Doshisha University

Effect of Automobile Taxation System Revision in Japan

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Abstract:

Although automobiles offer increased convenience, problems associated with their mass consumption became apparent at the end of the 20th century, and a radical solution to these problems is yet to be found. In order to mitigate problems such as traffic accidents, traffic jams, and global warming, automobile manufacturers have been engaged in developing technologies from various perspectives, including the improvement of fuel efficiency and the introduction of hybrid engines. Furthermore, automobile manufacturers are now developing technologies for the future, such as fuel-cell vehicles, as well as new technologies for accident prevention, such as inter-vehicle communication and road-vehicle communication.

In this paper, after reviewing problems with the existing taxation system for automobiles, we have simulated how the sale, acquisition, ownership of new vehicles; travel behaviors; the level of economic welfare of households; CO_2 emissions by automobiles change when the automobile taxation system is converted into one where taxes are imposed in the travel phase by using the "GENDAI Model for transport and environmental policy assessment". This model is a multi-sector equilibrium model developed by the GENDAI Advanced Studies Research Organization.

From the simulations, we found that by shifting the share of tax imposition to the travel phase, considerable improvements result in the level of economic welfare of households, the reduction in CO_2 emissions.

Keywords: Automobile taxation system, Earmarked tax revenue for road construction, Economic welfare, Compensating variation, Global warming, CO_2 emissions

JEL codes: R42, H29, D58, D60

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This paper is an English translation of the paper "The Effects of Automobile Tax System Revision—The Results of Simulation by Using Multi-Sector Equilibrium Model—" (Hiroaki Miyoshi, Yuko Akune, and Masayoshi Tanishita), which was written in Japanese. This English version, however, has some slight changes and includes an additional estimation of the effect of the taxation system revision on economic welfare of households.

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1. Introduction

Although automobiles offer increased convenience, problems associated with their mass consumption became apparent at the end of the 20th century, and a radical solution to these problems is yet to be found. Problems caused by automobiles include traffic accidents, traffic jams, and global warming. In order to mitigate these problems, automobile manufacturers have been engaged in developing technologies from various perspectives, including the improvement of fuel efficiency, the introduction of hybrid engines, and the development of the collision mitigation brake system. They have also successfully introduced these technologies in the automobile market. Automobile manufacturers are now developing technologies for the future, such as fuel-cell vehicles, as well as new technologies for accident prevention, such as inter-vehicle communication and road-vehicle communication.

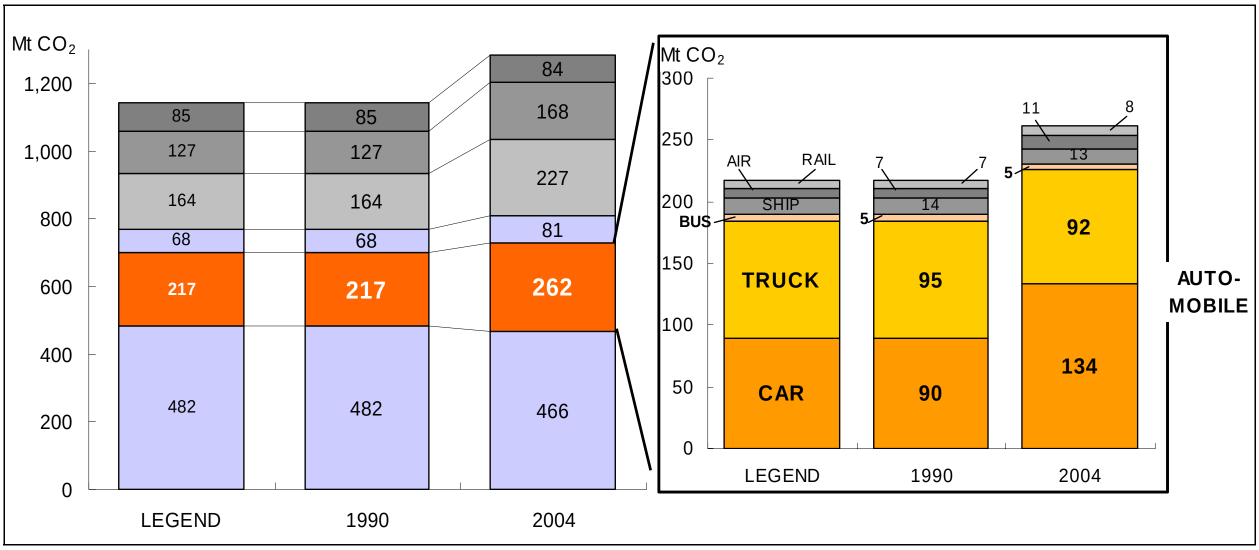
In this paper, we will analyze how the revision of the existing taxation system can contribute to the rapid market penetration of new automobiles that are equipped with some of the abovementioned technical innovations. We also analyze the effects of the taxation system revision on automobile acquisition and ownership; travel behaviors; the level of economic welfare of households; and CO_2 emissions by automobiles.

This paper is organized as follows. At first, we show the changes in CO_2 emissions and traffic accidents in Japan (II) and then review problems with the existing automobile taxation system (III). We will then explain the features and the structure of the "GENDAI Model for transport and environmental policy assessment", a multi-sector equilibrium model developed by the GENDAI Advanced Studies Research Organization (IV). Finally, using this model, we will simulate the effects of the taxation system change which shifts from acquisition/ownership phase to the travel (fuel) phase, on sales of new vehicles; automobile ownership; travel behaviors; the level of economic welfare of households; CO_2 emissions by automobiles when the existing automobile taxation system is converted into one where taxes are imposed in the travel phase (V).

2. Environmental problems and traffic accidents caused by automobiles

2.1. Environmental problems

In 2005, the "Kyoto Protocol" was adopted. The protocol was established with the aim to reduce the average CO_2 emission level in 1990 by at least 6% over the commitment period of 2008–2012. Fig. 1 shows the Japanese CO_2 emissions by sector in 1990 and 2004. In order to attain the targets set by the Kyoto Protocol, it was desirable to have a decreasing trend in this period. However, the actual CO_2 emissions seem to have increased by 12.4%, from 1144 Mt to 1286 Mt. It should be noted that CO_2 emissions in the transportation sector, a sector that includes emissions from automobiles, have increased from 217 Mt (19% of the total emission) to 262 Mt (20.3% of the total emission), and this growth of 20.3% has surpassed the growth rate of the total emission. In addition, approximately 90% of the emission from the transportation sector can be attributed to automobiles. More importantly, CO_2 emissions from passenger cars have increased by 49% since 1990, and this increase is certainly one of the causes of the increased CO_2 emissions over the period.



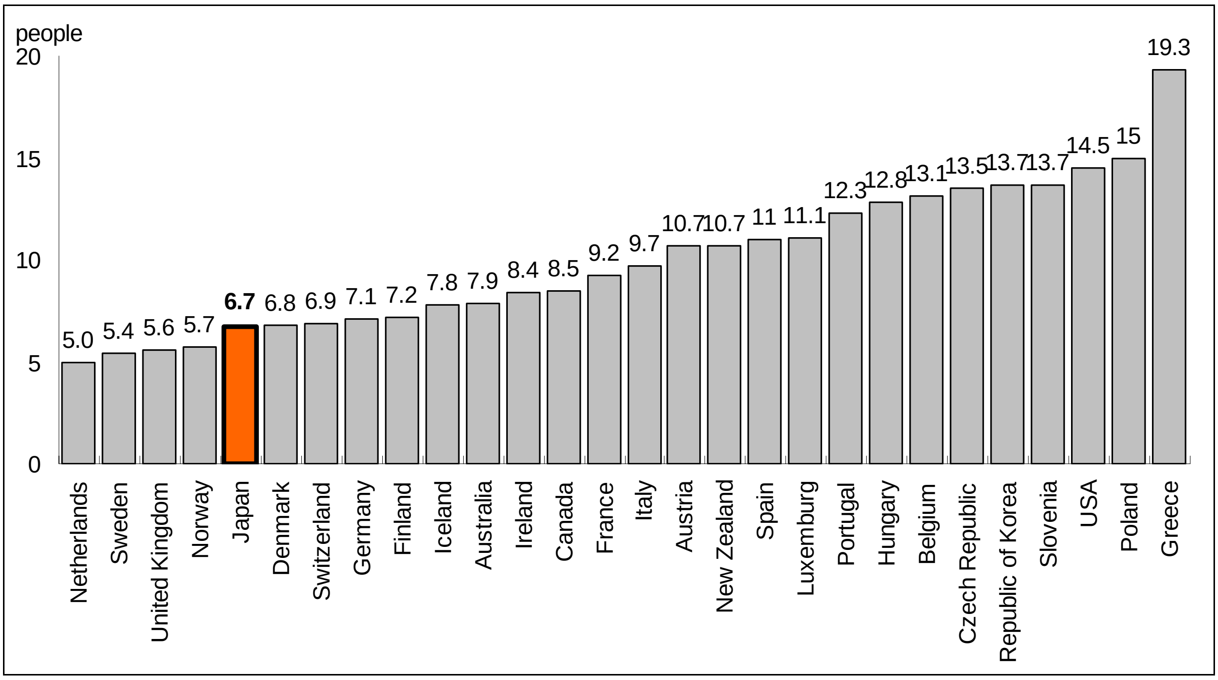
Source: Ministry of the Environment (Government of Japan)

Fig. 1 CO_2 Emissions in 1990 and 2004 in Japan

Therefore, in this model, we will examine the effects of the taxation system revision on CO_2 emissions from automobiles by considering these three points.

