COST STRUCTURE OF HIGHWAY BUILDING AND MAINTENANCE: HOW SHOULD WE LEVY TAXES ON FREIGHT VEHICLES?

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ABSTRACT

Recently, governments and logistics service providers have established advanced logistics systems that meet sophisticated and diversified demands of city logistics. It is necessary to introduce a principle of cost sharing among the infrastructure users in order to accomplish efficiency in logistics activities and to improve the environment.

In this paper, we aim to estimate the cost structure and cost responsibility for each automobile type on highway investment. Based on the estimation results, we will try to determine appropriate tax levels to be paid by highway users including freight vehicles from the perspective of social welfare. As a policy implication in city logistics, we will describe required adjustments that have to be done on the current policy on automobile-related taxes and charges.

1. INTRODUCTION

Consumer demands have become more sophisticated and diversified in recent years. To meet this demand, governments and logistics service providers in the field of city logistics have executed various policies and actions in establishing advanced logistics systems. Their policies and actions aim to contribute in the efficiency and environmental improvement of logistics activities.

Social cost (e.g. environmental cost, congestion cost and infrastructure cost) should be taken into account to adequately assess logistics activities in urban areas. If we neglect social cost, it would result in an inefficient logistics market and failure to maximize social welfare.

In this paper, we investigate “cost responsibility” which is the appropriate tax level to be paid by highway users from the perspective of social welfare. Focus is particularly directed to freight vehicles using the highway as they are the main transport mode in city logistics. When discussing cost responsibilities (appropriate tax levels), an important factor taken into consideration is “cost structure.”

Based on the above discussion, this paper examines the cost sharing among automobile types by estimating the cost structure and clarifying the cost responsibilities for each automobile type. The paper also draws some policy implications for a socially efficient logistics system based on the estimation results and comparison of the existing taxes and charges levied in urban areas.

2. COST STRUCTURE AND COST RESPONSIBILITY IN HIGHWAY INVESTMENT

COST STRUCTURE AND COST RESPONSIBILITY

In the discussion of how appropriate tax levels are set, two important factors should be taken into consideration - “cost structure” and “cost responsibility.”

“Cost structure” is defined as cost function where the social cost is determined by the usage of various vehicles under different environmental conditions. Recent studies have estimated various social costs (e.g. environmental cost, congestion cost, safety cost, etc.) as part of the full costs. If logistics service providers conduct business by minimizing their private costs, their activities would result in inefficient solutions from the perspective of maximizing social welfare. Governments, therefore, have to encourage logistics service providers to consider the social costs of their actions. In most case of highway development, we experience scale economy. In this situation the demand curve crosses the decreasing average cost curve, when the average cost exceeds the marginal cost. We cannot, therefore, recover the total cost of highway investment using marginal cost pricing. Government policies in some countries require the levying of full costs for highway use[1].

The second important factor is “cost responsibility”. In Japan, as in the case of several other countries, it is necessary to levy tax based on the cost responsibility of individual highway users. However, when we define the cost responsibility of these users, it is imperative to choose careful and understandable methods because it involves complex characteristics involving various interests of highway users.

COST RESPONSIBILITY AND CURRENT JAPANESE TAXATION SYSTEM

Among the cost factors comprising the full costs for highway use, the “highway investment cost” is claimed by the national and local governments. The highway investment cost is paid through tax revenues from highway users and non-users. After World War II, the Japanese government adopted the “earmarked highway taxes for users” based on the “beneficiaries-pay principle[2].” These highway taxes comprise three components, i.e. possession of motor vehicles, purchase of motor vehicles and fuel consumption. Figure 1 shows the percentage of tax revenue allotted for highway investment.

