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INTRODUCTION

Rail transportation in Japan is the second most common mode of transportation behind cars. In 2012, 32% of transportation sales were produced by rail (MLIT, 2013). Moreover, the annual number of passengers is 185 times larger than the population of Japan, and the rail transportation maintained 55% to 60% of its share in terms of passenger-kilometer from 1990 to 2010, while air and public vehicle transportation experienced declining enplanement (MLIT, 2012). Rail system and train car exports are one area of growth in Japan over the past decade (METI, 2011). Indeed, the Japanese government expects the international rail market to grow by 2.5% every year until 2020 (METI, 2011).

With all of this economic activity, however, there are social costs such as congestion and pollution. Studies also show that the cancelling and delaying of trains for two days due to a fire in January, 2014, affected 1.1 million users and reduced sales by approximately 27 to 32 billion Japanese yen (Central Japan Railway Company, 2014). Many former studies have estimated the social costs for other modes of transportation but rarely have examined rail transportation in Japan.

In this study, I examine several factors that are related to the social costs of rail transportation in Japan by using a constructed Japanese dataset and regression analysis. Unlike previous studies, the components of the social costs in this study focus on current environmental matters such as global warming and air pollution. Also, the regression analysis controls for population, revenue per passenger, passenger density, rail length, and gas emission. This study may help to improve technology and services, and minimize losses in the future of the rail industry.

This paper is organized as follows. First, I review the previous studies with attention to the types of social costs and method of estimation of social costs of rail transportation in Japan. Second, I explain the method and data used for estimating social costs, and describe specific equations for the main categories of social costs. Third, I discuss the descriptive and regression results. Finally, I summarize the major findings and discuss some limitations of the study, as well as the factors that should be examined in the future.

REVIEW OF LITERATURE

Preceding studies have identified several social costs associated with various modes of transportation, examined the noise pollution of rail transportation, evaluated the social costs including environmental factors, analyzed the economic impact of the overcrowding passengers, estimated the social costs of freight rail transportation, and evaluated the air pollutant costs by weight. The discussion below reviews these studies.

Transport activities create and increase environmental issues, accidents, and discomfort. Without the decision-making process of governments, these social costs are not accounted for by users when choosing modes of transportation. Therefore, social costs need to be recognized as losses to society. To determine the policy background, IMPACT (2008) provided a comprehensive overview of several previous studies mainly done within European countries. For instance, one of the studies examined the causation of congestion and delay based on capacity, construction, accidents, and weather. It found that 32%, 44%, 13%, and 10% of causation related to congestion and delay was due to these four factors, respectively, in the UK Network Rail. Even though the studies tended to include scarcity costs, such as costs due to limited facilities, rail networks, and spaces, and climate change costs, the studies indicated a wide variation of practical approaches for estimating the social costs of rail transportation in Japan.

Noise is one of the major pollutants caused by rail. Damages due to noise pollution include the loss of sleep, lower productivity, psychological discomfort and frustration. Levinson et al. (1997) examined the social costs of a high-speed rail system in California in order to evaluate the feasibility of high-speed rail by using data from 1967 to 1997. The authors calculated the noise damage and established an equation of the cost of noise damage per passenger-kilometer by regression analysis. The authors used a noise depreciation index (NDI), which is the percentage reduction of house price per noise level. The authors estimated the model under two different train speeds, 200 and 320 kilometers per hour (kph). Applying an average NDI of 0.62, and assuming a passenger travel discount rate of 7.5%, the expected cost of noise at 200 kph and at 320 kph is 0.0025 and 0.0043 dollars per passenger-kilometer, respectively. This study is significant because none of the former studies calculated the noise damage of rail transportation by passenger-kilometer. The authors, however, disregarded accidents and air pollution for the social costs of rail transportation, which I account for in this study.

Based on previous studies that estimate social costs, Mizutani et al. (2011) examined the social costs of vehicle transportation and analyzed the structure of the components of social costs by using a dataset of 111 Japanese cities in 2005. The authors include railway density to capture this competing mode of transportation when estimating the social costs of vehicle transportation. The regression results indicated the estimated coefficient on railway density is -0.027. The result suggests that rail transportation, an alternative to cars, reduce the social costs of vehicular transportation only slightly. This research also included environmental factors so, unlike other studies, the model in this study estimates the current economic impact of protecting the environment.