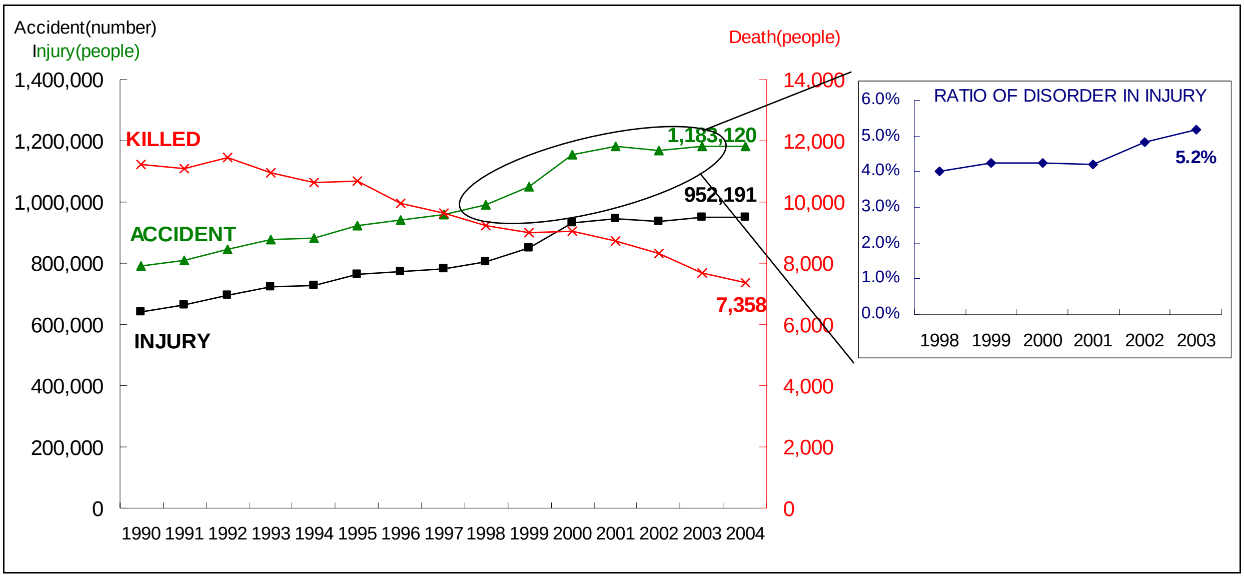
2.2. Traffic accidents

In this section, we will examine the actual situation of traffic accidents, a socially relevant problem associated with automobiles. First of all, in order to determine the frequency of traffic accidents in Japan, let us refer to Fig. 2, which shows the numbers of people killed in traffic accidents per 100,000 people population size in 2004 in countries studied by the IRTAD. According to these figures, the number of people killed in traffic accidents in Japan is 67, which is the 5th smallest number among all the countries studied.



Source: IRTAD

Fig. 2 People Killed in Accidents per 100000 people population size in 2004



Source: National Police Agency (Government of Japan)

Fig. 3 Number of Traffic Accidents and People Killed and Injured in Japan

Fig. 3 shows the changes in numbers of traffic accidents, people killed, and people injured in traffic accidents from 1990 to 2004 as well as the percentages of residually disabled persons among those injured in traffic accidents from 1998 to 2003. From this figure, we can understand that although the number of traffic accidents continued to increase until 2000, it has remained at a level of about 940,000–950,000 in recent years.

While the number of traffic accidents is on the rise, the number of people killed in traffic accidents has consistently decreased. The number fell to below 10,000 in 1997 and it decreased down to 7,358 in 2004. The number of people injured has increased in proportion to the increase in the number of traffic accidents. This number has shown a constant increase until 2000, and it has remained at an actual level of about 1,150,000–1,180,000 in recent years. It should be noted, however, that the percentage of residually disabled people among those injured in traffic accidents has increased from 4% in 1998 to 5.2% in 2003. As we have explained so far, in Japan, approximately 950000 traffic accidents occur in a year, and the number people injured in these accidents is proportional to the number of traffic accidents, while the number of people killed in these traffic accidents is on the decrease. On the other hand, the percentage of residually disabled peoples among those injured in these traffic accidents has shown an increasing trend.

The General Insurance Association of Japan has estimated the amount of human loss caused by traffic accidents to be 1214.5 billion yen (US $14,574 million) per year, which is equivalent to 0.2–0.3% of the annual GDP of Japan.

One of reasons for the decrease in the number of people killed in traffic accidents would be the introduction of safety regulations by the government. Table 1 shows a list of safety regulations that have been introduced since 1993; this table was prepared by Tanishita et al. (2006). According to this table, alarm systems for drivers who did not wear their safety belts were introduced in 1993 and a policy aiming to improve the safety performance of vehicular bodies in collisions was implemented in the period between 1996 and 2000.

Tanishita et al. (2006) demonstrated that the newer the automobile model was, the fewer were the traffic accidents. An examination of the effect of a taxation system revision on the incidence of traffic accidents is beyond the scope of this article. Instead, we will analyze how the revision of the taxation system can contribute to the rapid market penetration of new automobiles that embody high-safety performance.

Table 1 Car Safety Regulations regarding Body and Safety Belts in Japan after 1993

Year	Body	Safety belts
1993	-	Rear safety belt and alarm system for drivers who did not wear safety belts
1996	Standards for frontal impact protection	-
1999	Standards for side impact protection	-
2000	Standards for offset impact protections	-

Source: Tanishita et al. (2006)

3. The existing automobile taxation system and its problems

Before discussing the simulation, we will outline the existing automobile taxation system and problems associated with it[i].

3.1. The existing automobile taxation system

3.1.1 Tax items and their scales

Table 2 shows automobile-related tax items such as uses and tax revenues. In the existing automobile taxation system, taxes are imposed in each phase: acquisition, ownership, and travel. There are 8 tax items in all and the total tax revenue is 7,684.1 billion yen (as per account settlement for the year 2007).

Among such tax items, 6 items, excluding the automobile tax and the light motor vehicle tax, are earmarked as tax revenues for road construction; their uses are limited to road maintenance and improvement. The system of earmarked tax revenues for road construction was introduced in an effort toward urgent and systematic improvement of stone-age roads in our country, and the system was intended to impose taxes based on the benefit principle. This system started when the gasoline tax was designated as the earmarked revenue for road construction in 1953. Since then and following the First Road Improvement Program initiated in 1954, the government has realized increases in tax rates and the introduction of new taxes in response to increasing road investments.

On the other hand, the automobile tax and the light motor vehicle tax are categorized as general revenues for local governments and their uses are not limited to road construction. However, prefectural and municipal governments pour in large amounts of general revenues, which surpass these two tax revenues, for the maintenance and improvement of roads. Considering such practices, we will be able to deem the automobile tax and the light motor vehicle tax as de facto earmarked tax revenues for road construction.

3.1.2. Features of the taxation system

As explained above, the automobile taxation system, that is, the system of earmarked tax revenues for road construction is a system that intends to collect taxes based on the benefit principle. We can find the rationality of its existence in the point where the benefit has a close mutual relation with the burden. In other words, the title actually used is “tax” but the earmarked tax revenues for road construction are nothing more than “fees” paid by automobile users for their travels.

When we see automobile-related taxes as fees paid for road services, the automobile taxation system has the following features in terms of the payment structure and the tax distribution.

Table 2 List of Automobile-related Taxes

Phase of tax imposition	Title of tax	Type of tax	Use	System	Tax rate	Tax revenue (100 million yen)
Acquisition	Automobile acquisition tax	Prefectural	Earmarked tax revenue for road construction for prefectural and municipal governments	Tax imposition based on the acquisition value at the time of purchase (exempted if the value is 500000 yen or less)	Private vehicles (5%); commercial and light motor vehicles (3%)	4,855
Ownership	Automobile tonnage tax	National	80% of 3/4 of the entire revenue is the earmarked tax revenue for road construction for the national government (3/4 of the revenue is the national general revenue but from the background of its introduction and implementation, 80% is used as the earmarked tax revenue for road construction) and 1/4 is the earmarked tax revenue for road construction for the municipal government.	Tax imposition based on the weight of a vehicle at the time of every automobile safety inspection.	Private vehicles: 6,300 yen/year per 0.5 t; commercial vehicles: 2,300 yen/year per 0.5 t	10,740
	Automobile tax	Prefectural	General revenue for prefectural governments	Tax imposition against the owner on April 1 of every year.	Private vehicles (1,001~1,500 CC: 34,500 yen/year)	17,477
	Light motor vehicle tax	Municipal	General revenue for municipal governments	Tax imposition against the owner on April 1 of every year.	Private light motor vehicles (four-wheeled vehicle: 7,200 yen/year)	1,636
Travel	Gasoline tax	National	Earmarked tax revenue for road construction for the national government	Tax imposition on gasoline	48.6 yen/ ℓ	28,449
	Regional road tax		Earmarked tax revenue for road construction for prefectural and municipal governments		5.2 yen/ ℓ	3,044
	Diesel handling tax	Prefectural	Earmarked tax revenue for road construction for prefectural governments	Tax imposition on light oil	32.1 yen/ ℓ	10,360
	Petroleum gas tax	National	1/2 the entire revenue is the earmarked tax revenue for road construction for the national government and the other 1/2 is the earmarked tax revenue for road construction for the national and the prefectural governments	Tax imposition on LP gas	17.5 yen/kg	280

Note: Tax revenues as per account settlement for fiscal 2007
Source: Prepared by authors based on Japan Highway Users Conference and others, “DOUROGYOSEI 2006 (Road Administration 2006)”, internet websites of the Ministry of Finance and the Ministry of Internal Affairs and Communications etc..

