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Estimation of Social Costs of Transport in Japan

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Abstract

Using a dataset of 111 Japanese cities in 2005, the article estimates the social costs of car transport and analyses the structure of the components of and the relationship between social costs and city size. The following major results are obtained. First, the social costs of vehicular transport increase at an accelerated pace as city size becomes larger. Secondly, while the construction of roads does not work to decrease the social costs of vehicular transport, public transport has a tendency to decrease such costs, although with minimal effect. Thirdly, the traffic congestion component represents more than 45 per cent of the total social cost of vehicular transport. Cost due to global warming accounts for 5–11 per cent of the total. Fourthly, the social costs of vehicular transport are about 8 per cent of GDP. Fuel tax for cars covers only 16.3 per cent of the social costs of regular car use.

1. Introduction

With more people concerned about protecting the environment at both local and global levels, dependence on vehicular transport in cities has brought about problems. First, dependence on autos causes air pollution, which has detrimental health effects. Secondly, traffic congestion resulting from the excessive use of automobiles wastes time, money, fuel and economic and social opportunities. Furthermore, the noise from traffic congestion makes it hard to maintain a peaceful, attractive urban environment. What many people are perhaps most concerned about, however, is the idea that continued dependence on car use is likely to exacerbate the problem of global warming. Policy-makers in cities seek to address all these problems and worries by looking for constructive ways to regulate car use with the goal of improving or protecting the environment, while at the same time maintaining healthy economic conditions. In order to implement policies conducive to creating a sustainable environment, it is necessary to measure correctly the social costs of vehicular transport—that is, the external costs of such

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phenomena as traffic accidents, air pollution, noise, global warming and traffic congestion. By using a dataset from Japan, this paper aims to estimate the social costs of vehicular transport and to analyse the structure of the components of the total cost, as well as to examine the relationship between social costs and city size.

Many studies have estimated social costs. For example, in the US, by analysing a dataset from Los Angeles, Small and Kazimi (1995) and McCubbin and Delucchi (1999) estimate the social costs of air pollution from both gasoline cars and diesel trucks. Forkenbrock (1999) estimates not only the social cost of air pollution but also that of traffic accidents, noise and global warming. In Europe, there has been a considerable amount of research. For example, by using a dataset from Brussels for a study focusing on the social costs of accidents, air pollution, noise and traffic congestion, Mayeres *et al.* (1996) estimate the social costs of various types of vehicle, such as gasoline cars, diesel cars, buses and trucks. Moreover, they distinguish between social costs at peak and off-peak periods. ECMT (1998) estimates for 17 European countries the social costs of such phenomena as traffic accidents, air pollution, noise and global warming. Other studies from Europe include Eyre *et al.* (1997) for the UK and Danielis and Chiabai (1998) for Italy. Since 2000, UNITE (2003) and INFRAS/IWW (2004) have estimated various kinds of social costs, including that of global warming. In addition, studies from places other than the US and European countries have estimated social costs: Koyama and Kishimoto (2001) in Japan, Deng (2006) in Beijing, China, and Jakob *et al.* (2006) in Auckland, New Zealand.

Our study has several distinguishing characteristics, the most important of which is that we base our estimate of each individual city's social costs on the entire city's average speed at the peak period, and the total traffic volume of each city according to its types of road (i.e. regular roads or highways) and its types of vehicular transport. We consider each city's traffic conditions and urban structure when estimating the social costs of vehicular transport. Secondly, this study focuses on five kinds of social costs of vehicular transport, of which we give estimates for individual cities in Japan: traffic accidents, air pollution, noise, global warming and traffic congestion. Of previous studies, only those of Koyama and Kishimoto (2001) and UNITE (2003) estimate these five social costs. Thirdly, by using a dataset for 111 cities in Japan in 2005, we analyse the relationship between the social costs of vehicular transport and city size, investigating whether city size is proportional to social cost. This study is perhaps the first empirical analysis to estimate how social costs increase along with city size. Fourthly, with regression analysis, we evaluate the effects of urban infrastructure on the social costs of vehicular transport, determining the extent to which infrastructure and public transport reduce the social costs of a city's vehicular transport. Last, by comparing the degree of GDP, the fuel tax level and other factors, we assess the magnitude of social costs.

The structure of our study is as follows. First, we summarise previous studies, with attention to the following points: the kinds of social costs and sub-items considered to estimate social costs, the aggregate level, the method of estimation and the magnitude of the social costs of vehicular transport. Secondly, we explain our method for estimating social cost, describing specific equations for the five main categories of social costs. Thirdly, based on these equations, we conduct an empirical analysis using a dataset of 111 cities, to estimate the social costs of vehicular transport. By using comparisons of the cities' GDP and fuel tax levels, we evaluate the results regarding such matters as the relationship between social costs and city size, the effect of urban structure and infrastructure on social costs, and the magnitude of social costs. Finally, we summarise our major findings.

2. Previous Studies of the Social Costs of Transport

2.1 Kinds of Social Costs

First, we deal with air pollution, the main issue concerning most researchers who have aimed to estimate transport's social costs, examined previously by Small and Kazimi (1995), Eyre *et al.* (1997), Danielis and Chiabai (1998), WHO (1999) and McCubbin and Delucchi (1999).

Also widely considered as social costs of transport are traffic accidents, noise and traffic congestion, all of which are used, in addition to air pollution estimates, by Mayeres *et al.* (1996), Levinson *et al.* (1998) and Beuthe *et al.* (2002).

More recently, global warming believed to be caused by transport has been added to the list of its social costs, as can be seen in such previous studies as ECMT (1998), Forkenbrock (1999), Koyama and Kishimoto (2001), UNITE (2003) and INFRAS/IWW (2004).

Other social costs include damage to the landscape caused by transport facilities, the cost of separating pedestrian from motor traffic and the problem of space scarcity as land is allocated for roads. There are also costs associated with the impediments to cycling caused by transport facilities. Although few studies take these factors into account when calculating the social costs of transport, INFRAS/IWW (2004), for example, includes them.

In this study, we take for our estimation of the social costs of transport those most commonly used: traffic accidents, noise, air pollution, global warming and traffic congestion.

2.2 Aggregation Unit

Most previous studies use whole countries as the aggregation unit of social costs. For example, ECMT (1998), UNITE (2003) and INFRAS/IWW (2004) use whole countries in Europe, although these studies choose to focus on slightly different country groupings, employing cross-sectional datasets. On the other hand, some studies estimate the social costs of a single country by using a dataset for the individual country. Examples of these studies include Eyre *et al.* (1997) for the UK, Levinson *et al.* (1998) and Forkenbrock (1999) for the US, Danielis and Chiabai (1998) for Italy, Beuthe *et al.* (2002) for Belgium and Koyama and Kishimoto (2001) for Japan.

Studies using cities as aggregation units are few, although some such studies do estimate the social costs of transport. Included in this category are Small and Kazimi (1995), Mayeres *et al.* (1996), McCubbin and Delucchi (1999), Gibbons and O'Mathony (2002), Deng (2006) and Jakob *et al.* (2006). While it should be noted that these studies estimate social costs of transport for only one city, there are no studies using cross-sectional data to estimate social costs for different cities.

2.3 Estimation Approach of Social Costs

Traffic accidents. The most commonly used measures of the social costs of traffic accidents are deaths, injuries and damaged goods, of which the former two predominate, as shown in Persson and Ödegaard (1995), ECMT (1998), Koyama and Kishimoto (2001), Beuthe *et al.* (2002) and UNITE (2003). Some studies further sub-divide injuries according to the level of seriousness, as in Beuthe *et al.* (2002), UNITE (2003) and Koyama and Kishimoto (2001). Damaged goods as a measure are used in Levinson *et al.* (1998) and Beuthe *et al.* (2002).

