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KOBE
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ROKKO KOBE JAPAN

2015-18

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Discussion Paper Series

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[Abstract]: This study estimates and evaluates the social costs of highways in Japan. Five kinds of social costs of vehicular transport are considered: traffic accidents, air pollution, noise, global warming, and traffic congestion. Major findings of this study are as follows. First, social costs increase at an accelerated rate as traffic volume increases. Second, the largest component of vehicular transport's social costs on highways is traffic congestion, accounting for about 64%. The second largest component is traffic accidents, accounting for 24%. Third, among vehicle types, the social costs of buses are largest, at 105 yen per vehicle-km, about 16 times higher than the social costs of regular cars. Last, total social costs for whole highway networks are about 678,212 million yen, or about 0.13% of Japan's GDP. Compared with highway fare revenues and the operating costs of highways, social costs equal 62.6% and 98.6%, respectively.

[Key words]: Social costs; Car transportation; Highway; External costs

[JEL classification]: H4, H5, L9, Q5, R4

1. Introduction

The main purpose of this paper is to estimate and evaluate the social costs of highways in Japan. In general, with more people concerned about protecting the environment at both local and global levels, dependence on vehicular transportation in cities has brought about problems. Too much dependence on autos causes air pollution, which has detrimental health effects. Traffic congestion wastes time, money, and energy. The most troubling issue related to continuing

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dependence on car use, however, is global warming. In order to implement transport policies conducive to creating a sustainable environment, it is necessary to measure correctly the social costs of vehicular transport such as traffic accidents, air pollution, noise, global warming, and traffic congestion. By using a data set from Japan, this paper aims to estimate the social costs of vehicular transport on highways and to evaluate how extensive these social costs are by comparing, for example, highway fares relative to GDP.

Our study has several distinguishing characteristics. The most important point is that we estimate each individual highway's social costs by considering average speed at the peak period, total traffic volume, types of vehicular transport, and so on. Second, this study distinguishes five kinds of social costs of vehicular transport for individual highways in Japan: 1) traffic accidents, 2) air pollution, 3) noise, 4) global warming, and 5) traffic congestion. Third, by using a data set of over 50 individual highways in Japan in 2005, we analyze the relationship between the social costs of vehicular transport and traffic volumes in general. Last, by comparing highway fares, the degree of GDP, the fuel tax level, and other factors, we assess the magnitude of social costs, for the purpose of creating prudent transport policy.

In order to attain the objectives mentioned above, we organize our study as follows. First, we explain our method for estimating social costs. In this section, we describe specific equations for the five main categories of highways' social costs. The main methodology follows Mizutani et al. (2011), the main difference being that this study concerns highways while Mizutani et al. (2011) focuses on traffic in cities. Second, based on these equations, by using a data set for highways in Japan, we estimate the social costs of vehicular transport on highways. Last, by comparing highway fares, GDP and so on, we evaluate how extensive highways' social costs actually are. In this section, we also summarize our major findings.

2. Previous Literature

In this section, we survey previous studies on the social costs of intercity car transportation such as Levinson and Gillen (1998), Levinson et al. (1999), Forkenbrock (1999), Ozbay, Bartin and Berechman (2001), Ozbay, Bartin, Yanmaz-Tuzel and Berechman (2007), Van Essen et al. (2004) and Perez-Martinez and Vassallo-Magro (2013).

Levinson and Gillen (1998) develop a full cost model of a highway system, comprised of user, infrastructure, and time costs, as well as the social costs incurred by accidents, noise and air pollution. In this study, infrastructure costs are estimated by the regression method (OLS).

Levinson et al. (1999) investigate the full cost of transportation in order to compare transportation modes. They compare three intercity transportation modes such as airplane, highway and high-speed trains relative to the situation in the California corridor between Los Angeles and

San Francisco. As there is to date no high-speed train in California, the French TGV is used hypothetically for the estimation. Social costs estimated in this study are (i) traffic accidents, (ii) traffic congestion, (iii) noise, and (iv) air pollution. As a result, total social costs were 0.0073 for air transportation, 0.0020 for high-speed train and 0.0122 US dollar per passenger kilometer. As for highway, social cost is about 5.3% of full cost.