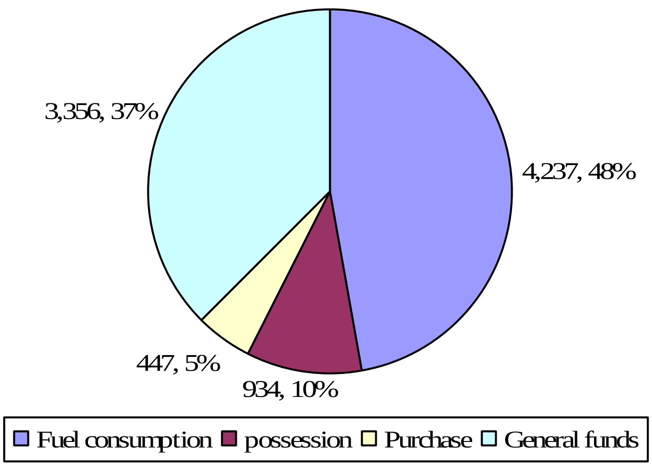

Figure 1 Tax revenue for highway investment (billion yen, FY2003)

This tax scheme has served as the main fiscal system in highway investment. This fiscal system has played an important role in the building and maintenance of Japan’s highway network. However, the current taxation level is determined to be common

[1] This trend is notable in the U.S., EU, and Switzerland. For details, see U.S. DOT (1997) and European Commission (2001).

[2] The beneficiaries-pay principle refers to the concept wherein the beneficiaries must bear expenses that are in proportion to their responsibilities. In other words, 1) automobile users (road users) bear the expenses of providing special funding source for road works to be used for road improvement, 2) road improvements would result in a reduction of driving time and enhancement of safety, and 3) effects of road improvements would be beneficial to road users.

across the country even though regional investments differ. There are only minor differences among automobile types even though there are large differences in the road damage or user benefit. Therefore, it cannot be said that the earmarked highway fund for users is set at the optimal level from the perspective of individual highway users.

It is therefore important to understand the cost responsibilities of individual highway users as accurately as possible in order to levy equitable cost responsibilities for these users and achieve optimal cost responsibilities, i.e. tax payment relationship for building and maintaining the highway network.

The most acceptable scheme to introduce optimal tax levels is by adjusting the current taxation system. If we adopt a simple evaluation standard, the cost responsibility can be divided into "cost responsibility for direct use" and "cost responsibility for privilege use." The former is closely related to marginal cost and tax revenue from fuel consumption. In contrast, the latter does not have a close relationship to the direct use of automobile, and thus, we consider that it should be recovered by tax revenues from purchase, possession and non automobile-related taxes.

In the following sections, we will review two approaches to estimate the cost structure, i.e. "econometrics approach" and "cost allocation study approach", and clarify the cost responsibilities for each automobile type on Japanese highway investment[3].

3. Review on Cost Structure in Highway Investment

ECONOMETRICS APPROACH

The econometrics approach is based on the economic theory used for estimating the cost function (cost structure). In this approach, cost is described by explanatory variables consisting of output variables, factor price variables, and network variables, among others. Recent studies in Japan have used the trans-log cost function in estimating cost functions. However, their scope of application is limited to public utility industries, such as in electricity, water supply, and communication[4]. In the field of transportation, there are some studies that estimated the cost structure of airline companies (e.g. Endo (2001)) and public bus services (e.g. Urakami (2003) and Tanabe (2003)). Unfortunately, no studies have been conducted on the cost structure of highway investment.

Levinson, Gillen, Kanafani and Mathieu (1996), Levinson and Gillen (1998), and Ozbay, Bartin and Berechman (2004) estimated the cost structure of highway investment using log-linear cost function comprising the above-mentioned variables. In particular, Levinson and Gillen concluded that the cost structure for cars has diseconomies of scale (i.e. marginal cost > average cost) while that for freight vehicles has economies of scale (i.e. marginal cost < average cost) (Table 1). In their study, Levinson and Gillen point out that the short-term marginal cost for combination trucks exceeds that of single

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[3] For the estimation of the cost responsibility on highway investment focusing on automobile types, see Misui (2005).