Previous studies generally estimate traffic accidents' social costs in two steps: first, estimating the number of accidents related to vehicular transport and evaluating the resulting damage; and, secondly, calculating the monetary value of damage resulting from accidents.

The first step can be approached in two ways. One, seen in studies such as ECMT (1998), UNITE (2003) and INFRASS/IWW

(2004), is the direct use of accident numbers from available data sources. This approach is accurate and convenient if data can be directly obtained, but infeasible if accident data are unavailable. The second approach, used in studies such as Persson and Odegaard (1995), Mayeres *et al.* (1996) and Beuthe *et al.* (2002), is to estimate the number of accidents by building equations describing the relationship between accidents and factors like road conditions. This approach is useful if accident data are unavailable, but is contingent upon the construction of a reasonable model for predicting accidents.

For the second step, calculating the monetary value of traffic accident damage, most previous studies use the number of fatalities, the number of severely injured persons and the number of accidents resulting in damage to property. Also used as social costs in previous studies, such as ECMT (1998) and INFRASS/IWW (2004), are WTP (willingness to pay) for avoiding traffic accidents, other economic costs such as loss of production due to accidents, administrative costs for ambulances and medical costs.

Air pollution. The most widely used measure for the social costs of air pollution is PM_{10}, as can be seen in Small and Kazimi (1995), Eyre *et al.* (1997), McCubbin and Delucchi (1999), WHO (1999), Koyama and Kishimoto (2001) and the European Commission (2005). In addition to PM_{10}, ozone, NO_X, SO_X and VOC are sometimes used, as shown in, for example, Small and Kazimi (1995), Eyre *et al.* (1997) and McCubbin and Delucchi (1999). Most studies, such as Small and Kazimi (1995), WHO (1999) and McCubbin and Delucchi (1999), consider the effects of pollutants on human health. In addition to human health effects, Eyre *et al.* (1997), UNITE (2003) and INFRAS/IWW (2004) consider pollutants' effects on agriculture and forests.

Of the two different approaches to air pollution, one uses air pollution's unit social costs. By multiplying the total volume of pollutants in a given area by the costs per pollutant produced by vehicular transport, the total social costs of air pollution are obtained. Mayeres *et al.* (1996), Eyre *et al.* (1997) and Levinson *et al.* (1998) use this approach. The second approach is to obtain the marginal social costs of air pollution in a given area, information descriptive of the relationship between the degree of air pollution and the traffic volume under given city conditions. Examples using this approach are Small and Kazimi (1995), WHO (1999) and INFRAS/IWW (2004).

Each approach has advantages and disadvantages. The former is a convenient way to estimate social costs, but if city conditions are different from those considered in previous studies, the estimates' reliability might decrease. On the other hand, while the latter approach describes the relationship between air pollution and traffic volume in city conditions, and thus would provide more reliable estimates of social costs, this approach requires more information about population, road conditions and so on.

Noise. The social costs of noise are estimated generally in two steps. First, noise level and its effect on areas are estimated. Secondly, the monetary values of noise levels are obtained.

The first step can be carried out in two ways, one using available information from previous studies to show the percentage of the population exposed to vehicular transport noise. Studies using this approach are ECMT (1998), UNITE (2003) and INFRAS/IWW (2004). The second approach, a more sophisticated method describing the relationship between noise level and traffic volume, can be seen in Mayeres *et al.* (1996) and Levinson *et al.* (1998).

The first approach is a convenient method of estimating social costs, but because the noise levels and the affected areas vary according to environmental conditions, it might be difficult to find among previous studies conditions similar to those under present consideration.

By considering the traffic volume of each vehicle type, traffic speed, city conditions such as population density and so on, the second approach establishes a model describing the relationship between traffic and noise. The second approach enables a more precise estimation of noise than the first approach. Noise produced by vehicular transport depends on many factors. The estimation model for congestion must take into account such factors as traffic volume, speed of vehicles, kinds of vehicles and city conditions. However, this approach requires extensive data, which cities often do not record, making it difficult for independent researchers to prepare adequate information.

Global warming. As for global warming measures, CO_2 is most commonly used—for example in studies by Mayeres *et al.* (1996), Eyre *et al.* (1997), Forkenbrock (1999), Koyama and Kishimoto (2001) and INFRAS/IWW (2004). Some studies, such as Mayeres *et al.* (1996) and Eyre *et al.* (1997), use CO in addition to CO_2.

The social cost of global warming is generally obtained by first estimating the volumes of pollutants causing global warming and secondly estimating the monetary values of the global warming damage resulting from pollution.

There are in general two approaches to estimating the pollutants causing global warming. Some studies—for example, UNITE (2003) and INFRAS/IWW (2004)—use the first, which relies on previous studies to estimate the volume of CO_2 as pollutants emitted by cars. The second approach is to use the volume of CO_2 per traffic volume by taking into account vehicle types and road conditions. This approach is used in Mayeres *et al.* (1996), Eyre *et al.* (1997) and Forkenbrock (1999).

In the second step, the monetary values of CO_2 emissions are estimated using unit social costs of CO_2 from previous studies. For example, INFRAS/IWW (2004) and UNITE (2003) use the unit costs for counter-measures as discussed in the Kyoto Protocol at the United Nation's Framework Convention on Climate Change in 1997.[1]

Congestion. Traffic congestion is measured as time lost in traffic congestion. To estimate the social costs of traffic congestion, the following procedure is generally used. First, the speed of vehicular transport is obtained from traffic volume. Estimation models are obtained from previous studies formulating the relationship between flow speed and traffic volume. For example, Mayeres *et al.* (1996) use a study by Kirwan *et al.* (1995) formulating such a relationship. Other studies such as Levinson *et al.* (1998) and UNITE (2003) use similar kinds of models.

In the second step, time loss by congestion is calculated based on the flow speed obtained in the first step. This step involves taking into account variations in traffic conditions. For example, Mayeres *et al.* (1996) estimate time loss from congestion by distinguishing vehicle types as well as time differences (peak and off-peak periods). Furthermore, INFRAS/IWW (2004) considers travel purpose when estimating time loss due to congestion.

In the last step, the social costs of traffic congestion are obtained from unit social costs by multiplying time loss by congestion.

2.4 Degree of Social Costs

From the social costs of vehicular transport, we select five items: traffic accidents, air pollution, noise, global warming and traffic congestion. These five items cannot include all social costs of transport, but we think they comprise a large proportion of total costs. For example, while we do not make a separate category for 'health', we calculate certain health-related costs under the heading of air pollution. We do not include items such as undesirable effects on the landscape, the cost of protecting pedestrians from motor traffic or the loss of space for cyclists and others due to the encroachment of roads. We believe that these costs are less important, both in terms of quantity and measurability, than the costs we have chosen and which most studies cited in our literature review have focused on. Table 1 is a summary of the five social costs. To the greatest extent possible, we show the unit social costs of each item (i.e. US dollar per vehicle-km, yen per vehicle-km).

Table 1 shows the nominal values in each currency unit. Because it cannot evaluate the range of the social costs of transport, for each previous study we have converted each cost into 2005 US currency values based on the exchange rate for the year in which the study was done. As a result, we find that the social costs of vehicular transport are about 6 to 15 for traffic accidents, 0.7 to 5.3 for air pollution, 0.6 to 3.2 for noise, 0.6 to 1.9 for global warming and 4.9 to 6.4 for traffic congestion, all in US cents per vehicle-km for gasoline cars in general.