Forkenbrock (1999) estimates both private cost and external cost (i.e. social cost) in intercity freight transportation in the US in 1994. External costs in this study include (i) traffic accidents, (ii) air pollution, (iii) the greenhouse effect, (iv) noise and (v) other external costs. These external costs are 1.11 US dollars per ton-mile in 1994, accounting for 11.6% of full costs.

By using a New Jersey data set, Ozbay, Bartin and Berechman (2001) also estimate the full marginal costs of highways, comprised of vehicle operating, congestion, accident, environmental and infrastructure costs.

In a further study, Ozbay, Bartin, Yanmaz-Tuzel and Berechman (2007) estimate the full marginal costs of highways for New Jersey's highway network. This cost is estimated based on marginal cost function for specific OD (i.e. origin and destination). Social costs in this study consist of (i) congestion, (ii) traffic accidents, (iii) air pollution and (iv) noise. Social costs are 6.57 US dollars per trip and account for 37.9% of full highway costs.

In a study by Van Essen et al. (2004) on the marginal costs of infrastructure use, the authors examine the three transportation modes of road, railway and air transportation. Costs included in this study are infrastructure, traffic accidents, air pollution and noise. As an example of intercity road truck transportation, the marginal costs of road use in the Hamburg-Munich corridor (about 720km) in Germany in 2001 are estimated. Social marginal costs in this case are 0.18 Euros per vehicle and account for 75% of full marginal costs.

Perez-Martinez and Vassallo-Magro (2013) analyze the decreasing trend in the external costs of freight transportation in Spain. In this study, the items included in external costs are traffic accidents, air pollution and climate change for both trucks and railways. The authors estimate that the external costs of trucks are 2.35 Euros in 2005, and that the costs of trucks are 8 times higher than those of railways.

Although there have been many studies on social costs, issues remain to be resolved. First, there is much variation in the degree of social costs, indicating that costs might be affected by region and situation. Second, the items included in social costs (i.e. congestion, air pollution, noise, traffic accidents and global warming) are not estimated together. Third—and this is related to the second reason—it is not clear what type is greatest among social costs. Furthermore, there is inadequate analysis of the relationship between kinds of vehicle and the degree of social costs.[1] In conclusion,

[1] Some studies such as Koyama (2004), Van Essen et al. (2004) and Nishikawa and Kon (2011)

there still much room for work in the investigation and analysis of the social costs of highways.

3. Methods for Estimation of Social Costs

3.1 Definition of Social Costs

The general models for the estimation of social costs of vehicle transport follow Mizutani et al. (2011). Although Mizutani et al. (2011) estimate social costs for each individual city, this study estimates costs for each individual highway. The social costs of vehicular transport consist of five items: traffic accidents, air pollution, noise, global warming, and traffic congestion. Therefore, the social costs of vehicle transport are defined as equation-(1).

$$SC_a = C_{acc,a} + C_{air,a} + C_{dB,a} + C_{war,a} + C_{con,a} \tag{1}$$

where, SC_a : Social costs of vehicular transport for highway-***a***,

$C_{acc,a}$: Social costs of traffic accidents for highway-***a***,

$C_{air,a}$: Social costs of air pollution for highway-***a***,

$C_{dB,a}$: Social costs of noise for highway-***a***,

$C_{war,a}$: Social costs of global warming for highway-***a***,

$C_{con,a}$: Social costs of traffic congestion for city-***a***.

3.2 Traffic Volume

The traffic volume of vehicle type-***b*** on section-***c*** of highway-***a*** (Q_a^b) is estimated as equation-(2) shows. Thus, the basic formula for the estimation of traffic volume is obtained from results of daily traffic volume on the observed road section. Observed daily traffic volume is shown in the *2005 Road Transport Census,* with observation being carried out mainly on bigger roads and trunk roads.

$$Q_a^b = d \cdot \left[\sum_c \left(DIS_{a,c} \cdot CAR_{a,c,w}^b \right) \right] + (365 - d) \cdot \left[\sum_c \left(DIS_{a,c} \cdot CAR_{a,c,h}^b \right) \right], \tag{2}$$

where Q_a^b : Annual traffic volume of vehicle type – ***b*** on highway-***a*** (vehicle-km),

$DIS_{a,c}$: Length of observed section-***c*** on highway-***a*** (km),

$CAR_{a,c,k}^b$: Daily traffic volume of vehicle type-***b*** on section-***c*** of highway-***a*** for day type-***k*** (vehicle/day),

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distinguish vehicle types, but these studies consider only noise.

d : number of weekdays (d=246 days),

a: highway , ***b***: type of vehicle (1= car, 2 = bus, 3 = small truck, 4 = truck), ***c***: section of highway, ***k***: day type (w = weekday, h = weekends).