[4] See Urakami (2003), etc.

trucks, and that the long-term marginal costs exceeds the short-term marginal costs across all automobile types. The conclusion of their study seems significant because it elucidates the economics of scale in highway investment. In our understanding, however, when they define ‘long-term’ cost, they introduce a strong assumption that the current infrastructure is optimally provided to meet the demand, and that the building cost covers the replacement cost of the end-of-life highway. It is necessary to examine the validity of this assumption.

Table 1 Cost structure estimation results from Levinson and Gillen (1998)

		Cars	Single trucks	Combination trucks
Long-term	Marginal cost	0.0188	0.0431	0.0514
	Average cost	0.017	0.063	0.101
Short-term	Marginal cost	0.0055	0.0075	0.0003
	Average cost	0.00075	0.0298	0.0032

Source: Levinson and Gillen (1998)

COST ALLOCATION STUDY APPROACH

The econometrics approach described above presents some important political implications. However, since there are some difficulties related to the analytical process, it cannot be decided if the cost is fairly paid by highway users on the basis of these econometrics estimation results.

The cost allocation study approach would be better suited because it uses stable financial data and a large number of studies have been conducted on this approach over several decades. However, the cost allocation study approach presents some demerits especially in the need for large volumes of data and complicated programs.

In this section, we will describe the previous two major studies concerning cost allocation study approach done by the U.S. DOT (1997) and Yamauchi (1987). The U.S. DOT (1997) analysed infrastructure costs on federal highway in the United States, allocated them among all automobile types in 2000, and suggest the necessity change in taxation system to make equitable cost sharing. In contrast, Yamauchi (1987) estimated cost sharing on Japanese expressways. Table 2 shows their findings.

Table 2 Cost allocation study estimation results
from the U.S. DOT (1997) and Yamauchi (1987)

	Type of costs	Cars	Single trucks	Combination trucks
U.S. DOT (1997)	Building cost (US dollar/vehicle-mile)	0.050 (1.00)	0.050 (1.00)	0.200 (4.00)
	Maintenance cost (US dollar/vehicle-mile)	0.063 (1.00)	0.075 (1.19)	0.758 (12.03)
Yamauchi (1987)	Type of costs	Cars	Small trucks	Ordinary trucks
	Building cost (Yen/vehicle-kilometer)	0.330 (1.00)	2.211 (6.70)	2.411 (7.31)
	Maintenance cost (Yen/vehicle-kilometer)	3.103 (1.00)	5.581 (1.80)	8.411 (2.71)

Note: The single truck in U.S. DOT (1997) is under 25,000 pounds.

Source: U.S. DOT (1997) Table V-5, Table V-9 and Yamauchi (1987) Table-2.

APPLICATION OF COST ALLOCATION STUDY APPROACH

In this section, we will estimate the cost responsibility by automobile type on highway investment in Japan using the cost allocation formulas shown in the U.S. DOT (1997) and Yamauchi (1987). The analysis uses the 1999 fiscal year data of 47 local governments with highway investment. Cost responsibility by automobile type is defined as the avoidable cost for each automobile type, i.e. cost that is avoided if there are no additional highway users.

As described above, using the cost allocation study approach to estimate cost responsibility is basically a tedious task because it requires large volumes of data and complex programs. However, there is a simpler method involving the use of the estimation results from U.S. DOT (1997) and Yamauchi (1987). Based on these, we will estimate the avoidable cost for each automobile type and the common cost using available statistical data combined with the cost allocation study approach.

The estimation approach comprises two stages. In the first stage, we divide the highway investment costs into building costs and maintenance costs. In the second stage, we allocate these costs to the avoidable cost by automobile type and common cost. We have to correspondingly apply all the data from the existing studies because the Japanese government has not published the cost allocation base for highway investment. We will therefore use the allocation bases proposed by the U.S. DOT (1997) and Yamauchi (1987) (Table 2)[5]. The cost and vehicle-kilometer data are the same as those presented in the previous section, and the ratio of total avoidable costs and common cost is 53:47 as indicated in Yamauchi (1987).