3. Method of Estimation of Social Costs

3.1 Major Characteristics of This Study

In this section, we explain our method of estimating the social costs of vehicular transport. First, we estimate the social costs of vehicular transport in each city by considering the types of vehicular transport such as cars, buses, small trucks and trucks. The total social costs of vehicular transport are the sum of the costs of the five items mentioned earlier. Thus, the social costs of vehicular transport in city *a* (SC_a) are defined as follows

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

where, SC_a = Social costs of vehicular transport in city *a*; $C_{acc,a}$ = social costs of traffic accidents in city a; $C_{air,a}$ = social costs of air pollution in city a; $C_{dB,a}$ = social costs of noise in city *a*; $C_{war,a}$ = social costs of global warming in city *a*; $C_{con,a}$ = social costs of traffic congestion in city *a*.

Secondly, in this study, we estimate the whole city's average speed at the peak period and the total traffic volume of each city, using actual measured information from government documents. We separate types of road (i.e. regular roads or highways) and types of vehicular transport in our estimation of the city's speed at the peak period, using as our data source the *2005 Road Transport Census* [*2005 Doro Kotsu Sensasu*], issued by the Ministry of Land, Infrastructure and Transport.

Last, the social costs are obtained by the estimation formula of each item of social costs, constructed on the basis of results from previous studies. As Japanese datasets are used in the estimation of social costs in this study, previous studies' estimation formulae based on cities in Europe and the US are not always appropriate, in which case we make modifications in order to avoid estimation bias related to city structure.

3.2 Key Variables for the Estimation of Social Costs

City's traffic volume. Traffic volume of vehicle type *b* in city *a* (Q_a^b) is the sum of traffic volumes on trunk roads ($Q_{a,trunk}^b$) and those on city roads ($Q_{a,city}^b$), as equation (2) shows. Equation (3) shows the estimation of traffic volume on trunk roads and equation (4) is for the traffic volume on city roads. Thus, the basic formula for the estimation of traffic volume is obtained from results of daily traffic volume on the observed road section

$$Q_a^b = Q_{a,trunk}^b + Q_{a,city}^b \quad (2)$$

$$Q_{a,trunk}^b = d \cdot \left[\sum_c \left(DIS_{a,c} \cdot CAR_{a,c,w,}^b \right) \right] + (365 - d) \cdot \left[\sum_c \left(DIS_{a,c} \cdot CAR_{a,c,h}^b \right) \right] \quad (3)$$

Table 1. Summary of social costs of vehicular transport

Study	*Place (year)*	*Mode*	*Unit*	*Accident*	*Air pollution*	*Noise*	*Global warming*	*Congestion*
Small and Kazimi (1995)	Los Angeles (1992)	Gasoline car	Cents/vehicle-mile	—	3.28	—	—	—
		Diesel truck (heavy-duty)	Cents/vehicle-mile	—	52.70	—	—	—
Mayeres *et al.* (1996)	Brussels (1991)	Small gasoline car (peak)	ECU/vehicle-km	0.079	0.036	0.002	—	0.269
		Small diesel car (peak)	ECU/vehicle-km	0.079	0.056	0.002	—	0.269
		Small gasoline car (off-peak)	ECU/vehicle-km	0.110	0.035	0.007	—	0.002
		Bus (peak)	ECU/vehicle-km	0.699	0.406	0.019	—	0.537
		Bus (off-peak)	ECU/vehicle-km	0.896	0.345	0.073	—	0.004
		Truck (peak)	ECU/vehicle-km	0.216	0.788	0.019	—	0.537
		Truck (off-peak)	ECU/vehicle-km	0.300	0.294	0.073	—	0.004
Eyre *et al.* (1997)	UK (1995)	Petrol (urban)	pence/km	—	1.060	—	—	—
		Gas (urban)	pence/km	—	0.375	—	—	—
		Diesel (urban)	pence/km	—	2.717	—	—	—
		Petrol (rural)	pence/km	—	0.500	—	—	—
		Gas (rural)	pence/km	—	0.211	—	—	—
		Diesel (rural)	pence/km	—	0.723	—	—	—
Levinson *et al.* (1998)	US (1995)	Highways	dollar/vehicle-km	0.03	0.0056	0.0068	—	0.0069
ECMT(1998)	15 EU countries, Switzerland, Norway (1991)	Cars	ECU/1000 vehicle-km	60	13	5	10	—
Danielis and Chiabai(1998)	Italy (1992)	Petrol vehicle	cents/vehicle-km	—	1.5	—	—	—
		Diesel vehicle (light-duty)	cents/vehicle-km	—	27.0	—	—	—
		Diesel vehicle (heavy-duty)	cents/vehicle-km	—	170.9	—	—	—

(Continued)

Table 1. (Continued)

Study	*Place (year)*	*Mode*	*Unit*	*Accident*	*Air pollution*	*Noise*	*Global warming*	*Congestion*
Forkenbrock (1999)	US (1994)	Truck	Cents/ton-mile	0.59	0.08	0.04	0.15	—
WHO (1999)[a]	Austria, France, Switzerland (1995)	Road transport for whole country	Million euro	—	49 715	—	—	—
McCubbin and Delucchi (1999)	Los Angeles (1991)	Gasoline (light-duty)	Cents/vehicle-mile (high)	—	23.2	—	—	—
		Diesel (light-duty)	Cents/vehicle-mile (high)	—	64.4	—	—	—
		Diesel (heavy-duty)	Cents/vehicle-mile (high)	—	324.0	—	—	—
Koyama and Kishimoto (2001)	Japan (1999)	Car	Yen/vehicle-km	7.1	1.8	3.6	2.2	7.3
		Bus	Yen/vehicle-km	7.4	69.2	35.6	9.4	14.6
		Truck	Yen/vehicle-km	7.9	59.1	35.6	7.8	14.6
		Small truck	Yen/vehicle-km	4.9	13.8	3.6	3.1	7.3
Beuthe *et al*(2002)	Belgium (1995)	Road (truck)	ECU/ton-km	0.00937	0.01820	0.00665		0.02108
Gibbons and O'Mathony (2002)[b]	Dublin (2005)	Car (small, petrol)	EURO/ passenger-km			0.5 (peak) 0.09 (off—peak)		
UNITE(2003)[c]	Germany (1998)	Private vehicles	EURO/1000 vehicle-km	129.51	7.70	4.6	4.91	44
		Bus/coach	EURO/1000 vehicle-km	111.05	96.40	40.8	18.01	132
		LGV	EURO/1000 vehicle-km	28.18	16.10	53.1	7.46	67
		HGV	EURO/1000 vehicle-km	22.82	71.80	35.0	19.60	133

Table 1. (Continued))

Study	*Place (year)*	*Mode*	*Unit*	*Accident*	*Air pollution*	*Noise*	*Global warming*	*Congestion*
INFRAS/IWW (2004)	17 EU countries (2000)	Car	EURO/1000 passenger-km	30.9	10.1	5.2	17.6	—
		Bus	EURO/1000 passenger-km	2.4	16.9	1.3	8.3	—
		Motor cycle	EURO/1000 passenger-km	188.6	3.3	16.0	11.7	—
		LDV	EURO/1000 ton-km	35.1	77.6	32.4	57.4	—
		HDV	EURO/1000 ton-km	4.75	34.0	4.9	12.8	—
Koyama (2004)	Japan (1999)	Car	Yen/vehicle-km	—	—	1.10	—	—
		Bus	Yen/vehicle-km	—	—	2.95	—	—
		Truck	Yen/vehicle-km	—	—	3.46	—	—
		Small truck	Yen/vehicle-km	—	—	1.34	—	—
Deng (2006)	Beijing (2000)	Road transport	Million $US	—	974	—	—	—
Jakob *et al.* (2006)[d]	Auckland (2001)	Public transport	NZ$/vehicle-km			0.73		
		Private car	NZ$/vehicle-km			0.062		