3.3 Peak Period

In this study, we distinguish peak-time period and off-peak-time period. We set up two peak-time periods totaling 6 hours, consisting of 3 hours in the morning and 3 hours in the evening. For each peak-time and off-peak-time period, we set up the speed of vehicle and traffic volume individually.

However, when we observe the real data for highways, there are highways with considerable traffic volume even in off-peak-time periods, especially in rural areas, where we believe that in fact there is no peak-time period. We did not set up peak-time and off-peak-time periods for 5 sections of highways because the estimated traffic volume exceeds the real numbers.

3.4 Speed on Highways

As for speed on highways, we estimate speed by distinguishing weekday or weekend, peak-time or off-peak-time. However, if the estimated speed on the section of a highway is higher than the designated speed limit of the section of the highway, we set the designated speed limit as the speed for that section.

There are two estimation methods of speed on highways. For the first, we use existing data on speed on a section of highway, if such data are available. As vehicle speed at the peak period, we use the existing data on vehicle speed. However, as data on vehicle speed during the off-peak period does not exist, we estimate the vehicle speed of a section of highway by using the relationship between speed and traffic volume at the peak-time period. Based on the data on vehicle speed and traffic volume at the peak-time period by type of highway, we obtain the results shown in Table-1.

Table-1 Estimated Vehicle Speed-Traffic Volume Relationship on Highways

Type of highway	Estimated Speed-Traffic Volume Equations
Highway with a speed limit of 100km/h	$V_a = -\underset{(-0,00000284)}{0.000019}\, q_{a,line}^2 + \underset{(0.0043)}{0.018}\, q_{a,line} + \underset{(1.40)}{82.58} \quad adjR^2 = 0.253 \quad N = 358$
Highway with a speed limit of 80km	$V_a = -\underset{(-0,0000036)}{0.000022}\, q_{a,line}^2 + \underset{(0.00557)}{0.021}\, q_{a,line} + \underset{(1.65)}{76.34} \quad adjR^2 = 0.195 \quad N = 406$
Highway with a speed limit of less than 80km	$V_a = -\underset{(0.0020)}{0.0069}\, q_{a,line} + \underset{(1.10)}{78.81} \quad adjR^2 = 0.049 \quad N = 209$

Urban Highway with a speed limit of 80km	$V_a = -\underset{(-0,00000716)}{0.000072}\, q_{a,line}^2 + \underset{(0.0344)}{0.080}\, q_{a,line} + \underset{(13.23)}{58.31}$ $adjR^2 = 0.580$ $N = 27$
Urban Highway with a speed limit of less than 80km	$V_a = -\underset{(0.0137)}{0.016}\, q_{a,line} + \underset{(6.366)}{57.56}$ $adjR^2 = 0.203$ $N = 96$

(Note): V_a : Vehicle speed (km/h) per lane on highway – a,

$q_{a,line}$: Traffic volume (vehicle/h) per lane

4. Models for the Estimation of Individual Social Costs

In this section, we will summarize the models for estimating five kinds of social costs of vehicular transport on a highway: (i) traffic accidents, (ii) air pollution, (iii) noise, (iv) global warming, and (v) traffic congestion. The basic models summarized here are based on Mizutani et al. (2011).