[5] It should be noted that the allocation base of U.S. DOT (1997) pertains to U.S. highways while the allocation base of Yamauchi (1987) pertains to Japanese expressways.

The estimation results are shown in Table 3. Due to the difference in the cost allocation formulas of the avoidable cost by automobile type, the estimated value for cars and small trucks based on U.S. DOT (1997) is smaller than that based on Yamauchi (1987). Moreover, the estimated value for ordinary trucks based on U.S. DOT (1997) is larger than that based on Yamauchi (1987).

As a policy implication, we attempt to compare the current fuel tax payment level (current cost sharing) and the cost responsibility (appropriate cost sharing). Based on this comparison, if the cost allocation formula of U.S. DOT (1997) is used, an overpayment for cars and small trucks and an underpayment for ordinary trucks are obtained. If the cost allocation formula of Yamauchi (1987) is used, there is underpayment across all automobile types on the average.

Table 3 Avoidable cost by automobile type
(Yen/vehicle-kilometer: National mean value)

	Type of costs	Cars	Small trucks	Ordinary trucks
U.S. DOT (1997)	Building cost	4.982	5.214	18.729
	Maintenance cost	0.695	0.849	8.255
	Total	5.677	6.063	26.985
Yamauchi (1987)	Building cost	6.125	6.374	10.572
	Maintenance cost	0.957	1.076	6.442
	Total	7.082	7.450	17.014
Current fuel tax payment level		6.456	6.356	8.105

Note: In addition to the above-mentioned avoidable costs, there is a common cost of 6,705,054 million yen.

Current fuel tax payment level is estimated by Misui (2005).

4. ESTIMATION OF COST STRUCTURE BASED ON ECONOMETRICS APPROACH

ASSUMPTION

In this section, we will estimate the cost responsibility of highway investment based on automobile types using the econometrics approach discussed above. This analysis uses the 1999 fiscal year data of 47 local governments in highway investment[6]. On the basis of economic theory, the model represents a log-linear cost function, where the explained variable is cost and the explanatory variables are output, factor price, and network (see Equation (1)). The signs for all the coefficients are assumed to be positive. The variables, their units, mean values, and data sources are explained in Table 4.

[6] The selection of 1999 fiscal year data is due to the constraint of output data.

$$ln(STC) = a_0 + a_1 \cdot ln(Vk_a) + a_2 \cdot ln(Vk_{st}) + a_3 \cdot ln(Vk_{ot}) + a_4 \cdot ln(N) + a_5 \cdot ln(P_k) + a_6 \cdot ln(P_l) + a_7 \cdot ln(P_m) \quad (1)$$

Table 4 Variables used in the estimation of cost structure

Variable		Mean value	Source
STC	Short-term total cost (building and maintenance cost, million yen)	113,778	"Local financial annual report"
Vk_a	Vehicle-kilometer of cars (million km)	6,675	"1999 Road traffic census"
Vk_{st}	Vehicle-kilometer of small trucks (million km)	1,748	"2000 Road traffic census"
Vk_{ot}	Vehicle-kilometer of ordinary trucks (million km)	1,184	"2001 Road traffic census"
N	Network (thousand km)	3.871	"Road annual report"
K	Capital (outstanding local government bonds, million yen)	1,816,906	"Local financial annual report"
P_k	Capital cost (expenditure for bonds/outstanding local government bonds, %)	0.100	"Local financial annual report"
P_l	Labor cost (thousand yen/person)	7,395	"Local financial annual report"
P_m	Material cost (other cost/highway area, thousand yen/km^2)	3,009,187	"Local financial annual report" "Road annual report"

Note: Samples comprise data from 47 local governments.
Factor prices are standardized on average.