[a] Numbers for WHO (1999) are averages for the three countries, Austria, France and Switzerland.
[b] Gibbons and O'Mathony (2002) do not distinguish each individual social cost. In this table, the total social costs of all items are shown.
[c] UNITE (2003) estimated the social costs of 18 countries for 1994, 1995 and 2005. However, we show results only for Germany in 1998 because these results are described in detail in UNITE (2003).
[d] Jakob *et al.* (2006) do not distinguish each individual social cost. In this table, the total social costs of all items are shown.

$$Q^b_{a,city} = d \cdot DIS_{a,city} \cdot CAR^b_{a,city,w} + (365-d) \cdot DIS_{a,city} \cdot CAR^b_{a,city,h} \quad (4)$$

where, Q^b_a = annual traffic volume of vehicle type b in city a (vehicle-km); $Q^b_{a,trunk}$ = annual traffic volume of vehicle type b on the trunk road in city a (vehicle-km); $Q^b_{a,city}$ = annual traffic volume of type b on the city road in city a (vehicle-km); $DIS_{a,trunk}$ = length of observed road section c on trunk road in city a (km); $DIS_{a,city}$ = total length of city road in city a (km); $CAR^b_{a,c,k}$ = daily traffic volume of vehicle type b in the road section c on trunk road in city a for day type k (vehicle/day); $CAR^b_{a,city,k}$ = daily traffic volume of vehicle type b on city road in city a for day type k (vehicle/day); and a = city, b = type of vehicle (1 = car, 2 = bus, 3 = small truck, 4 = truck); c = road section on trunk road; d = number of weekdays (d = 246 days), k = day type (w = weekday, h = weekends).

Observed daily traffic volume is shown in the *2005 Road Transport Census*, carried out mainly on bigger roads and trunk roads. A comparison of total traffic volume appearing in the *2005 Road Transport Census* with traffic volumes recorded in other sources showed that those from the census are about 30 per cent smaller than from other sources, which include smaller city roads. We include estimates of traffic volume on city roads, as shown in equation (4).

Speed on roads. We distinguish two kinds of roads: general roads and highways. For general roads, we estimate the average traffic speed of a city based on traffic speed data obtained from given observation points. The estimation formula for speed shows the relationship between vehicle speed and traffic volume. Taking into consideration variations in city conditions, the formula includes the ratio of roads passing through DID (densely inhabited district) areas. The estimated average traffic speed for general roads is as follows[2]

$$V_{a,lane} = \underset{(43.81)}{38.1274} - \underset{(-3.95)}{0.0059}\, q_{a,lane} - \underset{(-19.81)}{19.9388}\, DID_{a,lane} \quad (5)$$

$$\text{Adjusted } R^2 = 0.465$$

where, $V_{a,lane}$ = vehicle speed (km/h) per lane in city a; $q_{a,lane}$ = traffic volume (vehicle/h) per lane; and $DID_{a,lane}$ = the ratio of roads passing through DID (densely inhabited district) areas.

As for highway speed, we distinguish highways in large metropolitan areas from those in non-large metropolitan areas. Data from the *Road Traffic Census* [*Doro Kotsu Sensasu*] show traffic congestion at peak periods on highways in large metropolitan areas. The majority of social costs described here are caused at peak period so that, in the large metropolitan areas only, we distinguish peak and off-peak average speed. The average speed for highways at the peak period in the large metropolitan areas is the observed speed at the peak period.[3] On the other hand, the speeds of others (i.e. the highways in large metropolitan areas at the non-peak period and the highways in non-large metropolitan areas at both the peak and the off-peak periods) are the legal speed limits.[4]

3.3 Estimation Models of Individual Social Costs

In this section, we will explain the formula for estimating five items of social costs produced by vehicular transport on a city-base.

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 (6) shows. As these social costs vary according to type of damage, we distinguish types of victims.

$$C_{acc,a} = \sum_e (P_{acc,e} \cdot POP_{acc,a,e}) \quad (6)$$

where, $C_{acc,a}$ = social costs of traffic accident in city 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); and $\boldsymbol{e}$ = type of victims (1 = death, 2 = seriously injured, 3 = lightly injured).

Statistics on type of victims caused by accidents are obtained from the *Annual Report of Traffic Accidents* [*Kotsu Jiko Tokei Nenpo*]. The unit costs are obtained on the basis of WTP (willingness to pay), as was the case in previous studies such as INFRAS/IWW (2004) and Forkenbrock (1999). Based on reported statistics on traffic accidents in Japan from the Cabinet Office (2007), we define unit social costs as 229 032 000 yen for the death of a victim, 84 810 000 yen for a seriously injured victim and 846 000 yen for a lightly injured victim.

Air pollution. There are two approaches to estimating the social costs of air pollution, as classified by INFRAS/IWW (2004): top–down and bottom–up. The top–down approach, used in WHO (1999) and INFRAS/IWW (2004), applies the unit costs of air pollution obtained from previous studies, while the bottom–up approach calculates the social costs by examining, in order, pollutants produced by vehicular transport. If data for air pollution and vehicular transport traffic are available, the bottom–up approach is better because the method itself is precise. In this study, we employ the bottom–up approach to estimate social costs, as shown in equations (7) to (11)

$$C_{air,a} = \sum_{g} (P_{air,g} \cdot POP_{air,a,g}) \qquad (7)$$

$$POP_{air,a,g} = f_{air,g}(ATM_{PM,a}) \qquad (8)$$

$$ATM_{PM,a} = Tran_{PM} \cdot \left(atm_{PM,a} - atm_{PM,nntr,a}\right) \qquad (9)$$

$$atm_{PM,a} = \alpha_{air,PM} \cdot EMI_{PM,a} \qquad (10)$$

$$EMI_{PM,a} = \sum_{i} \sum_{b} (ER^{b}_{PM,i} \cdot Q^{b}_{a,i}) \qquad (11)$$

where, $C_{air,a}$ = social costs of air pollution in city 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 caused by air pollution (person); $f_{air,g}$ = 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 in city a; $Tran_{PM}$ = adjustment coefficient for the difference between Japan and Europe in PM_{10} (h = 1.07); $atm_{PM,a}$ = annual concentration level of PM_{10} (SPM) in city a; $atm_{PM,nntr,a}$ = annual concentration level of PM_{10} (0.012mg/m^3) caused by non-vehicular transport emissions in city a; $\alpha_{air,PM}$ = parameter for the impact of PM_{10} by vehicular transport pollutants on surrounding area per square km; $EMI_{PM,a}$ = annual amount of PM_{10} per square km of vehicular transport pollutants in city a (g/year); $ER^{b}_{PM,i}$ = coefficient for pollution by PM_{10} in road type i by vehicular transport type b (g/km);[5] $Q^{b}_{a,i}$ = traffic volume of vehicular transport type b on road type i in city a (vehicle-km); b = vehicular transport type (1 = passenger car, 2 = bus, 3 = small truck, 4 = truck); g = type of health damage by air pollution;[6] i = road type (1 = highway, 2 = ordinary roads).

The essence of these equations is as follows. First, equation (7) obtains the social costs from the number of victims of air pollution. Secondly, equation (8) shows the relationship between the number of air pollution victims and the level of concentration of air pollutants PM_{10}. Called the dose-response function, this relationship has often been used in previous studies such as Mayeres *et al.* (1996), WHO (1999) and the European Commission (2005). We employ the dose-response function based on the European Commission (2005). Equations (9) and (10) show methods of calculating the concentration level of air-polluting substances PM_{10} caused by vehicular transport. These equations exclude air pollution substances produced by sources other than cars. Last, equation (11) shows the method of estimating air pollution substances from traffic volume.