4.1 Traffic Accidents

First, the social costs of traffic accidents are estimated by multiplying the unit social cost of traffic accidents by the number of victims resulting from traffic accidents, as equation-(3) shows. As these social costs vary according to type of damage, we distinguish types of victims.

$$C_{acc,a} = \sum_{e}(P_{acc,e} \cdot POP_{acc,a,e}) \tag{3}$$

where, $C_{acc,a}$: Social costs of traffic accidents on highway – a (yen),

$P_{acc,e}$: Unit social cost of traffic accident type – e (yen),

$POP_{acc,a,e}$: Number of victims of type- e caused by traffic accidents (persons),

$\boldsymbol{e}$: Type of victims (1: death, 2 : injured)[2]

Based on reported statistics on traffic accidents in Japan from the Cabinet Office (2007), we define unit social costs as 229,032 thousand yen for the death of a victim and 5,044 thousand yen for an injured victim.

4.2 Air Pollution

According to INFRAS/IWW (2004), as for the estimation method of the social costs of air pollution, there are two approaches: top down and bottom up. In this study, following Mizutani et

[2] In Mizutani et al. (2011), type of victim is classified into three categories: (i) death, (ii) seriously injured and (iii) lightly injured. However, statistics on highways show no distinction between seriously injured and lightly injured, so that we had to use only two categories for statistics on victims.

al. (2011), the bottom up approach, which calculates the social costs by examining, in order, pollutants produced by vehicular transport, is chosen, as shown in equation-(4) to (8).

$$C_{air,a} = \sum_{g} P_{air,g} \times POP_{air,a,g} \tag{4}$$

$$POP_{air,a,g} = f_{air,g}(ATM_{PM,a}) \tag{5}$$

$$ATM_{PM,a} = atm_{PM,a} - atm_{back,PM} \tag{6}$$

$$atm_{PM,a} = \alpha_{air,PM} \times EMI_{PM,a} \tag{7}$$

$$EMI_{PM,a} = \sum_{b}(ER^{b}_{PM} \cdot Q^{b}_{a}) \tag{8}$$

where, $C_{air,a}$: Social costs of air pollution on highway – a caused by vehicular transport (yen),

$P_{air,g}$: Unit social cost of air pollution type- g (yen),

$POP_{air,a,g}$: Number of victims of type – g on highway – a caused by air pollution (person),

$f_{air,g}(\cdot)$: Exposed function by air pollution for type – g,

$ATM_{PM,a}$: Annual concentration level of air pollution substances of PM_{10} caused by vehicular transport on highway – a(μg／km^3),

$atm_{PM,a}$ [3]: Annual concentration level of PM_{10} (SPM) on highway – a,

$atm_{back,PM}$: Annual concentration level of PM_{10} caused by non-vehicular transport,

$\alpha_{air,PM}$: Parameter for the impact of PM_{10} by vehicular transport pollutants on surrounding area per 1km^2,

$EMI_{PM,a}$: Annual amount of PM_{10} per area of 1km^2 of vehicular transport pollutants on highway – a (g/year),

ER^{b}_{PM} : Coefficient for pollution by PM_{10} by vehicular transport type-b (g/km)[4],

Q^{b}_{a} : Traffic volume of vehicular transport type-b on highway-a (vehicle-km),

b : Vehicular transport type (b=1: passenger car, 2: bus, 3: small truck, 4: truck),

g: Type of health damage by air pollution[5],

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[3] The data on this measure for each highway are not available, so we estimate this measure based on the city's annual concentration level of PM10. By regression analysis, we obtain the following results.

$$atm_{PM,a} = 0.023 + 0.00111 EMI_{PM,a} + 0.0051 D$$
$$(61.44) \quad (2.91) \quad (10.66) \quad adjR^2 = 0.241$$

$atm_{PM,a}$: Annual average concentration level of PM_{10} (SPM) in city – a (mg/km^3),

$EMI_{PM,a}$: Annual amount of PM_{10} per area of 1km^2 of vehicular transport pollutants in city – a (g/ m^2/year),

D : Dummy of City in Pacific Ocean Belt Areas.

[4] The coefficient for pollution by PM_{10} is obtained by using the calculation method of the Ministry of the Environment.

The unit social cost for this measure is based on Mizutani et al. (2011).