In addition to environmental costs, social costs include the costs of accidents and congestion. Garrido (2012) estimated the influence of congestion of traffic in the city of Antofagasta, Chile, in terms of costs using a microsimulation technique. Before estimating the total costs of congestion, the author evaluated the influence of a crowded bus transport system with comprehensive models of bus mode. The author used a 25 kilometer strip and transport network of 14 stations running in Antofagasta, collected from the Chilean Bureau of Transport Scheduling. The result of the comparative analysis showed bus crowding imposed a higher bus fare by 0.16 to 0.18 dollars per kilometer per person, and a reduction of optimal effectiveness of bus subsidy by 4.4% to 8.3% per bus fare. Also, the author found the crowded bus positively impacted bus frequency and the traffic congestion level, and it had a negative impact on seat supply and average speed of a bus. Overall, this research indicates that a crowded bus creates additional costs on vehicle transportation rather than cost efficiency of capacity usage. These findings help to provide supporting evidence for why dense trains positively relate to the social costs.

In addition to the passenger rail transportation, freight rail transportation also creates social costs. Forkenbrock (2001) conducted a comparative analysis between truck and rail freight transportation to demonstrate more consistency of the transportation in metropolitan areas. The author estimated the external costs of four representative types of freight rail operating between urban areas in the United States. The data were collected from 36 firms of Class I railroads from 1987 to 1995. Within this research, non-market costs of accidents, emissions, noise, and global warming in freight rail transportation are recognized. The author found the external cost per ton mile for freight rail to be $0.24- $0.25, and the range of freight rail external costs accounts for 9.3% to 22.6% of the total costs of freight rail. These findings are significant for supporting the model of social costs in rail transportation because the datasets used in this study are capturing the non-market social costs. Other studies rarely include these four costs of freight rail transportation, thus, the datasets are the best available information for this study.

In earlier study, Forkenbrock (1999) compared the costs and benefits of truck freight transportation. The author evaluated general types of social costs including accidents, emission, noise, provision, operation, and maintenance of public facilities for a ton-mile freight shipment by truck. The highlight of this study is the estimated average air pollutant cost per ton of polluted air. The average air pollutant costs are $385, $213, and $263 per ton for pollutants of volatile organic compounds (VOC), mono-nitrogen oxides (NOx), and sulfur oxides (SOx), respectively. This study helps to identify relevant costs of air pollution and are used in the current study to estimate air pollution costs by pollutant type.

Overall, the preceding studies have established several relevant models of social costs, even though there are some differences in modes of transportation and types of social costs. These findings help identify what elements of economic activity should be included as social costs. The previous studies, however, have not examined the social costs of rail transportation in Japan. Thus, this study estimates and evaluates these social costs. The following section will focus on the model and data used in this study.

DATA AND METHODS

In this section, the methods and data used for estimating social costs of rail transportation in Japan and each variable used in the model are explained.

Methods

Building on the work of Mizutani et al. (2011), IMPACT (2008), and Forkenbrock (1999), the methods for estimating the social costs of rail transportation are first considered. The social costs of rail transportation must be external costs or negative externalities by its definition.

Thus, to estimate relevant social costs, each component of social costs should not be inside normal market activities or processes, as Varian (1984) defined.

The social costs of rail transportation are estimated by summing four major external cost items: accidents, air pollution, global warming, and noise. Although INFRAS/IWW (2004) and IMPACT (2008) included scarce infrastructure, such as the cost caused by delays, this is not included in this study because of data availability. Also, social costs are estimated by including both freight and passenger rail transportation and all types of cargoes, such as electronic, diesel, locomotive, and so on. Thus, in order to estimate the social costs, the total social costs of rail transportation in Japan (*SC*) are defined as follows:

$$SC = C_{acc} + C_{air} + C_{gw} + C_{noise}$$

where *SC* is the total of social costs of rail transportation in Japan, C_{acc} is the social cost of rail accidents in Japan, C_{air} is the social cost of air pollution due to rail transportation in Japan, C_{gw} is the social cost of global warming due to rail transportation in Japan, C_{noise} is the social cost of noise pollution due to rail transportation in Japan. Each of the social cost components were individually calculated as follows:

$$Accident: C_{acc} = \sum_{e} (P_{acc,e} * N_{acc,e})$$

where $P_{acc,}$ is the unit social cost of rail accident type *e*, $N_{acc,e}$ is the number of rail accidents, and e is type of accident (i.e., property damage, injury, and/or death).

$$Air: \mathrm{C}_{\mathrm{air}} = \sum_{e} (P_{air,e} * Q_{acc,e})$$

where $P_{air,e}$ is the unit social cost of polluted air type *e*, $Q_{acc,e}$ is the estimated quantity of polluted air by rail, and *e* is type of chemicals included in polluted air (i.e., VOC, NOx, and SOx).

$$Global\ warming: C_{gw} = \sum_{co2} (P_{co2} * Q_{co2})$$

where P_{co2} is the unit social cost of emission of CO2 caused by rail transport in Japan, and Q_{co2} is the estimated quantity of emission of CO2 by rail transportation in Japan.

$$Noise: C_{noise} = \sum_{noise} (P_{noise,t} * D_{\mathrm{noise,t}})$$

where P_{noise} is the social cost of noise by rail transport per passenger-kilometer, D_{noise} is passenger-kilometer in Japan, and t is time. Table 1 summarizes the type of social costs, their symbols, descriptions, units, and sources of data.