Moreover, in order to calculate the cost responsibility of highway users based on automobile type, we use the marginal cost by automobile type reflecting the cost responsibility for additional highway use from the perspective of social welfare.

ESTIMATION RESULTS

The estimation result shown in Equation (2) indicates that all the variables have positive signs. Although the R-squared value is quite high, the t-values of some variables are extremely low. This might be due to the following causes: data inconsistency and low correlation for the variable on vehicle-kilometer by automobile type[7].

[7] These problems will be investigated in future studies.

$$
\begin{aligned}
ln(STC) = {} & 7.203 + 0.292 \cdot ln(Vk_a) + 0.140 \cdot ln(Vk_{st}) + 0.006 \cdot ln(Vk_{ot}) \\
& (13.178) \quad (2.117) \qquad\qquad (1.092) \qquad\qquad (0.076) \\
& + 0.599 \cdot ln(N) + 0.141 \cdot ln(P_k) + 0.327 \cdot ln(P_l) + 0.951 \cdot ln(P_m) \\
& (8.598) \qquad\quad (1.023) \qquad\quad (0.745) \qquad\quad (15.157) \\
\overline{R}^2 = {} & 0.968
\end{aligned} \tag{2}
$$

Next, we derive Equation (3) by transforming Equation (2) into an exponential function, differentiating the function with the variable on vehicle-kilometer by automobile type, and then substituting the real value into all the variables in the function. We can then estimate the marginal cost by automobile type as given by Equations (3)-(5).

Short-term marginal cost for cars (yen/vehicle-kilometer)

$$
\begin{aligned}
SMC_a = {} & 1{,}344.04 \cdot 0.292 \cdot Vk_a^{-0.708} \cdot Vk_{st}^{0.140} \cdot Vk_{ot}^{0.006} \\
& \cdot N^{0.599} \cdot P_k^{0.141} \cdot P_l^{0.327} \cdot P_m^{0.951}
\end{aligned} \tag{3}
$$

Short-term marginal cost for small trucks (yen/vehicle-kilometer)

$$
\begin{aligned}
SMC_{st} = {} & 1{,}344.04 \cdot 0.140 \cdot Vk_a^{0.292} \cdot Vk_{st}^{-0.860} \cdot Vk_{ot}^{0.006} \\
& \cdot N^{0.599} \cdot P_k^{0.141} \cdot P_l^{0.327} \cdot P_m^{0.951}
\end{aligned} \tag{4}
$$

Short-term marginal cost for ordinary trucks (yen/vehicle-kilometer)

$$
\begin{aligned}
SMC_{ot} = {} & 1{,}344.04 \cdot 0.006 \cdot Vk_a^{0.292} \cdot Vk_{st}^{0.140} \cdot Vk_{ot}^{-0.994} \\
& \cdot N^{0.599} \cdot P_k^{0.141} \cdot P_l^{0.327} \cdot P_m^{0.951}
\end{aligned} \qquad 5)
$$

Furthermore, we can estimate the average cost in the same manner as the incremental cost. After transforming Equation (2) into the exponential function for only the object variable of vehicle-kilometer, we divide the difference by substituting the real value into the variable and substituting a minute real number (e.g. 1), and substituting the real value into all the variables in the function (Equations (6)-(8)).

Short-term average cost for cars (yen/vehicle-kilometer)

$$
\begin{aligned}
SAC_a = {} & 1{,}344.04 \cdot (Vk_a^{0.292} - 1^{0.292}) \cdot Vk_{st}^{0.140} \cdot Vk_{ot}^{0.006} \\
& \cdot N^{0.599} \cdot P_k^{0.141} \cdot P_l^{0.327} \cdot P_m^{0.951} / Vk_a
\end{aligned} \tag{6}
$$