4.3 Noise

The social costs of noise are estimated by equation-(9) and (10). Noise is transformed into monetary value. In this study, we modify the equation shown in the *Doro Toshi no Hyoka ni Kansuru Shishin Kento Iinkai* (1998).

$$C_{dB,a} = P_{dB} \cdot \left(EMI_{dB,a} - EMI^{*}_{dB} \right) \cdot POP_{dB,a} \tag{9}$$

$$POP_{dB,a} = \sum_{h} DIS_{a,h} \cdot R_{dB} \cdot PD_{a,h} \tag{10}$$

where, $C_{dB,a}$: Social costs of noise by vehicular transport on highway-*a* (yen),

P_{dB} : Unit social cost of noise (yen/dB),

$EMI_{dB,a}$: Noise level caused by vehicular transport on highway-*a* (dB(A))[6],

$EMI_{dB}*$: Standard noise level (50dB),

$POP_{dB,a}$: Exposed population to noise level $EMI_{dB,a}$ (person),

$DIS_{a,h}$: Road length in surrounding area type-*h* on highway-*a* (km),

R_{dB} : Affected areas exposed to noise (extension from the roadside of highway = 10m),

$PD_{a,h}$: Population density in surrounding area-*h* on highway-*a* (person/km^2),

h : Surrounding area (h=1: DID area, 2: non-DID area)

Again, the unit social cost for this measure is based on Mizutani et al. (2011).

4.4 Global Warming

The social costs of global warming are calculated by equation-(11) and (12).

$$C_{war,a} = P_{war} \cdot EMI_{CO2,a} \cdot Tran_{CO2} \tag{11}$$

$$EMI_{CO2,a} = \sum_{b} ER^{b}_{CO2,a} \cdot Q^{b}_{a} \tag{12}$$

where, $C_{war,a}$: Social cost of global warming caused by vehicular transport on highway-*a*,

P_{war} : Unit social cost of emission of CO_2 (yen/t- CO_2),

$EMI_{co2,a}$: Annual emission of CO_2 on highway-*a* (g- CO_2/year),

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[5] Health damage caused by air pollution is classified into two major categories: mortality and morbidity, as in the previous study by the European Commission (2005).

[6] Noise level is estimated with equations based on the *Doro Toshi no Hyoka ni Kansuru Shishin Kento Iinkai* (1998).

$Trans_{CO2}$: Transformation coefficient for ton unit of emission of CO_2,

$ER_{CO2,a,b}$: Coefficient for emission of CO_2 by vehicular transport type-*b* on highway-*a* (g-CO2/km),

Q^b_a: Traffic volume of vehicular transport type-*b* on highway-*a* (vehicle-km),

b : Vehicular transport type（***b***=1 : passenger car, 2 : bus, 3 : small truck, 4 : truck）.

As for the unit social cost for this measure, we assume that it is 1,233 yen/t- CO_2. This cost is obtained from information from the European Commission (2005), in which the unit social cost for this measure is 9 Euro/t- CO_2 and the exchange rate is 137 yen/Euro.

4.5 Traffic Congestion

The social costs of traffic congestion are estimated in three steps. First, daily time loss due to traffic congestion is estimated. Time loss is specified as a function of traffic volume and road length and speed, as shown in equation-(15). Second, annual time loss due to traffic congestion is calculated. As equation-(14) shows, congestion conditions on weekdays and weekends are different, so we obtain the time loss separately. Last, the monetary value of traffic congestion is obtained, as equation-(13) shows.

$$C_{con,a} = \sum_b P^b_{con} \cdot TL^b_a \tag{13}$$

$$TL^b_a = tl^b_{a,k=weekday} \cdot d_w + tl^b_{a,k=holiday} \cdot d_h \tag{14}$$

$$tl^b_{a,k} = \sum_i \left(\frac{DIS_{a,i}}{V_{a,i}} - \frac{DIS_{a,i}}{V^*_i} \right) \cdot Q^b_{a,i,k} \quad , \tag{15}$$

where $C_{con,a}$: Social cost of traffic congestion on highway-*a* (yen),

P^b_{con} : Unit social cost of time loss caused by traffic congestion of vehicle type-*b* on highway-*a* (yen / minute-vehicle),

TL^b_a : Annual time loss caused by traffic congestion of vehicle type-*b* on highway-*a* (minute-vehicle/year),

$tl^b_{a,k}$: Daily time loss caused by traffic congestion on day type-*k* of vehicle type-*b* on highway-*a* (minute-vehicle/day),

d_k : Number of weekdays and weekends per year, *k* = *w*(weekday), *h*(weekend) (d_w = 246 days, d_h = 119 days),

