determine whether the differences are significant. We set the following questions to answer the objectives:

- Does RTD differ between modes? Is there any significant difference between the coefficients of density term?
- Does RTS differ between modes? Is there any significant difference between the coefficients of scale term?
- What are the policy implications?

2 Methods

We specified a Trans-log cost function model in which traffic density variable (car-km/track-km) replaced the output variable (car-km). In principle, using either variable in the model would yield the same Returns to Density (RTD) and Returns to Scale (RTS) — except that the former allows for an easier calculation of the RTS than the latter as shown in (1) and (2) respectively.

$$RTS_{D_t} = \left[\frac{\partial LnC}{\partial LnN}\right]^{-1} \tag{1}$$

$$RTS_Q = \left[\frac{\partial LnC}{\partial LnQ} + \frac{\partial LnC}{\partial LnN}\right]^{-1} \tag{2}$$

Where:
D_t = traffic density; Q = output; C = cost; N = network length.

We divided the continuous variable by their sample mean. By doing so, we could easily hold variables, other than track density and network length, at their mean values when plotting the RTD and the RTS. This would yield smoother RTD and RTD curves suitable for economic interpretations. We imposed homogeneity of degree one through dividing the operating cost and the input prices by one input price. All continuous variables were subsequently converted to the natural log form. This enabled us to treat the coefficients on the right-hand side of the equation as the cost elasticities. The base model, prior to the inclusion of mode dummy intercepts and mode dummy interactions, was defined as follows:

$$\begin{aligned}
Ln\left(\frac{C_{ELM}}{\overline{C}_{ELM}}\Big/\frac{P_M}{\overline{P}_M}\right) = {} & \alpha + \beta_{D_t} Ln\,\frac{D_t}{\overline{D}_t} + \beta_{P_E} Ln\left(\frac{P_E}{\overline{P}_E}\Big/\frac{P_M}{\overline{P}_M}\right) + \beta_{P_L} Ln\left(\frac{P_L}{\overline{P}_L}\Big/\frac{P_M}{\overline{P}_M}\right) \\
& + \beta_{P_M} Ln\left(\frac{P_M}{\overline{P}_M}\Big/\frac{P_M}{\overline{P}_M}\right) + \beta_N\, Ln\,\frac{N}{\overline{N}} + \frac{1}{2}\beta_{D_tD_t}\left(Ln\,\frac{D_t}{\overline{D}_t}\right)^2 \\
& + \frac{1}{2}\beta_{P_EP_E}\left(Ln\left(\frac{P_E}{\overline{P}_E}\Big/\frac{P_M}{\overline{P}_M}\right)\right)^2 + \frac{1}{2}\beta_{P_LP_L}\left(Ln\left(\frac{P_L}{\overline{P}_L}\Big/\frac{P_M}{\overline{P}_M}\right)\right)^2 \\
& + \frac{1}{2}\beta_{P_MP_M}\left(Ln\left(\frac{P_M}{\overline{P}_M}\Big/\frac{P_M}{\overline{P}_M}\right)\right)^2 + \frac{1}{2}\beta_{NN}\left(Ln\,\frac{N}{\overline{N}}\right)^2 \\
& + \beta_{D_tP_E} Ln\,\frac{D_t}{\overline{D}_t}\, Ln\left(\frac{P_E}{\overline{P}_E}\Big/\frac{P_M}{\overline{P}_M}\right) + \beta_{D_tP_L} Ln\,\frac{D_t}{\overline{D}_t}\, Ln\left(\frac{P_L}{\overline{P}_L}\Big/\frac{P_M}{\overline{P}_M}\right) \\
& + \beta_{D_tP_M} Ln\,\frac{D_t}{\overline{D}_t}\, Ln\left(\frac{P_M}{\overline{P}_M}\Big/\frac{P_M}{\overline{P}_M}\right) + \beta_{D_tN} Ln\,\frac{D_t}{\overline{D}_t}\, Ln\,\frac{N}{\overline{N}} \\
& + \beta_{P_EP_L} Ln\left(\frac{P_E}{\overline{P}_E}\Big/\frac{P_M}{\overline{P}_M}\right) Ln\left(\frac{P_L}{\overline{P}_L}\Big/\frac{P_M}{\overline{P}_M}\right) + \beta_{P_EP_M} Ln\left(\frac{P_E}{\overline{P}_E}\Big/\frac{P_M}{\overline{P}_M}\right) Ln\left(\frac{P_M}{\overline{P}_M}\Big/\frac{P_M}{\overline{P}_M}\right) \\
& + \beta_{P_EN} Ln\left(\frac{P_E}{\overline{P}_E}\Big/\frac{P_M}{\overline{P}_M}\right) Ln\,\frac{N_{it}}{\overline{N}} + \beta_{P_LP_M} Ln\left(\frac{P_L}{\overline{P}_L}\Big/\frac{P_M}{\overline{P}_M}\right) Ln\left(\frac{P_M}{\overline{P}_M}\Big/\frac{P_M}{\overline{P}_M}\right) \\
& + \beta_{P_LN} Ln\left(\frac{P_L}{\overline{P}_L}\Big/\frac{P_M}{\overline{P}_M}\right) Ln\,\frac{N}{\overline{N}} + \beta_{P_MN} Ln\left(\frac{P_M}{\overline{P}_M}\Big/\frac{P_M}{\overline{P}_M}\right) Ln\,\frac{N}{\overline{N}} + \varepsilon
\end{aligned} \tag{3}$$