Short-term average cost for small trucks (yen/vehicle-kilometer)

$$
\begin{aligned}
SAC_{st} = {} & 1{,}344.04 \cdot Vk_a^{0.292} \cdot \left(Vk_{st}^{0.140} - 1^{0.140}\right) \cdot Vk_{ot}^{0.006} \\
& \cdot N^{0.599} \cdot P_k^{0.141} \cdot P_l^{0.327} \cdot P_m^{0.951} / Vk_{st}
\end{aligned} \tag{7}
$$

Short-term average cost for ordinary trucks (yen/vehicle-kilometer)

$$SAC_{ot} = 1{,}344.04 \cdot Vk_a^{\ 0.292} \cdot Vk_{st}^{\ 0.140} \cdot \left(Vk_{ot}^{\ 0.006} - 1^{0.006}\right) \cdot N^{0.599} \cdot P_k^{\ 0.141} \cdot P_l^{\ 0.327} \cdot P_m^{\ 0.951} / Vk_{ot} \quad (8)$$

The cost responsibility and the economies of scale by automobile type can be derived using the marginal costs and average costs derived above.

We then attempt to compare the tax payment of highway users in the fuel consumption phase (current cost sharing) with the cost responsibility (appropriate cost sharing) derived above. Table 5 shows the results of the estimation and comparison.

Table 5 Marginal cost and average cost based on automobile type
(Yen/vehicle-kilometer: National mean value)

	Cars	Small trucks	Ordinary trucks
Marginal cost	5.191	8.937	0.679
Average cost	16.326	40.997	4.464
Current fuel tax payment level	6.456	6.356	8.105

Note: Short-term cost for cars have low t-values.
Current fuel tax payment level was estimated by Misui (2005).

From the above results, cars represent overpayment, while small trucks represent underpayment in the short-term. Moreover, the estimation results show the economy of scales across all automobile types (i.e. marginal cost < average cost). This economy of scale in cars is in contrast with the estimation results given by Levinson and Gillen (1998).

Based on the result that an economy of scale is found across automobile types, we could suggest that highway investment policies in the future should aim to increase users by utilizing the existing infrastructure rather than to expand networks. In other words, the highway investment policy should be directed at improving service quality,.though we cannot judge the desirable level of highway infrastructure without including congestion and environmental cost into calculating marginal cost. Considering the above, it is now important to discuss and suggest directions that have to be taken on highway investment policies and taxation policies.

5. CONCLUSION

This paper evaluated the cost structure of highway building and maintenance through two cost estimation approaches: econometrics approach and cost allocation study approach. On the basis of cost structure, we have clarified the cost responsibility based on automobile types. In particular, the estimation results from the cost allocation study approach revealed that if the cost allocation formula of U.S. DOT (1997) is used, the tax payment level for small trucks would decrease by approximately 5 percent while the tax payment level for ordinary trucks would increase by approximately 330 percent. If we adopt the cost allocation formula of Yamauchi (1987), the tax payment levels for small trucks and ordinary trucks would increase by approximately 117 and 210 percent, respectively. These estimation results indicate that the tax payment of freight transportation was lower than the desirable level. Trucks use highways, and consequently, logistics service providers are required to pay more for infrastructure use.

In addition, the estimation results from the econometrics approach show that there is economy of scale across automobile types. It is obvious that a more precise estimation is required, but this estimation result indicates the importance of a qualified highway service to increase highway demand. Thus far, the cost responsibility by automobile type and the cost structure of highway investment could not be determined. Therefore, we were unable to verify the current level of automobile-related taxes. In this sense, clarification of the cost responsibility of automobile types is useful in order to transform automobile-related taxes to balance the cost responsibility.

Japan's highways and expressways in urban areas are congested; Unfortunately, however, this paper does not make a distinction between cities and the countryside and assumes that all the highways in the country are homogeneous. In this sense, this paper is regarded as a basic research in order to estimate the cost structure and cost responsibility in city logistics. Cost structure and cost responsibility particularly described in urban areas, a more sophisticated econometric analysis, a more detailed classification of freight vehicle, and the analytical validity of scenario settings are topics for future research.

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