$DIS_{a,i}$: Road length of observation point -*i* on highway-*a* (km),

$V_{a,i}$: Average speed at observation point-*i* on highway-*a* (km/h),

V_i* : Legally permitted maximum speed at observation point -*i* (km/h),

$Q^{b}_{a,i,k}$: Traffic volume of vehicle type-b at observation point -i on highway-a (vehicle/day)

b : Vehicular transport type（$\boldsymbol{b}$=1 : passenger car, 2 : bus, 3 : small truck, 4 : truck）

i : Observation point,

k : Weekday and weekend (k = w: weekday, h: weekend)

Again, the unit social cost for this measure is based on Mizutani et al. (2011).

5. Estimation Results of Social Costs of Highways

This section describes the structure of the estimated social costs of vehicular transport on highways. We focus especially on the following points: (i) the relationship between social costs and traffic volume, (ii) the relationship between unit social costs per vehicle-km and traffic volume, and (iii) the structure and magnitude of social costs.

First of all, Figure 1 shows the relationship between the social costs of vehicular transport and traffic volume. The vertical axis is the social costs of highways. The horizontal axis is measured as average numbers of vehicles per hour on highways. The most important finding is that social costs increase at an accelerated rate as traffic volume increases. At around 3,000 vehicles per km of traffic volume, social costs seem to increase rapidly. A similar finding with regard to city size can be found in a study by Mizutani et al. (2011), which showed that cities with larger populations produce larger unit social costs.

Second, there are variations in the details of social costs. As for air pollution and noise, distribution becomes much larger than for accidents and traffic congestion, which are more related to the number of vehicles.

Figure 2 shows the relationship between unit social costs per traffic (vehicle-km) and number of vehicles per hour. The relationship is not linear. However, the fitted line by the quadratic curve shows a gentler slope than is the case in Figure 1.