3.1.2.1. High basic and low metered rate

When we consider an automobile tax as fees that automobile users pay for road travel services, we can say that there exists a two-part tariff structure made up of basic and metered rates. More specifically, the automobile acquisition tax, automobile tonnage tax, automobile tax, and light motor vehicle tax are collected as basic rates, regardless of whether road travel services are utilized. Likewise, among metered rates, energy taxes (gasoline tax, regional road tax, diesel handling tax, and petroleum gas tax) are imposed depending on the usage of road travel services (≒energy consumed).

When we aggregate the items in Table 2, the total amount obtained by levying basic rates is 3,470.8 billion yen, which constitutes 45.1% of the entire automobile-related tax revenue. On the other hand, the levying of metered rates, which are imposed on travel, accrues 4,213.3 billion yen, which constitutes 54.9% of the entire automobile-related tax revenue.

3.1.2.2. Lower taxes for commercial and light motor vehicle

In the public service sector, which includes utilities such as electricity, gas, and water systems, the payment structure is established by segmenting users into several groups from the perspective of commonality/similarity of costs.

While there is no such explicit tax distribution in the automobile taxation system, measures to change tax rates (fees) depending on the vehicle type and use are considered, as indicated in Table 2.

Firstly, with regard to energy taxes, different tax rates are imposed depending on the type of oil; tax rates for light oil and LPG are lower than those for gasoline. As regards the automobile acquisition tax and automobile tonnage tax, lower tax rates are applicable to commercial vehicles than private vehicles. Furthermore, in the automobile tonnage tax system, there is a separate category for light motor vehicles and a tax rate, which is lower than those for small-sized and standard-sized vehicles, is applicable to light motor vehicles.

In general, the existing automobile taxation system favors commercial vehicles and light motor vehicles (minicars) in comparison to private passenger cars.

3.2. Problems in the automobile taxation system

In this section, we will review problems in the existing automobile taxation system from the two perspectives of compliance with environmental requirements and principles for the level of public service fee, c'est-a-dire, cost-of-service principle, and value-of-service principle.

3.2.1. Problems related to basic rates (acquisition/ownership taxes)

As explained above, the existing automobile taxation system has a two-part tariff structure made up of basic and metered rates. Generally speaking, in a decreasing cost industry, which has large fixed costs, the collection of basic rates contributes to stable management by enhancing the stability of cost recovery. When we set the best marginal cost pricing, we will not be able to recover the fixed costs and will need to charge the pricing in some way or another to recover an amount equivalent to the fixed costs. In this case, consumers can get higher utility when such amounts are charged collectively as fixed basic rates, rather than tacking on such fees onto the marginal cost pricing, similar to consumption tax.

However, automobile users do not find enough grounds for paying basic rates for road travel services from either the cost-of-service principle or the value-of-service principle. Let us examine the system based on the cost-of-service principle, where the cost required to supply a service to a user is borne by the concerned user. In the case of electricity, gas, and water systems, individual fixed costs are imposed on every user regardless of service usage, for activities such as usage measurement and line installation. Therefore, there is rationality for the existence of basic rates. However, in the case of road travel services, there is no fixed fee associated with individual users. We should thus examine the system based on the value-of-service principle, where fees are charged based on value that each user obtains in the concerned service. In the case of telephone services, for example, there is a utility in that users can receive calls even if they do not make phone calls by themselves. Here, we can find a reason to collect basic rates. However, in road travel services, there is no such utility.

Even if we can accept the existence of basic rates, there are two problems in the existing automobile taxation system: the enormity of basic rates and the system where such rates are collected in the acquisition phase. We will first discuss the enormity of basic rates. The two-part-structured tariff will be an appropriate rate system as long as no consumers exit the market even if they are required to pay such basic rates. However, if the ratio of basic rates is large, just like the existing automobile taxation system, small-scale users will be excluded from the market. In addition, there will be a large internal subsidy from users with less road usage to users with larger road usage. Secondly, dead weight loss is caused by the automobile acquisition tax. It means that the automobile acquisition tax internalizes a part of the utilities for automobile users who wish to buy new vehicles. However, this utility is very different from that provided by the usage of roads. It is obvious that the system of the automobile acquisition tax has some rationality in the form of toll collection (for instance, as a kind of admission fees) when there is a certain mutual relationship between the acquisition of vehicles and the usage of roads, such as that in the high-growth period. However, most current vehicle acquisitions are replacements. The number of passenger cars and trucks owned was increased only up to 200000 between fiscal 2005 and fiscal 2006[2]. In addition, we can assume that there is virtually no mutual relationship between the number of vehicle replacements and the usage of road services. Therefore, we could conclude that the existing automobile acquisition tax does not have any meaning other than being a luxury tax.

Finally, let us examine the automobile taxation system from the perspective of the environment. As we explained above, the basic rates, which are collected regardless of vehicle usage, account for 45.1% of the total automobile-related tax revenue. This implies that the fee has a decreasing structure with the road travel distance. From the point of view of environment preservation, the fee should have an increasing structure with the road travel distance but the current tax structure has a completely opposite structure.

Therefore, we can conclude that it is necessary to shift the tax structure to one where taxes are imposed in the travel phase, both from the perspectives of the burden to beneficiaries and compliance with environmental requirements[3].

3.2.2. Problems related to the metered rate (energy taxes)

Energy taxes, which correspond to metered rates, work as metered rates only as long as there is a relationship between the energy consumed and the usage of road travel services.

However, with the recent emergence of hybrid vehicles and electric vehicles, the mutual relationship between energy consumption and usage of road travel services has become diluted. As long as the existing system continues, new energy vehicles such as electric cars will not be charged metered rates irrespective of how often they travel.

Therefore, the idea of approximating the usage of road travel services by the energy consumed is not suitable anymore. It will be thus necessary to consider a system that enables the measurement of the travel distance of each vehicle and the collection of fees depending on the vehicle weight and travel distance.

3.2.3. Problems related to tax distribution

As we have explained above, the existing automobile taxation system favors commercial vehicles and light motor vehicles in comparison to private vehicles.

However, the tax structure with such a tax distribution should be considered as an extremely strained system from the perspectives of the cost-of-service principle and the value-of-service principle.

Deterioration of roads is proportional to the fourth power of the axle weight. From the point of view of the individual cost-of-service principle (or marginal cost), in principle, large-sized vehicles (many of which use light oil) should bear heavier taxes while small-sized cars (many of which use gasoline) should bear less taxes. However, the current disparity within the tax rates on different oils shows the opposite tendency.

We can make the same remark from the perspective of the value-of-service principle (the ability-to-pay principle). Normally, we should make the burden of large-sized vehicles with lower price elasticity relatively heavier and make that of small-sized vehicles with higher price elasticity relatively lighter. However, the actual disparity within the tax rates on different oils shows the opposite tendency. The same can be said from the reverse elasticity rule of Ramsay with regard to joint cost allocation[4].

With regard to the disparity within rates for different oils, another important problem remains from the perspective of the environment. Despite the fact that light oils emit larger amounts of harmful substances (NO_X, SPM), the tax rates on light oil are considerably lower in comparison to those on gasoline. Therefore, the existing system should be regarded as retrogressive from the point of view of internalizing the external diseconomy[5].

So far, we have explained the problems of the tax structure in the existing automobile taxation system. In the following simulation, we will focus on the problems of basic rates (tax imposition in the acquisition/ownership phase). More specifically, we will examine how the sales volume of new vehicles; the acquisition, ownership, and travel behaviors of automobiles; the level of economic welfare of households; CO_2 emissions from automobiles; and traffic accidents change, when the acquisition tax (automobile acquisition tax) and the ownership tax (the automobile tonnage tax, automobile tax, light motor vehicle tax) are all abolished under tax revenue neutrality and the amount equivalent to such tax revenues is additionally imposed as tax in the travel phase (gasoline tax, regional road tax, diesel handling tax). Before the simulation, we will first describe the structure and features of the "GENDAI Model for transport and environmental policy assessment" developed by the GENDAI Advanced Studies Research Organization.

4. The structure and features of the "GENDAI Model for transport and environmental policy assessment"

This model is static model constructed on the basis of data for year 2000 to simulate the effects of reforms in automobile taxation systems on the acquisition, ownership, and travel behaviors of vehicles in Japan. In this model, five sectors ((i) household, (ii) shipper, (iii) distributor, (iv) automobile manufacturer, and (v) the government) are set as the social sectors, and the behavior of each sector is adjusted through market mechanisms. As a result, acquisition, ownership, and travel behaviors of vehicles are determined by this multi-sector equilibrium model[6].

4.1. Structures and basic behavioral principles of each sector

Table 3 and Fig. 4 show the structure and behavioral principle of each sector and the entire structure of the model.

4.1.1. Household

The decision to acquire, own, and travel in a vehicle is taken by a household based on the price in order to maximize utility under budget constraints.

First of all, with regard to the acquisition and ownership of passenger car(s), households are faced with 91 options: (1) whether to buy (a) vehicle(s); (2) if the decision is to buy, whether to buy 1 or 2 vehicles; (3) which type (standard-sized passenger car, small-sized passenger car, or light motor passenger car) to buy and what age (1, 2, 3, 4) should be chosen for the first and second vehicles[7]. Here, an age of 1 implies new vehicles purchased in the last two years (hereinafter, referred to as to buy and what age (1, 23 imply vehicles sold as new cars in the last 3ased in the last two years (hereinafter, referred to as to buy and what aand an age of 4 implies vehicles sold as new cars in the last 9–11 years.