Noise. The social costs of noise are estimated in two steps, the first of which is to estimate noise caused by vehicular transport, as shown in equation (12), which shows how noise affects people in surrounding areas. In the second step, as equation (13) shows, noise is transformed into monetary value

$$POP_{dB,a,i} = \sum_h DIS_{a,i,h} \cdot R_{dB} \cdot PD_{a,h} \quad (12)$$

$$C_{dB,a} = \sum_i P_{dB} \cdot \left(EMI_{dB,a,i} - EMI^*_{dB} \right) \cdot POP_{dB,a,i} \quad (13)$$

where, $C_{dB,a}$ = Social costs of noise by vehicular transport in city *a*; P_{dB} = unit social cost of noise (yen/dB); $EMI_{dB,a,i}$ = noise level caused by vehicular transport on road type *i* in city *a* (dB(A));[7] EMI^*_{dB} = standard noise level (50dB); $POP_{dB,a,i}$ = exposed population to noise level $EMI_{dB,a,i}$ (person); $DIS_{a,i,h}$ = road length of road type *i* in surrounding area type *h* in city *a* (km); R_{dB} = affected areas exposed to noise (extension from the roadside = 10m); $PD_{a,h}$ = population density in surrounding area-*h* in city *a* (person/km^2); *i* = road type (1 = highway, 2 = ordinary road); and *h* = surrounding area (1 = DID area, 2 = non-DID area.

Theoretically, noise caused by vehicular transport is affected by the speed of traffic, traffic volume, composition of vehicle type, distance from roads and so on. However, data on all these factors are not available for selected roads.[8] Therefore, we modify the equation shown in the *Doro Toshi no Hyoka ni Kansuru Shishin Kento Iinkai* (1998).

There are many variations in the unit social costs per noise level. These results are obtained with two different approaches: the hedonic approach and the CVM (contigent valuation method). The hedonic approach, as in Yashima and Kanemoto (1992) and Hidano *et al.* (1996), obtains unit social costs by analysing the relationship between noise level and land prices. The CVM approach, as in Kashima and Imanaga (2004) and Matsui *et al.* (2005), estimates the unit social costs of noise by analysing the willingness to pay for protection against noise. We use 5000 yen/dB, obtained from Koyama's (2004) result, considered moderate because it is obtained from several previous studies.

Global warming. The social costs of global warming are calculated in two steps, the first being to estimate annual emission of CO_2 from vehicular transport. In the second step, the monetary values of the social costs of CO_2 emissions are calculated. Equations (14) and (15) show the formulae of these two steps.

$$EMI_{CO2,a} = \sum_b \sum_i ER^b_{CO2,a,i} \cdot Q^b_{a,i} \quad (14)$$

$$C_{war,a} = P_{war} \cdot EMI_{CO2,a} \cdot Trans_{CO2} \quad (15)$$

where, $C_{war,a}$ = social cost of global warming caused by vehicular transport in city *a*; P_{war} = unit social cost of emission of CO_2 yen/t-CO_2; $EMI_{CO2,a}$ = annual emission of CO_2 in city *a* (g-CO_2/year); $Trans_{CO2}$ = 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 road type *i* in city *a* (g-CO_2/km); $Q^b_{a,i}$ = traffic volume of vehicular transport type *b* on road type *i* in city *a* (vehicle-km); *b* = vehicular transport type (1 = passenger car, 2 = bus, 3 = small truck, 4 = truck); and *i* = road type (1 = highway, 2 = ordinary road).

Oshiro *et al.* (2001) devised a formula for CO_2 emission according to vehicle type, and we employ their results in our own estimation.[9]

Last, we use previous studies to fix the unit social cost of CO_2 emission at 14 000 yen/t-CO_2. The value of unit social costs for this item varies among previous studies, the lowest being about 1296 yen in Mayeres *et al.* (1996) and the highest about 274 349 yen in Koyama and Kishimoto (2001). Other studies such as Watkiss (2005) show that unit social costs are about £35 to £140 in the case of the UK, which had a value of about 14 000 yen in 2005. We adopt here moderate values similar to those of INFRAS/IWW (2004).

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 (16). Secondly, annual time loss due to traffic congestion is calculated. As equation (17) shows, congestion conditions on weekdays and at weekends are different, so we obtain the time loss separately. Last, the monetary value of traffic congestion is obtained, as equation (18) shows

$$tl^b_{a,k} = \sum_i \left(\frac{DIS_{a,i}}{V_{a,i}} - \frac{DIS_{a,i}}{V^*_i} \right) \cdot Q^b_{a,i,k} \quad (16)$$

$$TL^b_a = tl^b_{a,k=weekday} \cdot d_w + tl^b_{a,k=weekend} \cdot d_h \quad (17)$$

$$C_{con,a} = \sum_b P^b_{con} \cdot TL^b_a \quad (18)$$

where, $C_{con,a}$ = social cost of congestion in city a; P^b_{con} = unit social cost of time loss caused by congestion in vehicle type b in city a (yen/minute-vehicle); TL^b_a = annual time loss caused by congestion in vehicle type b in city a (minute-vehicle/year); $tl^b_{a,k}$ = daily time loss caused by congestion of day type k in vehicle type b in city 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 road type i in city a (km); $V_{a,i}$ = average speed on road type i in city a (km/h); V^*_i = legally permitted speed on road type i (km/h); $Q^b_{a,i,k}$ = traffic volume of vehicle type k on road type i in city a (vehicle/day); b = vehicular transport type 1 = passenger car, 2 = bus, 3 = small truck, 4 = truck); i = road type (1 = highway, 2 = ordinary road); and k = weekday and weekend (w = weekday, h = weekend).

Time loss caused by congestion is calculated based on the value of time (VOT). Previous studies, such as INFRAS/IWW (2004), evaluate the VOT for each vehicle type, as VOT varies according to kinds of people, and vehicle types could serve as proxy variables for kinds of people. Furthermore, Mayeres *et al.* (1996) distinguish the VOTs for the peak and off-peak periods. Unfortunately, however, data on the VOT for peak and off-peak periods are not available to us. For the unit social costs of traffic congestion, we use results from the Ministry of Land, Infrastructure and Transport (2003): 62.86 for cars, 519.74 for buses, 56.81 for small trucks and 87.44 for trucks (yen/minute per vehicle).

4. Empirical Analysis of Social Costs

4.1 Sample Selection of Cities and Major Assumptions

Because metropolitan areas have not been officially defined in Japan, we base our calculations of the social costs of vehicular transport and related variables on city information. The total sample size for this analysis is 111 cities for the year 2005. Because the social costs of vehicular transport are highly affected not only by urban structure, infrastructure conditions and economic environment, but also by geographical and climate conditions, samples are selected with attention to regional balance and variation in city size.

It is important to consider the following points when calculating the social costs of vehicular transport. As the equations shown in the previous section indicate, the social costs of vehicular transport are calculated according to their individual five subcategories. Secondly, social costs are calculated separately according to type: passenger cars, buses, small trucks, and trucks. Last, traffic volumes and speed of vehicular transport vary among cities. Therefore, individual social costs vary among cities.

The data are based on the year 2005 because census data and main traffic data such as cities' speed and traffic volumes are available for that year. However, data regarding the unit costs of social costs are drawn from many sources at different times. Our unit costs for each item are based on the following sources: the Cabinet Office (2007) for accidents, the European Commission (2005) and the Cabinet Office (2007) for air pollution, Koyama (2004) for noise, Watkiss (2005) for global warming and the Ministry of Land, Infrastructure and Transport for traffic congestion. The unit costs used are summarised in Table 2.