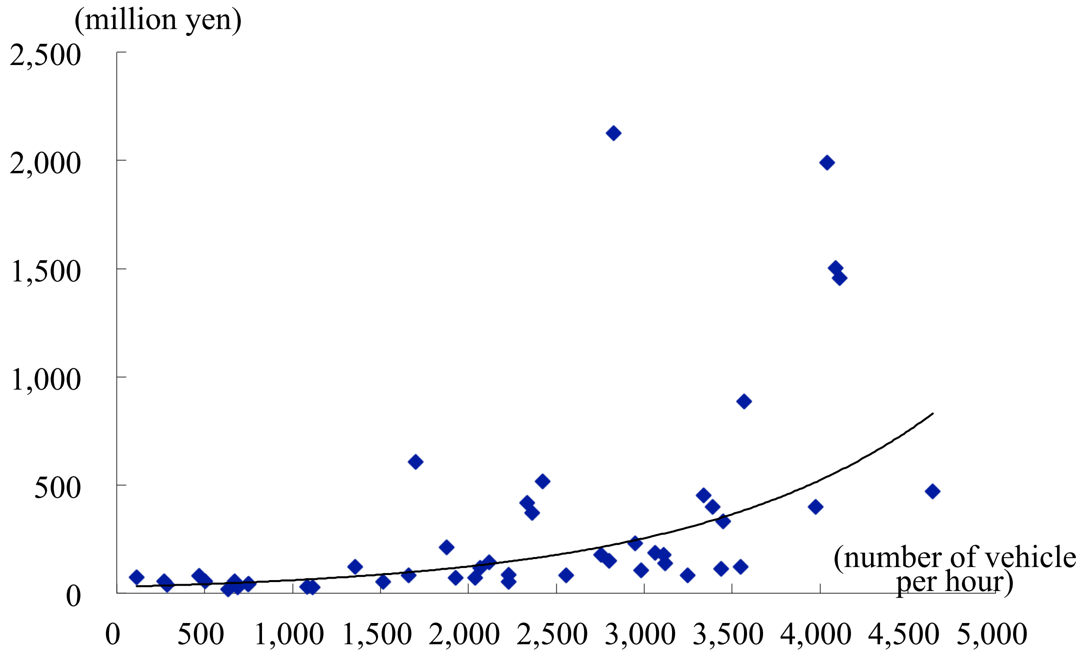

Figure 1 Relationship Between Social Costs of Vehicles and Number of Vehicles

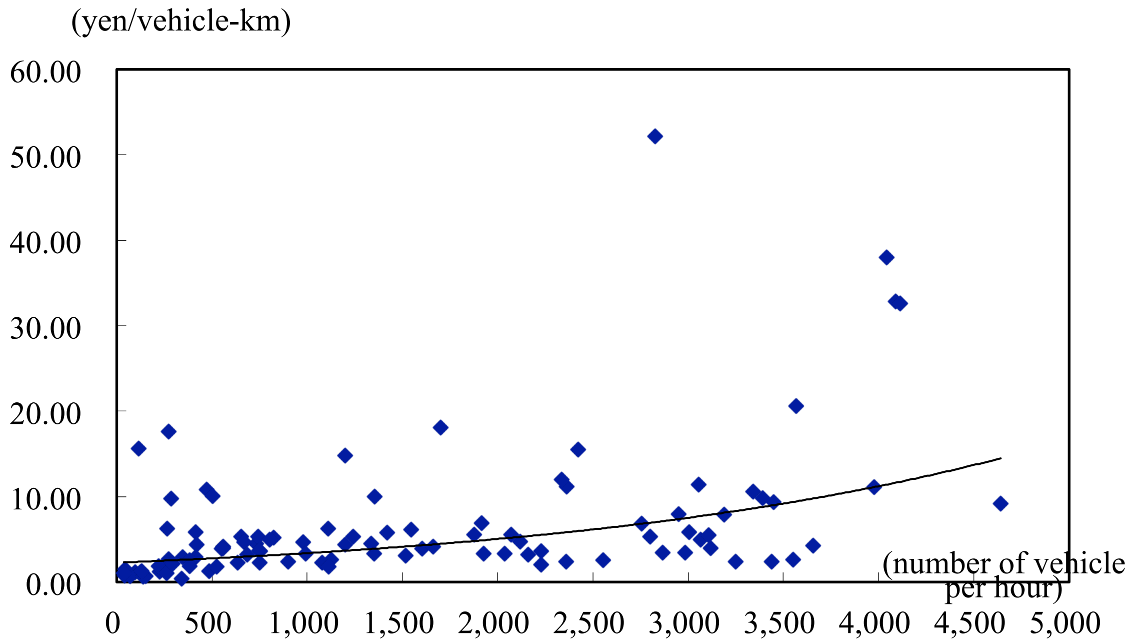

Figure 2 Relationship Between Social Cost per Traffic and Number of Vehicles

Third, the structure and the magnitude of social costs for whole highway networks are shown in Table 2. From this table, we discern the following facts. The largest component of vehicular transport's social costs on highways is traffic congestion, accounting for about 64%. The second largest component is traffic accidents, accounting for 24%. Compared with these two components, other components such as air pollution, noise and global warming make up only a small percentage of costs. In particular, air pollution resulting from a city's transport accounted for 18 to 21%, according to Mizutani et al. (2011), but in the present study the air pollution component is smaller. In general, highway speed is high and most highways connect cities in less populated areas, so that social costs due to air pollution become smaller.

Table 3 shows the social costs of types of vehicles. According to this table, the total social costs of buses are the highest, based on vehicle-km, at about 16 times higher than for regular cars. However, buses transport more passenger than regular cars, so that the figure would be lower if based on passenger-km. Trucks' social costs are about 3 times higher than those of regular cars.

As for the magnitude of social costs of vehicles shown in Table 4, total social costs for whole highway networks are about 678,212 million yen, or about 0.13% of Japan's entire GDP. Compared with highway fare revenues (1,083,600 million yen) and the operating costs of highways (687,770 million yen), social costs account for 62.6% and 98.6%. Thus, the social costs of vehicles on highways are almost the same as highways' operating costs. If we include both the operating costs and social costs of highways, current fare revenues do not cover these costs. If it is considered necessary to cover these costs, then highway fare should be increased.