Table 3 Structure and Behavioral Principle of Each Sector

Sector	Structure	Behavioral principle
(i) Household	Assuming an average family (single representative household) in Japan	Utility maximization
(ii) Shipper	Assuming 1 shipper	Determine demanded (ton-km) road transport services for each vehicle type (standard-sized truck, small-sized truck, and light motor truck) depending on the GDP, which is exogenously given. For standard-sized trucks and small-sized trucks, determine business categories (private, commercial) of the distributor by the cost-minimization behavior.
(iii) Distributor	Assuming five companies in all with one company for each vehicle type and business category (company with standard-sized commercial trucks, company with small-sized commercial trucks, company with standard-sized private trucks, company with small-sized private trucks, and company with light motor private trucks)	Cost minimization
(iv) Automobile manufacturer	Assuming six companies in all with one company for each vehicle type (standard-sized passenger car, small-sized passenger car, light motor passenger car, standard-sized truck, small-sized truck, and light motor truck)	Sell vehicles at the price level of the base year, regardless of sales volume.
(v) Government	—	Set tax rates for automobile-related taxes and allocate tax revenues to the investment for road improvement.

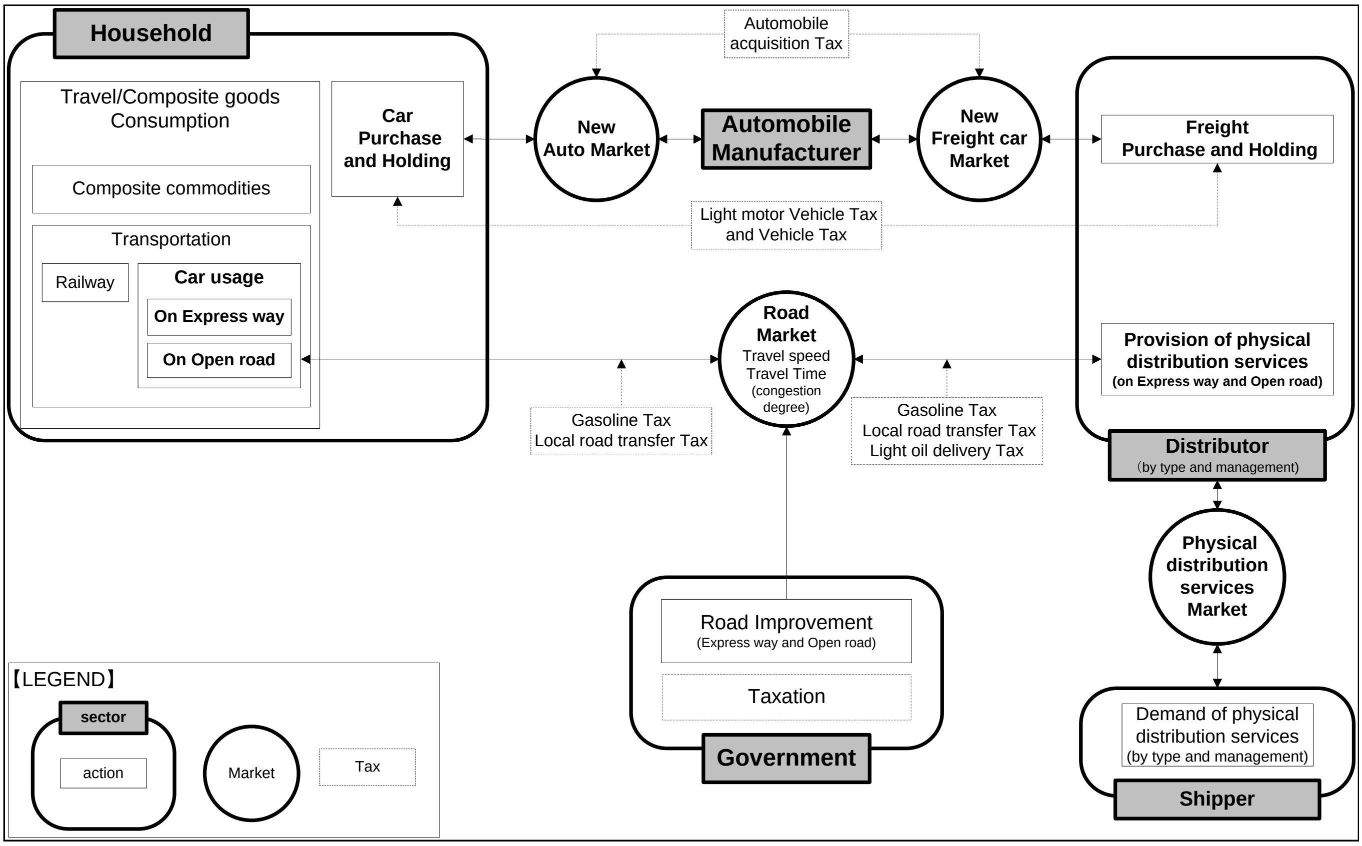


Fig. 4 Model Structure

Households estimate the utility levels that they can obtain from each option, including the utility that they can obtain from expenses other than those incurred during acquisition and ownership of (a) passenger car(s) (travel/composite goods consumption in Fig. 4). Since we assumed average families (single representative households) as the type of household in this model, one of the 91 options maximizes the utility level. However, in this model, a household does not clearly choose that specific option. This model assumes a structure where a household probabilistically chooses an option for the acquisition and ownership of vehicles by the logit model by considering the relative levels of utility provided by each option. The utility used in the logit model is consisted the utility that is decided by expenditure on travel/composite goods consumption by each option and the fixed- utility by provided by each option, which was obtained by a regression analysis for which the actual choice probabilities for each acquisition/ownership. The product of the choice probability for each option and the number of households will be the number of households that choose each acquisition/ownership pattern (see also Appendix A-1).

The acquisition and ownership of (a) passenger car(s) (travel/composite goods consumption in Fig. 4) for 91 vehicle acquisition/ownership patterns are determined by the following three steps (see also Appendix A-2).

In the first step, we determine the consumption of travel and composite goods (goods/services other than travel) that maximize utility when their costs are given. Here, the budget constraint is the disposable income after deducting the cost for the acquisition and ownership of a vehicle (price of vehicle for 1 term) as well as the costs for its maintenance and repair (including insurance and other fees, automobile acquisition tax, automobile tonnage tax, automobile tax, and light motor vehicle tax) decided in above decisions of car owned. In the second step, we use the travel expenses (the product of the costs of travel and consumption of travel) determined in the first step as the budget constraints and determine the expenses for travel by passenger car and travel by train that maximize utility when their costs are given. In the third and final step, we use the travel by passenger car expenses (the product of the expenses of travel by passenger car and travel by passenger car) determined in the second step as the budget constraints and determine the expenses for travel on expressways and travel on open roads when their costs are given. Here, the cost for travel on expressways includes the total of the travel time cost and fuel price for travelling 1 km on expressways, gasoline tax, regional road tax, and expressway toll. Likewise, the cost for travel on open roads includes the total of the travel time cost and fuel price for travelling 1 km on open roads, gasoline tax, and regional road tax (see also Appendix A-2). As a result, the levels of utility a household are obtained.

4.1.2. Shipper

A shipper's demand (ton-km) for road transport services for each vehicle type (standard-sized truck, small-sized truck, and light motor truck) is determined only by the GDP, which is exogenously given, and the demand is not affected by the unit transportation cost.

Then, with regard to transportation by standard-sized trucks and small-sized trucks, shippers determine traffic volumes for two different business categories—private and commercial—by the cost-minimization behavior, given unit transportation costs per ton-km for the two business categories.

Here, the shipper is not assumed to clearly choose one specific business category with a lower price but they will probabilistically choose a business category by the logit model by considering the relative levels of both transportation costs (see also Appendix A-3).

4.1.3. Distributor

Distributors cover all the abovementioned transportation demands of the shipper.

The total travel distance for each vehicle type/business category (km) is equivalent to the amount obtained by dividing the transport demand of the shipper by the load capacity per vehicle, which is exogenously set.

These values are determined regardless of the choice behavior of each distributor and the choice of the truck ownership structure by age. Further, the choice between travel on expressways and travel on open roads is determined by the stochastic cost-minimization behavior of each distributor, and it will be reflected in the unit transportation cost to the shipper.

First, the ownership structure of trucks by their age is probabilistically determined by the logit model using the relative levels of composite costs for acquisition/ownership by age. These composite costs will include not only the price of the trucks and costs for their maintenance and repair but also the automobile acquisition tax, automobile tonnage tax, automobile tax, and light motor vehicle tax (see also Appendix A-4). Ownership by age is determined by multiplying the total truck ownership with each age-based probability estimated by the logit model. The total truck ownership is obtained by dividing the total transportation distance by the fixed transportation distance based on vehicle type and business category.

Next is the issue of the choice between travel on expressways and travel on open roads. It is not assumed that distributors clearly choose a specific option based on a lower price; in fact, it is assumed that they will probabilistically choose one option by the logit model by considering the relative levels of travel costs in both cases. Here, the costs for travel on expressways and travel on open roads imply the total of the travel time cost and fuel price required for travelling 1 km by exercising each option, the gasoline tax, regional road tax, and expressway toll (see also Appendix A-5).

4.1.4. Automobile manufacturer

We assume six automobile manufacturing companies in all with one company for each vehicle type (standard-sized passenger car, small-sized passenger car, light motor passenger car, standard-sized truck, small-sized truck, and light motor truck). Each company sells its vehicles at the price level of the base year, regardless of the sales volume.

4.1.5. Government

The government sets tax rates for automobile-related taxes, namely, the tax in the acquisition phase (automobile acquisition tax), those in the ownership phase (automobile tonnage tax, automobile tax, and light motor vehicle tax), and those in the travel phase (gasoline tax, regional road tax, diesel handling tax, and petroleum gas tax). The government invests these tax revenues into road improvement activities.