4.2 Estimation Results of Social Costs

This section describes the structure of the estimated social costs of vehicular transport regarding the following points: the relationship between social costs and city size; the relationship between unit social costs and

Table 2. Values of unit costs and parameters used for the estimation of social costs

Kinds of social cost	*Symbol*	*Sub-item*	*Unit cost*	*Unit (thousand yen)*
Traffic Accident	$P_{acc,e}$	Death	232 742	per person
		Seriously injured	86 184	per person
		Lightly injured	860	per person
Air Pollution	$P_{air,g}$	Mortality	142 064	per person
		Hospital admissions	270.08	per admission
		General practitioner visits: asthma	7.16	per consultation
		General practitioner visits: respiratory symptoms	10.56	per consultation
		Respiratory symptoms in asthmatics: adults	17.56	per event
		Respiratory symptoms in asthmatics: children	37.81	per event
		Respiratory medication use-adults and children	0.14	per day
		Cough day	5.13	per day
		Symptom day	5.13	per day
		Chronic bronchitis	25 657.96	per case
Noise	P_{dB}	—	4.935	per dB per square metre
Global warming	P_{war}	—	12.962	per ton-CO_2
Traffic congestion	P_{bcon}	Passenger car	0.06142	per minute-vehicle
		Bus	0.50785	per minute-vehicle
		Small truck	0.05551	per minute-vehicle
		Truck	0.08544	per minute-vehicle

Note: These numbers are all year 2005 values.

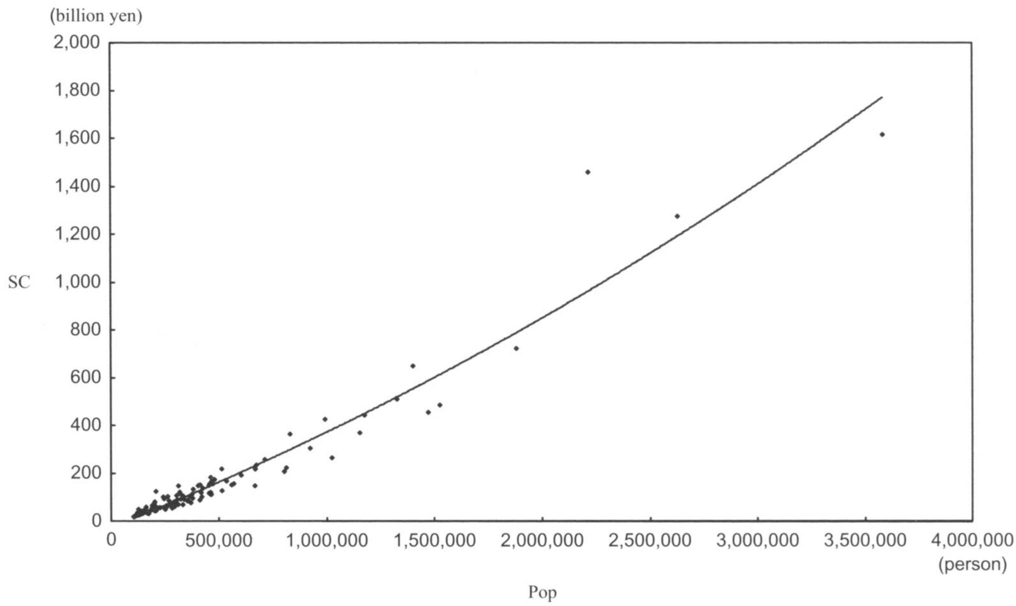

Figure 1. Relationship between social costs and city size.
Notes: The fitted line is as follows:
$SC = 908.469$ [9.72] + 0.0357(Pop) [11.79] + $0.155\text{x}10^{-8}$ $(\text{Pop})^2$ [26.13]
$R^2 = 0.939$. R^2: coefficient of determination. Numbers in square brackets are t-statistics.

population density; the structure of social costs; and, the magnitude of social costs.

First, Figure 1 shows the relationship between the social costs of vehicular transport and the city size measured as population. The most important finding is the fact that social costs increase at an accelerated rate as the city size increases, indicating that a city with a larger population produces larger unit social costs. As the fitted line by the quadratic curve shows, the coefficient of the term of the square of population shows positive with statistical significance. Therefore, in terms of the social costs of transport, a smaller size city is desirable.

Secondly, however, there are variations in the details of social costs. For example, Figure 2 shows that the relationship between population density and unit social costs per traffic is not linear. As the fitted line by the quadratic curve shows, the coefficient of the term of the square of population density shows a negative sign. Therefore, the unit social costs per traffic increase, but the rate of increase decreases as population density increases, suggesting that public transport and infrastructure conditions might affect social costs, a city with higher population density having in general more convenient public transport and perhaps less car usage.

Thirdly, the structure of social costs in a city is shown in Table 3. We divided city size into four categories and discovered the following facts. The largest component of vehicular transport's social costs is traffic congestion, accounting for more than 45 per cent, with social costs of traffic congestion comprising a larger percentage in large cities. In cities with populations of more than 1 million, traffic congestion's social costs comprise more than 62 per cent. The second large component is air pollution, accounting for 18–21 per cent. Global warming is the fourth-largest component after accidents, accounting for around 5–11 per cent.

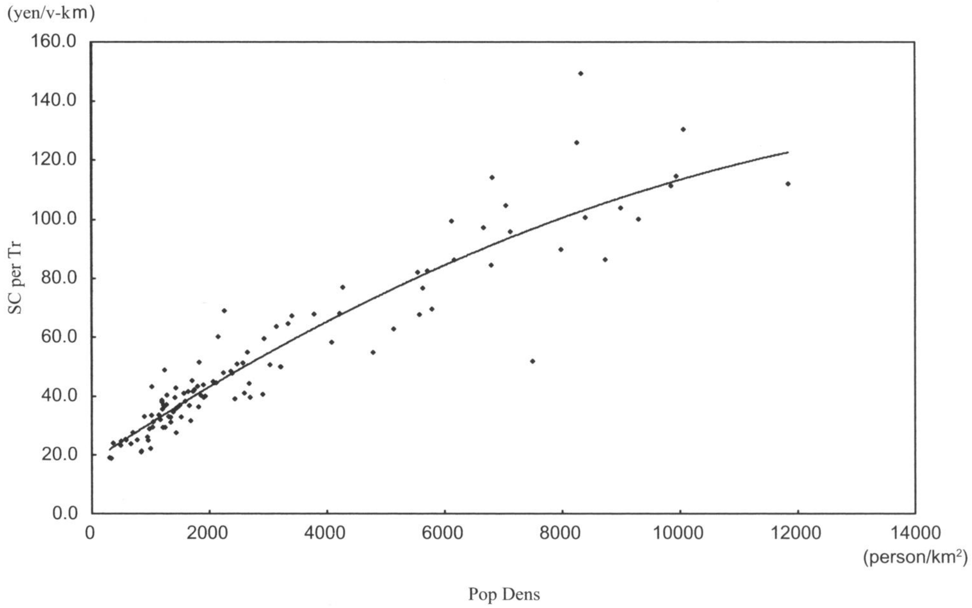

Figure 2. Relationship between unit social costs and population density.
Notes: 'PopDens' refers to population density in a city. 'SC per Tr' refers to social costs per traffic. Units: population density (person/km2), social costs per traffic (yen/vehicle-km). The fitted line is as follows:
SC per Tr = 17.954 [7.94] + 0.0134(Pop Dens) [10.06] – 0.386x10^{-6} (Pop Dens)^2 [–2.92]
R^2 = 0.876. R^2: Coefficient of determination. Numbers in square brackets are t-statistics.