Where:
C_{ELM} = cost of energy, labour, and material & repairs
D_t = traffic density (car-km/track-km)
P_E = energy price
P_L = labour price
P_M = material & repair price
N = network length (track-km)
ε = error term

We used data from 46 Japanese urban rail companies from 2004 to 2015. The data was sourced from Japan Annual Statistics of Railways. The variable definitions are presented in Table 1.

Variable	**Definition**	**Unit**
C_{ELM}	The sum of annual energy, labour, and maintenance costs after accounting inflation.	Yen
P_E	Price per unit of energy consumed for the specific year after accounting inflation.	Yen

Variable	**Definition**	**Unit**
P_L	Salary per full-time equivalent employee for the specific year after accounting inflation.	Yen
P_M	Material and repair expenditure per rolling stock for the specific year after accounting inflation.	Yen
D_t	The journey (thousand km) travelled by all rolling stocks divided by the length (km) of track in operation for the specific year.	Thousand KM
N	The length of track in operation for the specific year.	KM
DM_M	Urban rail operators that are registered with Japan Monorail Association	Binary
DM_U	Urban rail operators that are registered with Japan Subway Association	Binary
DM_O	Urban rail operators that are neither registered with Japan Monorail Association nor Japan Subway Association (omitted condition)	Binary

Table 1: Variable Definitions (Inflation base year was set at 2015)

3 Results

Returns to Density

An excerpt from the regression results is presented in Table 2; where $\boldsymbol{\beta_{D_t}}$ is the coefficient for density (car-km per track-km), $\boldsymbol{DM_M}$ is mode dummy for monorail, and $\boldsymbol{DM_U}$ is the mode dummy for under-ground.

Coefficient	**Value**
β_{D_t}	0.7490696
$\beta_{D_t DM_M}$	-0.2523734
$\beta_{D_t DM_U}$	-0.290507

Table 2: Excerpt from the Regression Results for RTD

We calculated the RTD for each rail mode as follows:

$$RTD_{DM_O} = \left[\beta_{D_t}\right]^{-1} = 1.335 \tag{4}$$

$$RTD_{DM_M} = \left[\beta_{D_t} + \beta_{D_t D_{MM}}\right]^{-1} = 2.013 \tag{5}$$

$$RTD_{DM_U} = \left[\beta_{D_t} + \beta_{D_t D_{MU}}\right]^{-1} = 2.181 \tag{6}$$

Among the three, under-ground has the highest RTD (at 2.181), followed by monorail (at 2.013), and over-ground (at 1.335). Note that the values of all RTDs were above one. This means that an output increase (resulting in a density increase) would favour all the rail modes in terms of experiencing lower average cost — albeit at different rates. However, there was no significant difference between monorail and under-ground when we tested null hypotheses on RTD differences as follow:

- H$_0$: RTD_{DM_O} = RTD_{DM_M} (significance value: 0.0169)
- H$_0$: RTD_{DM_O} = RTD_{DM_U} (significance value: 0.0005)
- H$_0$: RTD_{DM_M} = RTD_{DM_U} (significance value: 0.6965)

Returns to Scale

An excerpt from the regression results is presented in Table 2; where $\boldsymbol{\beta_{D_t}}$ is the coefficient for density (car-km per track-km), $\boldsymbol{DM_M}$ is mode dummy for monorail, and $\boldsymbol{DM_U}$ is the mode dummy for under-ground.