4.2. Market clearing conditions

So far, we have discussed the behavioral principle of each sector. The behavior of each sector is adjusted through arbitration by four agents: new automobile markets (passenger car market and truck market), distribution market, and road traffic. The number of new vehicles acquired, number of vehicles bought, and the travel distances of households and distributors will be determined by these markets.

In this case, the road traffic market (expressways and open roads) and the travel time costs, which include a part of the travel cost, are determined as the point of intersection of the supply curve, which is drawn as the inverse of the macro Q–V curve (function depicting the relationship between the road dimensions and the travel speed) (see also Appendix A-6) and the traffic demand curve, which represents a decreasing function of the travel time costs.

4.3. Economic welfare

We obtain the change in economic welfare caused by vehicle taxation system revision by calculating the compensating variation. First, we measure the required income level to determine the level of utility before a taxation system revision under the price structure after the revision. Then we calculate the change in economic welfare by subtracting the measured income from the income in 2000, which is the base year in this model (see also Appendix A-7).

4.4. Elasticity

Thus far, we have explained the structure of the ”GENDAI Model for transport and environmental policy assessment”. We will now describe the elasticity of the major variables in this model vis-à-vis each tax item.

Table 4 shows the extent to which the values of each variable change when taxes related to acquisition, ownership, and fuel are each increased by 10%, in comparison to the case where there is no amendment in the taxation system.

According to this table, the total travel distance and the energy consumed have the largest elasticity vis-à-vis the fuel tax (–0.054, –0.056), followed by the ownership tax (–0.015, –0.015) and the acquisition tax (–0.004, –0.005). On the other hand, for the number of passenger cars bought, the highest elasticity is that against ownership tax (–0.011), followed by those against fuel tax (–0.007) and acquisition tax (–0.003).

Table 4 Effects of tax increases of 10%

	Fuel tax 10% increase	Automobile acquisition tax 10% increase	Ownership tax 10% increase
Total travel distance	–0.54	–0.04	–0.15
Energy consumed	–0.56	–0.05	–0.15
Number of vehicle owned (passenger cars)	–0.07	–0.03	–0.11

Note (1) The ownership tax includes the light motor vehicle tax, automobile tax, and automobile tonnage tax.

Note (2) The elasticity against each tax item is obtained by dividing each value by 10.

Note (3) With regard to trucks, the elasticity of the number of vehicles bought against each tax item is almost zero. This is because the number of trucks bought is largely determined by the amount of transportation demanded by the shipper (function of GDP).

Note (4) These figures do not include the effects of improvement in fuel efficiency and expansion of road dimensions.

Next, we calculated the fuel price (including taxes) elasticity of the energy consumed to compare it with the results of previous studies. The results revealed that the price elasticity of gasoline consumption was –0.15 and that of light oil consumption was –0.01. Futamura (1999) and Hasuike (2001) estimated the price elasticity of gasoline consumption to be approximately –0.2; the value obtained in this study is lower than that obtained in their studies. Likewise, with regard to light oil consumption, our value is lower than that in Yokoyama et al. (–0.0424).

5. Simulation of effects of the automobile taxation system revision

In this section, making use of the ”GENDAI Model for transport and environmental policy assessment”, we will simulate how the sale of new vehicles; their acquisition, ownership, and travel behaviors; the level of economic welfare of households; CO_2 emissions by cars change when we convert the existing automobile taxation system to one that is implemented in the travel phase.

For this purpose, we will first describe the simulation scenario.

5.1. Simulation scenario

5.1.1. The base case

We determine the behavior of acquisition, holding, and transporting a vehicle and truck;

economic welfare; and CO_2 emission by using the value of the GDP, a household's disposable income and tax, and price of goods and services in 2000. So the base case employs the theoretical figures for 2000 and these figures are reconstructed in our model.

5.1.2. The comparative case

We has discussed about problems of taxations in the section 3. Both the acquisition tax (automobile acquisition tax) and ownership tax (automobile tonnage tax, automobile tax, light motor vehicle tax) have the problem that automobile users do not find enough grounds for paying basic rates for road travel services from either the cost-of-service principle or the value-of-service principle. The acquisition tax has another problem that it let consumer surplus decrease and the tax revenue is very different from that provided by the usage of roads. Therefore, as a comparative case, we have considered a tax revenue neutrality case where the acquisition tax and ownership tax are abolished and the amount equivalent to such tax revenues are additionally imposed as taxes in the travel phase (gasoline tax, regional road tax, diesel handling tax). We will simulate acquisition, ownership, and travel behaviors; the level of economic welfare of households; CO_2 emissions; etc.[8].

In the comparative case, the amount of taxes in the travel phase is 1.8 times that in the base case. Likewise, the gasoline tax (gasoline tax + regional road tax) and diesel handling tax are 96.8 yen/ℓ (base case: 53.8 yen/ℓ) and 57.8 yen /ℓ (base case: 32.1 yen/ℓ).

For the simulation, we assumed that the GDP levels, the disposable incomes of households, the fuel efficiencies of vehicles, road dimensions, and the price levels of goods and services remained constant, similar to the base case.

5.2. Results of simulation

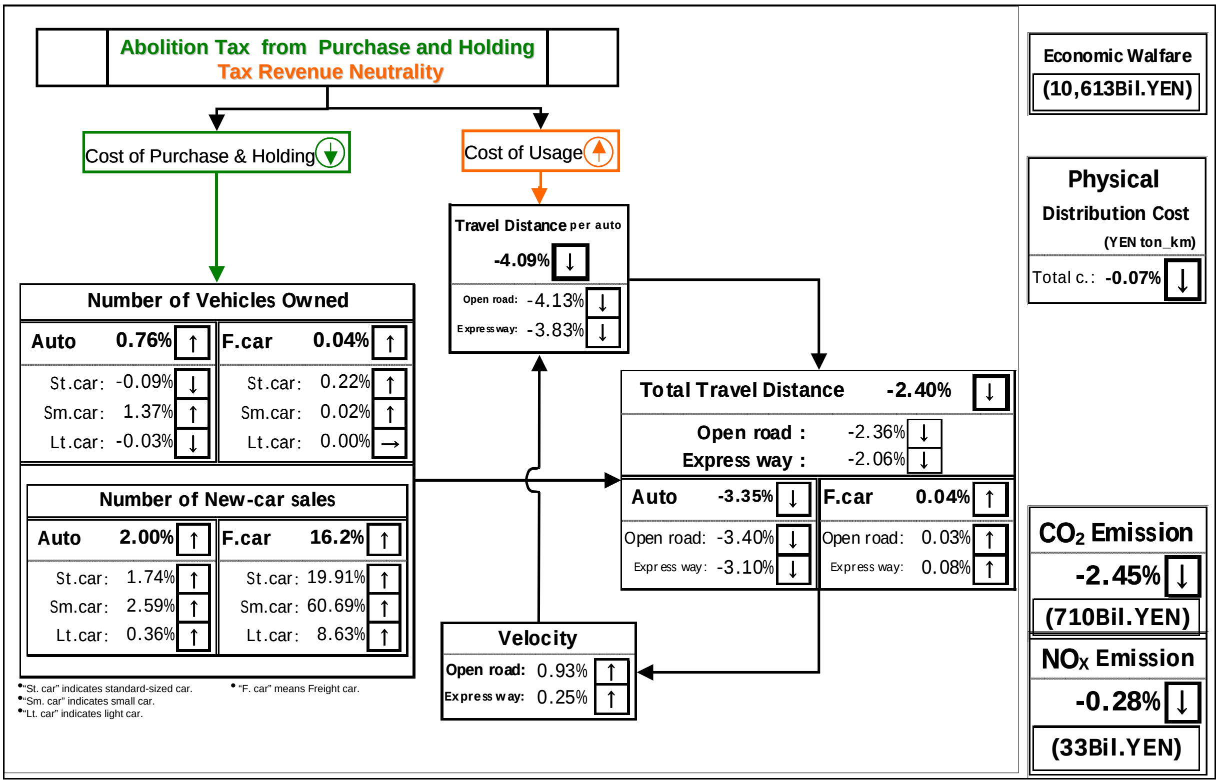
We conducted simulations in the above mentioned scenario. In Fig. 5, we have indicated values with regard to acquisition, ownership, and travel behaviors; level of economic welfare of households; CO_2 emissions; etc. for the comparative case. The values in Fig. 5 show the rates of change in values in the comparative case in comparison to those in the base case.

Hereinafter, we will analyze the effects of the taxation system revision separately for acquisition, ownership, and travel behaviors; level of economic welfare of households; CO_2 emissions by cars.

5.2.1. Changes in the acquisition/ownership behaviors

5.2.1.1. Passenger cars

Firstly, the sales volumes of new passenger cars (Age 1) in the comparative case increase by 2.0% as compared to those in the base case. This is because in the comparative case, taxes in the acquisition and ownership phases have been abolished. Consequently, households enjoy higher levels of utility in (1) the "case where they buy (a) vehicle(s)" than in the "case where they do not buy vehicles," in (2) the "case where they buy two vehicles" than in the "case where they buy one vehicle," and in (3) the "case where they buy (a) new vehicle(s)" than in the "case where they buy (a) used vehicle(s)."



Note: Values in the figure show rates of change in the comparative case in comparison to those in the base case.

Fig. 5 Outcomes of the Simulation

When we observe the results by vehicle type, the sales volumes for standard-sized vehicles and small-sized vehicles show an increase of 1.74% and 2.59%, respectively, and they are larger than that for light motor vehicles (0.36%). We can see from Fig. 5 that in the existing taxation system and in all taxes imposed in the acquisition and ownership phases, smaller tax rates are applicable to light motor vehicles in comparison to those for standard-sized vehicles and small-sized vehicles. As a result, in the comparative case where taxes in the acquisition and ownership phases are abolished, the level of utility will be higher in the case where a household buys (a) standard-sized vehicle(s) or (a) small-sized vehicle(s) in comparison to that in the case where a household buys (a) light motor vehicle(s). Therefore, the sales volumes of standard-sized vehicles and small-sized vehicles will be higher than those of light motor vehicles.