Table 3. Estimation results of social costs of vehicular transport

	Social costs (billion yen, with percentages in parentheses)					
City size (population)	*Total*	*Accident*	*Air pollution*	*Noise*	*Global warming*	*Traffic congestion*
More than 1 million	750.4 (100.0)	94.9 (12.7)	133.9 (17.8)	17.0 (2.3)	40.8 (5.4)	463.8 (61.8)
1 million to 500 000	226.8 (100.0)	45.5 (20.1)	46.9 (20.7)	5.2 (2.3)	16.6 (7.3)	112.2 (49.6)
500 000 to 300 000	119.2 (100.0)	23.7 (19.9)	24.6 (20.6)	2.7 (2.3)	9.6 (8.0)	58.7 (49.2)
Less than 300 000	54.8 (100.0)	11.7 (21.2)	11.2 (20.4)	1.2 (2.2)	5.8 (10.6)	25.0 (45.6)

Note: These numbers are sample means of all observations (cities) in each category.

4.3 Regression Analysis of the Effect of Urban Structure on Social Costs

Empirical models. In this sub-section, we will analyse the effect of urban structure on the social cost of transport. No previous studies directly examine this point but there are related studies. For example, Stewart and Bennett (1975) investigate the relationship between urban structure and gasoline consumption as a proxy variable of transport demand. Schimek (1996) studies how characteristics of urban structure such as population density affect car dependency. Newman and Kenworthy (1989) and Mindahi *et al.* (2004) investigate how urban structure and economic conditions affect car dependency, which is associated with gasoline consumption. Here, we focus on the social costs of, rather than the demand for, vehicular transport. Furthermore, we are more interested in urban size. If the social costs of vehicular transport increase more sharply than the increasing rate of urban size, then from a city planner's point of view, a large city is undesirable. However, as city size increases, more public transport is provided, which is likely to suppress the use of cars. There is the large city's merit of agglomeration economies, diminishing car dependency per person. Thus, economic activities, infrastructure and transport conditions should all be considered when estimating costs.

Based on this argument, we specify the regression model to explain the social costs of vehicular transport, as equation (19) shows. Urban structure is summarised in four components: city size, infrastructure conditions, economic activity level and condition of public transport

$$\ln SC = \alpha + \beta_{POP} \ln POP + \beta_{RD} \ln RD + \beta_{MP} \ln MP + \beta_{BD} \ln BD + \beta_{SD} \ln SD \quad (19)$$

where, SC = social costs of vehicular transport in a city, POP = city population (+); RD = road density (+); MP = total sales of products per person (–/+); BD = bus network density (–); and SD = railway station density (–).

City size is explained as city population (*POP*). Road density in a city (*RD*) is included as affecting traffic congestion and is measured by total road length per city area. Included in the category of economic conditions is the item of total sales of products per person in a city (*MP*). Regarding public transport conditions, both bus network density (*BD*) and railway station density (*SD*) are used. Bus network density is obtained by dividing total bus route length by city area. Railway station density is also obtained by dividing the number of stations by city area. We acknowledge the shortcoming that this study does not include public transport's service level, such as the number of trains and buses, but unfortunately data for this variable are unavailable to us on a city basis.

As equation (19) shows, the regression formula is specified as the log-linear function. Therefore, the coefficient of each explanatory variable shows elasticity to social costs. The expected signs of these variables are positive for city population and road density but negative for bus density and railway station density. The sign of the coefficient of the total sales of products per person is an empirical question, but we expect it to be negative because the larger a city is, the more likely it is to have a strong city centre less dependent on vehicular transport than a smaller city is likely to have.

Definition of variables. The basic data are collected on a city basis for the year 2005, with total observations of 111 cities. Statistics of variables used for the regression analysis are summarised in Table 4. Variables are defined as follows. First, the social costs of vehicular transport (*SC*) are the sum of five external costs produced by vehicular transport: traffic accidents, air pollution, noise, global warming and traffic congestion.

We define explanatory variables as follows. City population (*POP*) is the total population registered in a city. Road density (*RD*) is obtained by dividing the total road length of a city by total city area. The total sales of products per person (*MP*) are obtained by dividing the total sales of products in a city by the total population. Numbers to obtain the variables (i.e. city population, road length, city area, total sales of products) are collected

Table 4. Statistics of variables used for regressions

Variables	*Unit*	*Mean*	*Standard deviation*	*Maximum*	*Minimum*
SC (social costs of vehicular transport)	billion yen	167.8	250.1	1 615.8	19.3
POP (city population)	person	482 329	518 375	3 579 628	103 652
RD (road density)	km/km^2	13.082	3.649	21.098	4.852
MP (total sales of products per person)	million yen per person	2.236	2.991	26.782	0.093
BD (bus network density)	km/km^2	0.954	0.323	2.142	0.365
SD (railway station density)	stations per km^2	0.137	0.136	0.851	0.000

from *Statistical Observations of Municipalities* [*Tokei de Miru Shichouson no Sugata*], issued by the Ministry of Internal Affairs and Communications. Bus network density (*BD*) is obtained by dividing the total route-km of the bus network by the city area, which is taken from the *Census of Road Transport* [*Doro Kotsu Sensasu*] issued by the Ministry of Land, Infrastructure and Transport. Last, railway station density (*SD*) is defined by dividing the number of stations by the city area, the main source for which information is the *Annual Report of Regional Transport* [*Chiiki Kotsu Nenpo*] issued by the Ministry of Land, Infrastructure and Transport for major cities, and individual city maps for smaller cities.

Results. We apply regressions to equation (19). Because we use a cross-section dataset, the main estimation method is the OLS (ordinary least squares) method. The OLS method assumes that the error term has a common variance. However, in order to avoid the heteroscedasticity problem, which is that the error term is a non-constant variance, we also estimate the regressions by using the OLS with the HCSE (heteroscedasticity-consistent standard error) and the ML (maximum likelihood) methods. Table 5 shows the estimation results, which indicate that there is not much difference among methods. Furthermore, the coefficients of the explanatory variables show a reasonable sign, with the goodness of fit of the regression being reasonably high.

These results produced interesting findings. First, the social costs of vehicular transport increase at a higher rate as city population increases. The coefficient of city population (*POP*) is 1.136, indicating that social costs increase by 11.36 per cent when the population increases by 10 per cent. Therefore, a smaller city is better in terms of social costs.

Secondly, the construction of roads does not work to decrease the social costs of vehicular transport. As road density (*RD*) increases, social costs tend to increase. Presumably, the construction of roads increases car usage by increasing its perceived convenience, paradoxically exacerbating traffic congestion.

Thirdly, public transport has a tendency to decrease social costs, although the effects of the decrease are minimal because the coefficients of both bus network density (*BD*) and railway station density (*SD*) are small, −0.132 and −0.027 respectively. These results suggest that we should not rely too heavily on public transport to reduce the social costs of vehicular transport.