TABLE 1

Kinds of social costs, symbols, description, unit, and source

Types of social costs	Symbol	Description	Sub-item	Unit	Source
Rail Accident	Cacc	Cost of rail accident based on willingness to pay	Property damage	case	Railway Bureau, Ministry of Land, Infrastructure, Transport and Tourism
			Death	person	Railway Bureau, Ministry of Land, Infrastructure, Transport and Tourism
			Injure	person	Railway Bureau, Ministry of Land, Infrastructure, Transport and Tourism
Air Pollusion	Cair	Cost of polluted air emission due to rail transport	SOx	ton	OECD statistics
			NOx	ton	OECD statistics
			VOC	ton	OECD statistics
Global Warming	Cgw	Cost of global warming due to rail transport	Cabon doixide	ton	Ministry of the Environment
Noise	Cnoise	Cost of noise pollution due to rail transport	-	passenger kilometre	Ministry of Land, Infrastructure, Transport and Tourism

TABLE 2

Variable Symbols, Definitions, Sources, Expected Signs

Variable	Symbol	Description	Unit	Source	Expectation
Social costs	SC	total social costs of rail transportation	million yen	-	N/A
Revenue	REV	real revenue per passener	thousand yen per thousand passenger	Policy Bureau, Ministry of Land, Infrastructure, Transport and Tourism	+
Population	POP	total population in Japan	thousand people	Ministry of Internal Affairs and Communications	+
Passenger density	PD	passenger density per rail length	thousand passenger per kilometer	Policy Bureau, Ministry of Land, Infrastructure, Transport and Tourism	+
Rail length	RL	total operating railroad length	kilometer	Policy Bureau, Ministry of Land, Infrastructure, Transport and Tourism	+
Gas emission	GE	quantity of gas emissioned by rail	thousand ton	Ministry of the Environment	+

Following Mizutani et al. (2011), the empirical model used to estimate the relationship between several factors associated with social costs for rail transportation in Japan is specified as follows:

$$\text{In } SC = \alpha + \beta_{rev} \text{ In } REV + \beta_{POP} \text{ In } POP + \beta_{PD} \text{ In } PD + \beta_{RL} \text{ In } RL + \beta_{GAS} \text{ In } GAS + e$$

where SC is the estimated social costs of rail transportation in Japan, REV is real revenue per passenger, POP is total population in Japan, PD is passenger density, RL is operating rail length in Japan, and GAS is total gas emission of rail transportation in Japan.

Based on the concept that more rail transportation is associated with more social costs for rail transportation, the following relationships are expected. First, as the revenue of rail transportation increases, more passengers are likely to use rail transportation; thus, this variable is expected to be positively related to the social costs for rail transportation. Second, as the population in Japan increases, more people are likely to use rail transportation; thus, this variable is expected to be positively related to the social costs for rail transportation. Third, as the passenger density of rail transportation increases, more accidents or damages are likely to occur with rail transportation; thus, this variable is expected to be positively related to the social costs for rail transportation. Fourth, as the rail length increases, more businesses operate along the railroads; thus, this variable is expected to be positively related to the social costs for rail transportation. Fifth, as gas emissions increase, there is more air pollution; thus, this variable is expected to be positively related to the social costs for rail transportation. Table 2 summarizes the variables used in the regression equation as well as their symbols, descriptions, units, sources, and expected signs.

Data

For this study, time series data was collected from 1990 to 2012. All data necessary for estimating the social costs of rail transportation was collected from the Railway Bureau, Ministry of Land, Infrastructure, Transport and Tourism, OECD Statistics, Ministry of the Environment, and Ministry of Land, Infrastructure, Transport and Tourism. Rail transportation revenue data was obtained from the Policy Bureau, Ministry of Land, Infrastructure, Transport and Tourism. This is also the source for information on the number of passengers and rail length. Data on population and gas emission were collected from the Ministry of Internal Affairs and Communications and Ministry of the Environment, respectively. The next section discuss the result from the regression analysis.

RESULTS

The descriptive statistics are summarized in Table 3. From 1990 to 2012, the real social costs of rail transportation in Japan averaged 2.7 trillion yen per year, which is approximately 0.51% of Japanese real GDP of 2013. Similarly, real revenue per passenger averaged 293 thousand yen per passenger. The population in Japan averaged 127 million people and passenger density averaged 811 thousand people per kilometer. Rail length and gas emission averaged 27,000 kilometers and 75 million tons, respectively.