The number of vehicles owned in the comparative case will increase by 0.76% as compared to that in the base case. When we observe the results by vehicle type, we see that while the sales volumes for small-sized vehicles increase by 1.37%, the number of standard-sized and light motor vehicles owned decrease by 0.09% and 0.03% respectively. Such decrease in the number of standard-sized and light motor vehicles owned and increase in the sales volumes for new standard-sized and light motor vehicles will be explained by the shift from used cars to new cars associated with the abolition of the automobile acquisition tax.

5.2.1.2. Trucks

With regards to trucks, the sales volumes of new trucks and the number of trucks owned increase by 16.24% and 0.04%, respectively.

We will first explain the characteristics of the number of trucks owned. In this model, the shipper's road traffic volume (ton-km) for each vehicle type (standard-sized truck, small-sized truck, and light motor truck) is automatically determined by the GDP, which is exogenously given. Likewise, the number of trucks owned by a distributor (company with standard-sized commercial trucks, company with small-sized commercial trucks, company with standard-sized private trucks, company with small-sized private trucks, and company with light motor private trucks) is automatically determined once the transport demand of the shipper has been determined. Under such circumstances, the abolition of taxes in the acquisition and ownership phases will not affect the number of trucks owned.

However, if we abolish the taxes in the acquisition and ownership phases, the relative level of the transport cost per ton-km of commercial trucks vis-à-vis the transport cost of private trucks changes both for standard-sized trucks and small-sized trucks by following two effects. One is the increase of relative level of the transport costs for commercial trucks. This is because from Fig. 5 it is clear that in the existing automobile acquisition tax and automobile tonnage tax, lower tax rates are applicable to commercial vehicles in comparison to those for private vehicles, and if we abolish such taxes, the relative level of the transport costs for commercial trucks will increase in comparison to that for private trucks. The other is increase of relative level of the travel costs for private trucks in comparison to those for commercial trucks associated with the increase of the amount of taxes in the travel phase. This is because traffic efficiency of private trucks is lower than that of commercial trucks. The former effect is greater than the latter effect in this simulation. Therefore, in the comparative case, with regard to standard-sized trucks and small-sized trucks, the probability for the shipper to choose private trucks will increase as compared to that in the base case. However, private trucks have a smaller load capacity and travel distance (km) per vehicle. The shipper's choice of private trucks will thus contribute to the increase in the number of trucks. This effect caused by the shipper's choice between commercial trucks and private trucks will occur only for standard-sized trucks and small-sized trucks, for which a classification system divides commercial trucks from private trucks, and the number of trucks owned increases by 0.22% and 0.02%, respectively.

Finally, when we observe the demand for new vehicles, in the comparative case, the demand for new standard-sized trucks, new small-sized trucks, and new light motor trucks has considerably increased by 19.91%, 60.7%, and 8.63%, respectively, as compared to that in the base case. This increase is caused by the accumulation of two different effects of the shipper's choice of private trucks and the increase in the new car preference associated with the abolition of the automobile acquisition tax.

5.2.2. Changes in the travel behavior

5.2.2.1. Travel distance per vehicle (km)

In this section, we will discuss the changes in the travel distance per vehicle (km).

First, with regard to trucks, the travel distance per vehicle is exogenously determined for each distributor. However, as the travel distance per vehicle of private trucks is smaller than that of commercial trucks, the shift from commercial trucks to private trucks will decrease the average travel distance per vehicle (this is not indicated in Fig. 5).

On the other hand, with regard to passenger cars, in the comparative case, the average travel distance has decreased by 4.09% as compared to the base case. We can explain these phenomena from two factors: (1) the relaxation of budgetary constraints on the travel/composite goods consumption associated with the abolition of taxes in the acquisition and ownership phases and (2) the change in the cost for travel by passenger cars.

First, with regard to the relaxation of budgetary constraints, if taxes in the acquisition and ownership phases are abolished, the costs of travel and composite goods, other than vehicle ownership, increase. Under such circumstances, travel by passenger cars will increase.

Second, we explain the effect of the change in the cost for travel by passenger car. In this model, the cost for travel by passenger cars includes the travel time cost, the fuel cost required for travel, gasoline tax, regional road tax, and expressway toll. In the comparative case, since the total value of the gasoline tax and the regional road tax is 1.8 times that in the base case, the cost for travel by passenger car increases and works as a factor that decreases the travel distance per vehicle. Likewise, the travel time cost included in the cost for travel by passenger car is equivalent to the inverse of the speed. The speed is determined by the relationship between the total travel distance and the road dimensions (see below). When we consider the case of open roads as an example, the road dimensions do not change and the total travel distance decreases by 2.40%; consequently, the speed increases by 0.93%. Therefore, the travel time cost will be reduced and under such circumstances, and it will work as a factor that increases the travel distance per vehicle.

The travel distance will be determined by the accumulation of all these effects. In the comparative case, the negative effect of the increased tax will be greater in comparison to that in other effects and the travel distance per vehicle for passenger cars will decrease by 4.09% as compared to the base case.

5.2.2.2. The total travel distance

The total travel distance (km) is the product of the number of vehicles owned and the travel distance per vehicle.

First, with regard to passenger cars, as the travel distance per vehicle decreases by 4.09% while the number of vehicles owned increases by 0.76%, the total travel distance decreases by 3.35%.

On the other hand, the total travel distance of trucks does not change because the transportation amount does not change. On the whole, in the comparative case, the total travel distance decreases by 2.40% in comparison to the base case.

5.2.3. The level of economic welfare of households

As a result of the above changes in behaviors, the change in economic welfare of households calculated as the compensating variation is 1.0613 trillion yen. This result implies that the positive effect by the abolishment of the acquisition tax and the ownership tax is significantly greater than the negative effect by the increase in the travel phase taxes.

5.2.4. CO_2 Emissions

CO_2 emissions are proportional to the energy consumed, which is obtained by dividing the total travel distance (km) by the actual travel fuel efficiency (km /ℓ). The total travel distance (km) in the comparative case decreases by 2.40% in comparison to the base case. The actual travel fuel efficiency also improves because the travel speed increases. Due to these increases, the energy consumed will be reduced in the comparative case, and as a result, CO_2 emissions are reduced by 2.45% as compared to the base case. If we calculate the monetary value of the decreased CO_2 emissions by using the basic unit of CO_2 as 2,300 yen/tonnage[9], we observe that the value is appropriate for a total of 71 billion yen.

Detail explanation is beyond the scope of this article, we also calculate how NO_X emissions by automobiles change by the taxation system revision. NO_X emissions also are reduced by 0.28% as compared to the base case. If we calculate the monetary value of the decreased NO_X emissions by using the basic unit of NO_X as 580,000 yen/tonnage[10], we observe that the value is appropriate for a total of 12.9 billion yen.

6. Concluding remarks

In this paper, we reviewed problems in the existing automobile taxation system and we simulated how the sale, acquisition, ownership and travel behaviors of new vehicles; the level of economic welfare of households; CO_2 emissions by cars would change when the existing automobile taxation system is converted into one where taxes are imposed in the travel phase by using the "GENDAI Model for transport and environmental policy assessment", a multi-sector equilibrium model developed by the GENDAI Advanced Studies Research Organization.

From this simulation, we found that an amendment by which tax imposition if shifted to the travel phase will have considerable effects on the improvement of the level of economic welfare of households, the reduction of CO_2 emissions.

This research will be extended in following three directions.

First, we are engaged in the segmentation of family types in the household sector. The model used in this paper considers only one household type, which is the average household (single representative household) in Japan. However, when we think about the future of automobiles, we can imagine that acquisition, ownership, and travel behaviors of households will change dramatically due to the aging of population. In order to follow up such future change, we are now engaged in works to divide households into three groups by the age of the head of household. This will enable us to understand how changes in the composition of households by the age of their heads affect acquisition, ownership, and travel behaviors of households as a whole.

Second, we are considering the introduction of the used car market. In this model, it is possible to purchase used passenger cars at a certain price infinitely, regardless of the constraints on the actual number of used vehicles. Likewise, in this model, only distributors decide whether they intend to maintain possession of trucks possessed or replace them with new trucks, and we have not yet developed a model for a scenario where they sell their trucks and replace them with other used trucks. Therefore, we are now considering the modeling of behaviors related to the sale and purchase of used cars.

Third, the simulation logic needs to be refined for the physical distribution service market. In the current model logic, the shipper's transport demand for each vehicle type is automatically determined by the GDP, which is exogenously given, and it is unaffected by the unit cost of transport. We are now considering the revision of this model and the modeling of alternative relations with other modes of transport such as trains in order to determine the effects of a taxation system revision on the choice of the mode of transport. Likewise, in this logic, we have assumed the load capacity per vehicle and the travel distance of the distributor as steady values. We are also considering the modeling of effects of a taxation system revision on such traffic efficiency indicators.

From the time that the Koizumi administration came into power, the automobile taxation system, the system of earmarked tax revenues for road construction, and the issue of shifting to general tax revenues assumed greater political significance. By using this model effectively, we will engage in policy recommendations regarding the automobile taxation system from comprehensive perspectives, including the promotion of new automobile technologies, improvement of the level of economic welfare of households, and the development of solution to global environment problems and traffic accidents.

Appendix A: Detailed description of the model

The main logic of the model is as follows.

(A-1) The choice of passenger car ownership of a household

We define that the total utility for a household, U^i, in the case where a household choose a passenger car acquisition and ownership pattern i will be determined by summing up the utility of travel and composite goods consumption, U_c^i, and the utility of passenger car ownership, U_o^i.