Coefficient	**Value**
β_N	0.9430847
β_{NDM_M}	-0.4184442
β_{NDM_U}	0.0251065

Table 3: Excerpt from the Regression Results for RTS

We calculated the RTS for each rail mode, and tested null hypotheses on RTS differences, as follow:

$$RTS_{DM_O} = [\,\beta_N]^{-1} = 1.060 \tag{7}$$

$$RTS_{DM_M} = \left[\,\beta_N + \beta_{ND_{MM}}\right]^{-1} = 1.906 \tag{8}$$

$$RTS_{DM_U} = \left[\,\beta_N + \beta_{ND_{MU}}\right]^{-1} = 1.033 \tag{9}$$

- H$_0$: RTS_{DM_O} = RTS_{DM_M} (significance value: 0.0004)
- H$_0$: RTS_{DM_O} = RTS_{DM_U} (significance value: 0.6601)
- H$_0$: RTS_{DM_M} = RTS_{DM_U} (significance value: 0.0004)

Because RTS_{DM_O} and RTS_{DM_U} are close to unity, we tested null hypotheses on

- H$_0$: RTS_{DM_O} = 1 (significance value: 0.0884)
- H$_0$: RTS_{DM_U} = 1 (significance value: 0.4776)

Among the three, monorail has the highest RTS (at 1.906), followed by over-ground (at 1.060), and under-ground (at 1.033). At 95% confidence, we could not say that the RTS value was significantly different from one — for each over-ground and under-ground. This means that any scale increase would not necessarily favour over-ground and under-ground in terms of experiencing a lower average cost. On the other hand, any scale increase would favour monorail in terms of experiencing a lower average cost.

4 Conclusions and Contributions

We conclude that the cost structure of each urban rail mode (over-ground, monorail, and under-ground) in Japan supports a higher density operation. Subject to capacity constraints, an urban rail operator will experience a lesser average cost when it increases outputs (car-km) while maintaining the current network size. The cost structure of monorail supports operating in a wider geographical area. However, there is a lack of evidence to say the same for over-ground and under-ground. Subject to capacity constraints, a monorail operator will experience a lesser average cost when it serves a wider network — but not necessary so for an over-ground or under-ground operator.

Knowing RTD and RTS will help policymakers, regulators and stakeholders have a better understanding on the cost structure of each urban rail mode. This is a useful insight when making certain decisions such as the followings:

- *Construction*
  For a better decision on urban rail project investment, the RTD and RTS could be incorporated into the cost-benefit analysis together with the infrastructure costs, the projected demand, and other relevant details[1].

- *Expansion*
  Policymakers in Japan will have a better understanding on future operating cost differences between rail modes. This will help them prioritise resource allocation when considering two or more urban rail network expansions.

- *Pricing*
  The RTD and RTS provide a general picture to regulators in Japan on how operating cost can vary across urban rail modes. When setting the right ceiling price, RTD and RTS can be considered along with an operator’s full cost level.

- *Market liberalisation*
  Larger over-ground and under-ground systems could be divided into smaller scales to liberalise the urban rail market further and encourage new entries. This is because of their RTS values, which sit close to unity.

For a more conclusive understanding on cost differences between urban rail modes, we suggest this empirical research be replicated in other regions where data are sufficient. In the regions where the cost function studies are rare, especially on the urban rail services, we anticipate more cooperation towards identifying and gathering the essential data. It would be interesting to know whether or not the findings would

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[1] The mechanism of its implementation should be a topic in future discussions.

be similar. We foresee that the differences in urban rail mode definitions between regions will be a challenge in summing up the current and future empirical findings.

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