TABLE 3

Result from descriptive statistics

Variables	**Mean**	**Standard Deviation**	**Maximum**	**Minimum**
SC	2,700,491.7	228,714.7	2,981,444.0	2,248,198.9
REV	292.7	6.6	304.2	278.6
POP	126,678.5	1,403.1	128,084.0	123,611.0
PD	811.3	18.0	840.4	783.4
RL	27,475.0	139.5	27,796.0	27,230.0
GE	75,088.7	1,035.9	81,105.2	66,384.4

TABLE 4

Result from regression analysis

Variables	**OLS**

Intercept	453,843.17	
	(-2,031,136.28)	
REV	-4,755.82	**
	(1,517.08)	
POP	19.85	*
	(7.49)	
PD	56.72	
	(592.66)	
RL	-88.28	
	(70.38)	
GE	46.66	***
	(2.09)	
R- Squared	0.99	
Adjusted R-Squared	0.98	
F-statistic	236.23	
Observation	23	

*p < 0.05 (two-tailed).

**p < 0.01 (two-tailed).

***p< 0.001 (two-tailed).

Table 4 summarizes the results from the regression analysis. The results support the hypothesis of a positive relationship among the social costs and the independent variables. The R-squared of 0.99 indicates that 99% of the variation in social costs of rail transportation about its mean is explained by the variation in real revenue, population, passenger density, rail length, and gas emission. Moreover, the F-statistic is statistically significant which indicates that the estimated relationship is a significant one.

The variables population, passenger density, and gas emission are positively related to social costs, as is expected. That is, as population increases by one thousand people, its estimated impact is to raise social costs by 19.85 million yen. This variable is statistically significant.

Likewise, as the passenger density increases by one thousand people per kilometer and as the gas emission increases by one thousand tons, it is estimated to increase social costs by 56.72 million yen and by 46.66 million yen, respectively. Gas emission is statistically significant. The variable real revenue and railroad length are estimated to be negatively related with the social costs, which is unexpected. As the rail length is extended by one kilometer, the social costs decrease by 88.28 million yen, but this is not significant. As real revenue increases one thousand yen, social costs significantly decrease by 4755.82 million yen.

Likely reasons for the negative coefficients on real revenue and rail length may be the effects of over boarding, low-cost air carriers, and the polarization of population growth. First, unlike vehicle transportation, rail can transport passengers even in cramped conditions. For instance, the hourly boarding rate of selected lines in the Tokyo area was 167% of capacity on average, with 209% the highest (MLIT, 2011). This rate indicates that over boarding may reduce the social costs of rail transportation in Japan, especially in the metropolitan areas. Second, low-cost air carriers, LCC are a booming industry in Japan. Indeed, the number of LCC users is growing 4.1 % greater than non-LCC users in 2012 (MLIT, 2013). People might not use rail transportation for long distances, which usually are more profitable for rail companies. Third when the population in Japan grows slightly, the regional population becomes seriously polarized in urban and rural areas. Large cities, such as Tokyo, Osaka, and Nagoya, increase their population dramatically while small towns suffer from depopulation. Along with the governmental attempts at economic recovery by increasing public projects, local governments and the national government may be unnecessarily building railroads. Finally, only 23 years of data are used to estimate the social costs of rail transportation of Japan. If more years were available, the quality of the analysis would improve.

SUMMARY AND CONCLUSION

The main purpose of this study is to estimate the social costs of rail transportation of Japan and to analyze the structure of the components of social costs and selected variables by regression analysis. This study is different from former studies because the social costs are investigated with environmental items and the well-being of passengers. Attributed to previous studies, I expected that all of the variables were positively correlated to the social costs of rail transportation of Japan.

The main findings of the regression results are as follows. First, the variables population, passenger density, and gas emission are positively related to social costs. Moreover, gas emission is statistically significant related to the social costs of rail transportation. Second, the variables real revenue per passenger and rail length are estimated to be negatively related to the social costs, which is unexpected. I assume that reasons for the negative correlation are due to over boarding for rail transportation, the rise of LCC, and polarization of the Japanese regional population. Overall, although some variables do not positively relate to the social costs as expected, the regression results are statistically strong to support my hypothesis.

This study measures five major variables of social costs of rail transportation, yet it has some limitations. First, scarce infrastructure is disregarded in the social costs of this study. Secondly, there are only 23 observations available for use. Finally, some values used for the social costs are converted from foreign resources into Japanese currency. In future research, it will be of interest to reexamine the social costs of rail transportation in Japan. The effectiveness of technology development in minimizing the social costs would benefit from a longer time span because limited data exist at present under Japanese datasets.

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