We define the total utility for household as follows:

$$U^i = U_c^i + U_o^i.$$

Here, the utility of travel and composite goods consumption for a household, U_c^i, can be described by the indirect utility function as follows (for variable names, see A-2):

$$U_c^i = (\alpha_1 \quad p_1^{1-\delta_1} + \beta_1((1+\tau_c)p_2)^{1-\delta_1})^{\frac{1}{\delta_1 - 1}} M_1^i.$$

Then, we formulate the choice probability for a household with passenger car ownership pattern i by the logit model. The choice probability for a household with passenger car ownership pattern i is given as follows:

$$P^i = \frac{\exp(\mu_1 U^i)}{\sum_i \exp(\mu_1 U^i)}$$

where μ_1 is scale parameter of the logit model.

The value of the utility of ownership for each passenger car acquisition pattern, U_o^i, was obtained by a regression analysis for which the actual choice probabilities for each acquisition/ownership pattern in 1999 were considered as explained variables. The actual choice probabilities for each acquisition/ownership pattern in 1999 were calculated based on proprietary data owned by the GENDAI Advanced Studies Research Organization.

(A-2) The decision for expenditure on travel consumption and composite goods in a household

The decision for expenditure on travel/composite goods in a household can be formulated as utility maximization formulas in the following three steps. As utility functions, we employed the CES utility function in the first and second steps and the Cobb-Douglas function in the third step.

Each passenger car ownership pattern i has a different budget constraint formula, generalized cost determined by the sub-step (for example, the generalized cost of travel in the first step), and the distributed parameter of the utility function. Hereinafter, we will describe the method of formulation of the utility maximization formulas in the case where the household possesses one passenger car by omitting the suffix i .

[Utility maximization formula for the first step: Decision for expenditure on travel/composite goods (except travel) consumption]

A household determines the expenditure on travel/composite goods (except travel) consumption to maximize its utility under a given price of travel/composite goods. The problem is to

$$Max \quad U_c = U_1 = (\alpha_1^{\frac{1}{\delta_1}} q_{11}^{\rho_1} + \beta_1^{\frac{1}{\delta_1}} q_{12}^{\rho_1})^{\frac{1}{\rho_1}},$$

$$s.t. \quad p_{11} q_{11} + p_{12} q_{12} (1 + \tau_c) = M_1$$

where

U_1 : level of utility of travel/composite goods consumption;

α_1 : distributed parameter for travel ($\alpha_1 > 0$);

β_1 : distributed parameter for composite goods other than travel ($\beta_1 > 0$), $\alpha_1^{\frac{1}{\delta_1}} + \beta_1^{\frac{1}{\delta_1}} = 1$;

δ_1 : elasticity of substitution of travel and composite goods by number of passenger cars owned;

ρ_1 : coefficient related to the elasticity of substitution; it is determined separately depending on the number of passenger cars owned: $\rho_1 = (\delta_1 - 1)/\delta_1$;

p_{11} : generalized cost (including taxes) of travel per kilometer (this generalized cost of travel is determined from the cost for "travel by passenger car" and that for "travel by train")

p_{12} : cost of composite goods other than travel (excluding consumption tax) (This cost is composed of the physical distribution cost and the other costs. The physical distribution cost is determined endogenously by the model);

τ_c : consumption tax,

q_{11} : travel consumption,

q_{12} : composite goods consumption other than travel,

M_1 : the amount obtained after deducting the cost for acquisition and ownership of a passenger car decided in above "(A-1) The choice of passenger car ownership of a household" (price of a vehicle for 1 term) as well as costs for maintenance and repair (including insurance and other fees, automobile acquisition tax, automobile tonnage tax, automobile tax, and the light motor vehicle tax) from the disposable income (including the value of time)[11].

When we solve this utility maximization formula, we obtain Marshallian demand functions for travel and composite goods other than travel as follows:

Demand function for travel:

$$q_1 = \alpha_1 M_1 / (p_1^{\delta_1} (\alpha_1 p_1^{1-\delta_1} + \beta_1 ((1+ \tau_c) p_2)^{1-\delta_1}),$$

Demand function for composite goods other than travel:

$$q_2 = \beta_1 M_1 /(((1+ \tau_c) p_2)^{1-\delta_1} (\alpha_1 p_1^{1-\delta_1} + \beta_1 ((1+ \tau_c) p_2)^{1-\delta_1})).$$

Based on Tanishita and Kashima (2002), we have set the elasticity of substitution of travel and composite goods, δ_1, by the number of passenger cars owned as follows:

Household without vehicle: 0.411,

Household with one vehicle: 0.552,

Household with two vehicles: 0.603.

[Utility maximization formula for the second step: Decision to travel by passenger car or by train]

A household determines whether travel should occur by passenger car or by train based on the budget constraints on travel consumption decided in the first step and given the costs of travel by passenger car and travel by train. The problem is thus to

$$Max \quad U_2 = (\alpha_2^{\frac{1}{\delta_2}} q_{21}^{\rho_2} + \beta_2^{\frac{1}{\delta_2}} q_{22}^{\rho_2})^{\frac{1}{\rho_2}},$$

$$s.t. \quad p_{21} q_{21} + p_{22} q_{22} = M_2,$$

where

U_2: level of utility of travel consumption,

α_2: distributed parameter for travel by passenger car ($\alpha_2 > 0$),

β_2: distributed parameter for travel by train ($\beta_2 > 0$), $\alpha_2^{\frac{1}{\delta_2}} + \beta_2^{\frac{1}{\delta_2}} = 1$,

δ_2: elasticity of substitution of travel by passenger car and travel by train by number of passenger cars owned,

ρ_2: coefficient related to the elasticity of substitution determined separately depending on the number of passenger cars owned, $\rho_2 = (\delta_2 - 1)/\delta_2$,

p_{21}: generalized cost (including taxes) of travel by passenger car per kilometer (This generalized cost is determined from the cost for travel on expressways and that for travel on open roads in the third step.),

p_{22}: generalized cost (including taxes) of travel by train per kilometer (this amount can be calculated from the railroad fare, access/egress times, waiting time, etc.),

q_{21}; distance travelled by passenger car (km),

q_{22}: distance travelled by train (km),

M_2: $M_2 = p_1 q_1$ (determined in the first step).

Based on Tanishita and Kashima (2002), we set the elasticity of substitution of travel by passenger car and travel by train, δ_2, by the number of passenger cars owned as follows:

Household with one vehicle: 1.230,
Household with two vehicles: 1.110.

[Utility maximization formula for the third step: Decision to travel on expressways or travel on open roads]

A household determines whether travel should occur on expressways or on open roads based on the budget constraints of travel by passenger car decided in the second step and given the cost of travel by passenger car and travel on open roads. The problem is thus to

$$Max \quad U_3 = q_{31}^{\alpha_3} q_{32}^{1-\alpha_3},$$
$$s.t. \quad p_{31} q_{31} + p_{32} q_{32} = M_3$$

where

U_3 : level of utility of travel by passenger car,

α_3 : distributed parameter of travel on expressways ($\alpha_3 > 0$),

$1 - \alpha_3$: distributed parameter of travel on open roads ($\alpha_3 > 0$),

p_{31} : generalized cost (including taxes) of travel on expressways per kilometer (this generalized cost is determined from the fuel cost (including taxes), actual travel fuel efficiency, and travel time cost),

p_{32} : generalized cost (including taxes) of travel on open roads per kilometer (this amount is determined from the fuel cost (including taxes), actual travel fuel efficiency, and travel time cost),

q_{31} : distance travelled on expressways (km),

q_{32} : distance travelled on open roads (km),

$M_3 = p_{21} q_{21}$ (determined in the second step).

We have calculated the actual travel fuel efficiency (km/ℓ) for each road type by the following formula, which is based on Kashima and others (2003):

Actual travel fuel efficiency by road type (km/ℓ)

$$= 54.87 e_c / ((356.9/v - 1.706 v + 0.0128 v^2 + 105.2))$$

Where e_c is the fuel efficiency by vehicle type (10/15 mode) (km /ℓ) and v is the speed by road type.

(A-3) Choice of business categories (private or commercial) by shipper

The shipper's choice of the business type (private or commercial) for standard-sized vehicles and small-sized vehicles will depend on the following logit model:

$$\Pr^1{}_j = \frac{1}{1+\exp(\theta_1(pt_e - pt_j) + \psi_1)},$$

where

$Pr^1{}_j$: choice probability for private trucks,

pt_e : unit cost of transportation for commercial trucks per ton-km (calculated from the depreciation cost, costs for maintenance and repair, motor vehicle insurance, automobile acquisition tax, automobile tonnage tax, automobile tax, light motor vehicle tax, personnel costs, the travel cost determined by cost of travel on expressways, travel distance by expressways, cost of travel on open road , travel distance by open road (See A-5),

pt_j : unit cost of transportation for commercial trucks per ton-km.

We calculated the parameter values of θ_1 and ψ_1 based on actual data for 1991–2000. The values used were as follows.

	θ_1	ψ_1
Standard-sized trucks	–0.0041	0.2340
Small-sized trucks	–0.000059	–2.4321

(A-4) Choice probability of distributor truck ownership by age

The distributors' choice of trucks ownership by age of is derived by the following logit model:

$$Pr_a = \frac{\exp(\theta_2(pv_a - pv_1))}{\sum \exp(\theta_2(pv_a - pv_1))},$$

where

Pr_a : probability of truck ownership by age,

pv_1 : composite costs for the acquisition and ownership of a vehicle of Age 1 (new vehicle) (calculated from the depreciation cost, costs for maintenance and repair, automobile acquisition tax, automobile tonnage tax, automobile tax, light motor vehicle tax, etc.) ,

pv_a : composite costs for the ownership of a vehicle of Age a (a = 2, 3, 4, 5) (calculated from the depreciation cost, costs for maintenance and repair, automobile tonnage tax, automobile tax, light motor vehicle tax, etc.).