4.4 Magnitude of the Social Costs of Vehicular Transport

Comparison with GDP. Table 6 is a comparison of the magnitude of vehicular transport's social costs with the GDP. For better understanding, we include results from

Table 5. Estimation results of regressions

Variables	*Case 1* OLS	*Case 2* OLS with HCSE	*Case 3* ML
α (constant)	−8.823***	−8.828***	−8.718***
	(0.400)	(0.395)	(0.402)
β_{POP} (city population)	1.136***	1.136***	1.128***
	(0.030)	(0.028)	(0.031)
β_{RD} (road density)	0.467***	0.467***	0.467***
	(0.074)	(0.061)	(0.070)
β_{MP} (total sales of products per person)	−0.018	−0.018*	−0.015
	(0.023)	(0.022)	(0.022)
β_{BD} (bus network density)	−0.132**	−0.132**	−0.124**
	(0.063)	(0.062)	(0.060)
β_{SD} (railway station density)	−0.027**	−0.027	−0.026**
	(0.013)	(0.018)	(0.012)
Adjusted R^2	0.951	0.951	–
Log likelihood	–	–	23.986

Notes: Numbers in parentheses are standard errors. Symbols are statistically significant at 1 per cent (***), 5 per cent (**) and 10 per cent (*).

previous studies. It can be seen that the social costs of vehicular transport represent about 8 per cent of GDP. This result is very similar to that of INFRAS/IWW (2004). In the case of ECMT (1998), the ratio is smaller than in our estimation because it does not include the social costs of congestion. Koyama and Kishimoto's (2001) estimation results are from a whole country's data and our results are close to their higher values. Based on a dataset from Germany, only UNITE's (2003) results are rather low and may reflect less harsh, more smooth, traffic conditions, causing lower external costs.

Our conclusion is that social costs due to vehicular transport have a magnitude of about 8 per cent of GDP. These costs are certainly high enough for the government to consider ways of reducing them. One idea might be to impose more fuel taxes.

Comparisons regarding a fuel tax for vehicle users. Finally, we evaluate the extent to which a fuel tax on vehicular transport can cover social costs. We classify the social costs of vehicular transport, obtained in section 4.2, into the four types of vehicle with which they are associated. The results of social costs classified into vehicle type are shown in Table 7. These monetary values are for the year 2005. This table shows that trucks' social costs per vehicle-km are four times higher than those of regular cars.

With these findings in mind, we evaluate fuel tax coverage. Kanemoto (2007) shows the fuel tax level by vehicle type, with the total fuel tax for regular cars being 58.9 yen per litre for gasoline and 36.1 yen per litre for diesel oil. Based on Kanemoto's (2007) information, the fuel tax for regular cars covers only 16.3 per cent (= 58.9/361.5) of social costs and for trucks covers only 7.5 per cent (= 36.1/481.1).[10] These results show that the fuel tax coverage ratio to social costs is very small, at most about 16 per cent. Furthermore, the fuel tax coverage ratio to social costs of heavy vehicles such as trucks is much smaller than for regular cars. From an environmental point of view, therefore, keeping fuel taxes on heavy vehicles at the current level does not make sense.

Table 6. The percentage of social costs to GDP

Study	*Total*	*Accident*	*Air pollution*	*Noise*	*Global warming*	*Traffic condition*
ECMT (1998)	3.9	2.5	0.6	0.3	0.5	–
Koyama and Kishimoto (2001)	5.6–11.3	1.0	1.7–2.4	1.2–1.7	3.7	2.5
UNITE (2003)	1.9	0.1	0.4	0.3	0.2	0.9
INFRAS/IWW (2004)	7.3	—	—	—	—	—
This study (2010)	8.0	1.4	1.6	0.2	0.6	4.4

Note: The sample in this study is based on city data and GDP information is not available for cities. Taxable income for the whole country is about one-third of national GDP in Japan. Data are available regarding taxable income for each city. Therefore, we estimate GDP from the taxable income by multiplying by three.

Table 7. The social costs and vehicle type

Items	*Car*	*Bus*	*Small truck*	*Truck*
Social costs per litre (yen/litre)	361.5	1 111.4	358.7	481.1
Social costs per vehicle-km (yen/vehicle-km)	38.5	362.0	43.6	131.1

5. Conclusion

The main purposes of this paper were to estimate the social costs of vehicular transport and to analyse the structure of the components of social costs and the relationship between social costs and city size. The main characteristics of our study were as follows. First, it investigated the social costs of vehicular transport with a city dataset including such items as traffic volume and the flow speed of cars. Secondly, this study considered five kinds of social costs of vehicular transport: traffic accidents, air pollution, noise, global warming and traffic congestion. Previous studies estimating these five social costs were few. Thirdly, our study investigated the relationship between the social costs of vehicular transport and city size, attempting to determine whether bigger city size entails higher social costs than smaller city size. Our study was probably the first such empirical investigation. Last, with regression analysis, we evaluated the effects of an urban structure's infrastructure on the social costs of vehicular transport.

The most important findings are as follows. First, social costs increased at an accelerated rate as city size increased. Thus a city with a larger population produced larger unit social costs. Therefore, in terms of transport's social costs, a smaller size city is desirable. On the other hand, when we checked the relationship between population density in a city and the unit social costs per traffic, the relationship was not linear.

Secondly, from the regression results, it was proved that the social costs of vehicular transport increased at an accelerated pace as city size increased. Furthermore, the construction of roads did not work to decrease the social costs of vehicular transport. However, public transport did have a tendency to decrease the social costs of vehicular transport, even though the effects of the decrease were minimal.

Thirdly, the largest component of social costs was traffic congestion, at more than 45 per cent of the total. Furthermore, social costs due to traffic congestion reached a larger percentage in large cities. The second large component was air pollution, accounting for 18–21 per cent of total social costs. Although global warming has been recently viewed with great concern, global warming caused by transport accounted for only 5–11 per cent of total social costs.

Last, the magnitude of the social costs of vehicular transport seemed large, at about 8 per cent of GDP. Furthermore, the fuel tax for vehicular transport in Japan covered only 16.3 per cent of the social costs of regular car use. The ratio for heavy vehicles such as trucks was smaller, so that from an environmental point of view, the current fuel tax on heavy vehicles is too low.

Our results suggest that the best cities are compact cities and that policy-makers should work towards the goal of creating them.

Notes

1. In INFRAS/IWW (2004), the lower level of unit cost of CO_2 and the higher level of unit costs of CO_2 are used. The lower level of unit costs is obtained from information regarding the Kyoto Protocol. On the other hand, the higher unit costs are obtained by setting up a target of achieving a 50 per cent reduction of CO_2 by 2030.
2. According to Doll and Jansson (2005), there are two kinds of model specifications in the speed-flow model: the logit model and the linear model. From the sample distribution, the linear model seems more appropriate than the logit model. Therefore, we specify the linear model.
3. The large metropolitan areas are cities of more than 1 million in population. The peak period for highways in the large metropolitan areas is assumed to be 6 hours per day.
4. Although the legal speed limit for highways varies among routes and sections, we use a uniform value assumed to be 80km/h.
5. The coefficient for pollution by PM_{10} is obtained by using the calculation method of the Ministry of the Environment.
6. 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).
7. Noise level is estimated with equations based on the *Doro Toshi no Hyoka ni Kansuru Shishin Kento Iinkai* (1998).
8. For example, Koyama (2004) considers the attenuation effects of noise due to types of building. However, because we lack this information, the equation in this study is an approximation of noise level.
9. The results of Oshiro *et al.* (2001) are as follows:
   $$ER_{CO2,a,b,i} = \alpha / V_{a,i} - \beta V_{a,i} + \gamma V^2{}_{a,i} + \delta$$
   where $ER_{CO2,a,b,i}$ = coefficient for emission of CO_2 by vehicular transport type b on road type i in city a, (g-CO_2/km); and $V_{a,i}$ = average speed (km/h) on road type i.
   Oshiro *et al.* (2001) estimate individually the parameters, α, β, γ, δ, for cars, buses, small trucks and trucks.
10. Kanemoto's (2007) study shows that the social costs are about 124.0 yen per litre for cars, smaller than our estimated social costs. Consequently, his result shows that the fuel tax covers about 47.5 per cent (= 58.9/124.0).

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