Table 2 Estimated Social Costs of Highways

	Total	Traffic Accidents	Air Pollution	Noise	Global Warming	Traffic Congestion
Total (million yen)	678,212 (100.0%)	164,460 (24.2%)	15,727 (2.3%)	32,349 (4.8%)	32,466 (4.8%)	433,210 (63.9%)
Per km (million yen)	83.638	20.281	1.939	3.989	4.004	53.424
Per vehicle-km (yen)	8.278	2.007	0.192	0.395	0.396	5.287

(Note):

(1) These numbers are aggregate results of whole highway networks in Japan.

(2) Total network length of highways is 8,108.9 km and total vehicle-km is 81,932.

(3) Highway fare revenues in FY2005 for all highways are 1,083,600 million yen. And the operating costs of highways (administration costs and depreciation) are 687,770 million yen.

(4) GDP in 2005 is 503,921 billion yen, based on IMF's World Economic Outlook Database.

Table 3 Social Costs and Vehicle Type

	Total	Traffic Accidents	Air Pollution	Noise	Global Warming	Traffic Congestion
Car	6.50 (1.00)	1.99 (1.00)	0.05 (1.00)	0.82 (1.00)	0.17 (1.00)	3.48 (1.00)
Bus	105.58 (16.39)	3.24 (1.63)	3.40 (68.00)	2.71 (3.30)	0.68 (4.00)	96.55 (27.74)
Small Truck	7.93 (1.22)	2.65 (1.34)	0.40 (8.00)	0.82 (1.00)	0.21 (1.24)	3.85 (1.11)
Truck	21.98 (3.38)	2.65 (1.34)	3.55 (71.00)	2.46 (3.00)	0.94 (5.53)	12.37 (3.55)

(Note):

(1) Unit: yen / vehicle-km

(2) These numbers are the sample mean of 102 observations of highway networks.

(3) Total vehicle-km at the sample mean is 486 (car), 15 (bus), 86 (small truck), 217 (truck) million vehicle-km.

Table 4 Magnitude of Social Costs

	Total Social Costs of Highways	Total Fare Revenues of Highways	Total Operating Costs of Highways	GDP in Japan
Total (million yen)	678,212	1,083,600	687,770	503,921,000
Ratio of Total Social Costs of Highways to Each Item	1.000	0.626	0.986	0.001

(Note):

(1) Fare revenues of highways are an aggregate of all highways in FY2005.

(2) Total operating costs of highways consist of administration costs and depreciation.

(3) GDP in 2005 is obtained from IMF’s World Economic Outlook Database.

6. Concluding Remarks

The main purpose of this paper is to estimate and evaluate the social costs of highways in Japan. This study has several distinguishing points: 1) we estimate each individual highway's social costs by considering average speed at the peak period, total traffic volume, and types of vehicular transport; 2) we distinguish five kinds of social costs of vehicular transport: (a) traffic accidents, (b) air pollution, (c) noise, (d) global warming, and (e) traffic congestion; 3) we analyze the relationship between the social costs of vehicular transport and traffic volume by using a data set of over 50 individual highways; and 4) we assess the magnitude of social costs by comparing with GDP, highway fare revenues and the operating costs of highways.

Our findings based on the estimated results of social costs of highways are as follows.

(1) Social costs increase at an accelerated rate as traffic volume increases. At around 3,000 vehicle per km in traffic volume, social costs seem to increase rapidly.

(2) Accidents and traffic congestion are more related to number of vehicles than are air pollution and noise.

(3) The relationship between unit social costs per traffic (vehicle-km) and number of vehicles is not linear, but the fitted line by the quadratic curve shows a gentle slope.

(4) The largest component of vehicular transport's social costs on highways is traffic congestion, accounting for about 64%. The second largest component is traffic accidents, accounting for 24%.

(5) Compared with these two components, other components such as air pollution, noise and global warming represent a small percentage of costs.

(6) Among vehicle types, buses' social costs are largest at 105 yen per vehicle-km, about 16 times higher than those of regular cars.

(7) Total social costs of whole highway networks are about 678,212 million yen, or about 0.13% of Japan's GDP. Compared with highway fare revenues (1,083,600 million yen) and the operating costs of highways (687,770 million yen), social costs equal 62.6% and 98.6%, respectively.

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[2015.5.25 1203]