We calculated the values of θ_2 for each distributor from actual data for 1995–2000. The values used were as follows.

	θ_2
Company with standard-sized commercial trucks	–0.04039
Company with standard-sized private trucks	–0.01037
Company with small-sized commercial trucks	–0.18888
Company with small-sized private trucks	–0.09744

(A-5) Choice of travel by road by distributor

The choice probability for travel on expressways is derived from the following logit model:

$$\mathrm{Pr}^3 = \frac{1}{1+\exp(\theta_3(pr_1 - pr_2)+\psi_3)},$$

where

Pr^3 : choice probability for travel on expressways,

pr_1 : cost of travel on open roads (per kilometer) (total of the travel time cost, fuel cost, and fuel tax required for travelling 1 km),

pr_2 : cost of travel on expressways (per kilometer) (total of the travel time cost, fuel cost, fuel tax, and expressway toll required for travelling 1 km).

In calculating the fuel cost, we have calculated the fuel consumption (km/ℓ) for travelling 1 km on open roads and expressways from the following formula obtained from the National Institute for Land and Infrastructure Management (2000):

Small-sized trucks/light motor trucks: $195.2/v - 1.9v + 0.015v^2 + 116.3$,

Standard-sized trucks: $17.7/v - 9.6v + 0.073v^2 + 558.7$,

Where v is the speed by road type.

We calculated the values of θ_3 and ψ_3 from actual data for 1991–2000. We used the following values.

	θ_3	ψ_3
Company with standard-sized trucks (Private and commercial trucks)	–0.0310	2.7938
Company with small-sized trucks (Private and commercial trucks) and company with light motor trucks	–0.0339	3.015

(A-6) Micro Q–V curve

We obtained the following result after estimating the macro Q–V curves for open roads and expressways separately.

$$\text{Expressways:}\quad v = 6.00 * \frac{RS^{0.15}}{Q^{0.12}},$$

$$\text{Open roads:}\quad v = 8.84 * \frac{RS^{0.44}}{Q^{0.39}},$$

Here, v is the speed by road type (km/h); RS, is the road dimensions by road type (km^2); and Q, travel distance in vehicle-km by road type.

(A-7) Economic welfare

We measured the compensating variation as the change in the economic welfare caused by automobile taxation system revision.

$$\text{Compensating variation} = \overline{M_s} - M_b^{'},$$

Here, $\overline{M_s}$ is the disposable income of a household in 2000 (excluding value of time) and $M_b^{'}$ is the income required to attain the level of utility in the base case under the price structure after a taxation system revision.

Appendix B: List of data used

[Household]

<table>
<tr><th colspan="2">Item</th><th>Organization</th><th>Title of data source</th></tr>
<tr><td colspan="2">Income (monetary)</td><td>MIAC</td><td>National Survey of Family Income and Expenditure</td></tr>
<tr><td colspan="2">Travel and leisure activities</td><td>MIAC</td><td>Survey on Time Use and Leisure Activities</td></tr>
<tr><td colspan="2">Earners per household</td><td>MIAC</td><td>National Survey of Family Income and Expenditure</td></tr>
<tr><td colspan="2" rowspan="2">Choice probability of vehicle ownership</td><td>JAMA</td><td>Passenger car market trend</td></tr>
<tr><td>AIRA</td><td>Number of automobiles owned: AIRA statistics</td></tr>
<tr><td colspan="2">Vehicle price</td><td>MIAC</td><td>Retail Price Survey</td></tr>
<tr><td colspan="2">Insurance cost</td><td rowspan="2">MIAC</td><td rowspan="2">Retail Price Survey</td></tr>
<tr><td colspan="2">Parking fee</td></tr>
<tr><td colspan="2">Maintenance cost</td><td>JAMA</td><td>Passenger car market trend</td></tr>
<tr><td colspan="2" rowspan="3">Automobile tonnage tax</td><td>AIRA</td><td>Number of automobiles owned: AIRA statistics</td></tr>
<tr><td>JMIF</td><td>Jidousya Gaido bukku (Automobile guide book)</td></tr>
<tr><td>Nikkan Jidosha Shinbun</td><td>Yunyuusya Gaido Bukku (Imported automobile guide book)</td></tr>
<tr><td colspan="2" rowspan="2">Automobile tax</td><td>AIRA</td><td>Number of automobiles owned: AIRA statistics</td></tr>
<tr><td>AIRA</td><td>Number of automobiles owned: by classification</td></tr>
<tr><td colspan="2" rowspan="2">Fuel efficiency</td><td>AIRA</td><td>Number of automobiles owned: AIRA statistics</td></tr>
<tr><td>JMIF</td><td>Jidousya Gaido bukku (Automobile guide book)</td></tr>
<tr><td colspan="2">Expressway toll per kilometer</td><td>Zenkoku Kousoku Doro Kensetsu Kyogikai (Japan Highway Construction Council)</td><td>Kousoku-doro Binran (Highway handbook)</td></tr>
<tr><td colspan="2" rowspan="3">Vehicle travel distance</td><td>JAMA</td><td>Jyoyosya Sijyou Doukou Tyousa (Passenger car market trend)</td></tr>
<tr><td>MLIT</td><td>Statistical Yearbook of Motor Vehicle Transport</td></tr>
<tr><td>AIRA</td><td>Number of automobiles owned: by classification</td></tr>
<tr><td colspan="2">Travel rate of second vehicle</td><td>JAMA</td><td>Passenger car market trend</td></tr>
<tr><td rowspan="2">Expressway + open road</td><td>Expressway travel rate</td><td rowspan="2">JSTE</td><td rowspan="2">Road Traffic Census</td></tr>
<tr><td rowspan="2">Municipal road travel rate</td></tr>
<tr><td>All roads</td><td>MLIT</td><td>Statistical Yearbook of Motor Vehicle Transport</td></tr>
</table>

[Distributor]

<table>
<tr><th>Item</th><th>Organization</th><th>Title of data source</th></tr>
<tr><td>GDP</td><td>Cabinet Office</td><td>National Accounts</td></tr>
<tr><td>Road transport</td><td rowspan="3">MLIT</td><td rowspan="3">Statistical Yearbook of Motor Vehicle Transport</td></tr>
<tr><td>Traffic volume by type of vehicle</td></tr>
<tr><td>Traffic volume by type of vehicle and management</td></tr>
<tr><td>Choice probability of truck</td><td>AIRA</td><td>Number of automobiles owned: AIRA statistics</td></tr>
<tr><td>Truck price</td><td>GENDAI-</td><td>Hearing data</td></tr>
<tr><td>Depreciation</td><td>GENDAI-</td><td>Hearing data</td></tr>
<tr><td>Personnel cost</td><td rowspan="3">Automobile Business Association of Japan</td><td rowspan="3">Vehicle transport business management index</td></tr>
<tr><td>Insurance cost</td></tr>
<tr><td>Maintenance cost</td></tr>
<tr><td rowspan="3">Automobile tonnage tax</td><td>AIRA</td><td>Number of automobiles owned: AIRA statistics</td></tr>
<tr><td>AIRA</td><td>Number of automobiles owned: by classification</td></tr>
<tr><td>JMIF</td><td>Jidousya Gaido bukku (Automobile guide book)</td></tr>
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<tr><td>AIRA</td><td>Number of automobiles owned: AIRA statistics</td></tr>
<tr><td>Fuel efficiency</td><td>MLIT</td><td>Statistical Yearbook of Motor Vehicle Transport</td></tr>
<tr><td>Time cost</td><td>JH</td><td>Document of Project Evaluation and Monitoring Commission</td></tr>
<tr><td>Expressway toll per kilometer</td><td>Zenkoku Kousoku Doro Kensetsu Kyogikai (Japan Highway Construction Council)</td><td>Kousoku-doro Binran (Highway handbook)</td></tr>
<tr><td>Travel distance of truck</td><td>JSTE</td><td>Road Traffic Census</td></tr>
</table>

Note) MLIT stands for the Ministry of Land, Infrastructure and Transport; "MIAC," Ministry of Internal Affairs and Communications; JAMA, Japan Automobile Manufacturers Association; AIRA, Automobile Inspection & Registration Association; JMIF, Japan Motor Industrial Federation, Inc.; JSTE, Japan Society of Traffic Engineers; JTA, Japan Trucking Association; JASPA, Japan Automobile Service Promotion Association; JH, Japan Highway Public Corporation; and GENDAI, GENDAI Advanced Studies research Organization.

Notes:

[i] "3.The existing automobile taxation system and its problems" is based on Miyoshi (2001).

[2]Automobile Inspection & Registration Information Association,

http://www.airia.or.jp/number/index.html (accessed date: 2007.11.27).

[3]Sugiyama & Imahashi (1989), Imahashi (1995), and Obuchi (1993) demonstrated over-taxation in the acquisition and ownership phases in a taxation system related to earmarked tax revenues for road construction,. Imahashi (1995) showed if the emphasis is shifted to fuel tax, the resulting tax system would approximate the pricing system and as a result, the idea of rerouting general revenues would not be supported anymore. With regard to the environment, Endo, Tanishita, and Kashima (1999) conducted a simulation of the effect of reducing fuel consumption in the case where 50% of the ownership tax has been shifted to the fuel tax under the tax revenue neutrality. They concluded that fuel consumption will be reduced by 8.2% with an increase in the travel speed. and the travel fuel efficiency will improve with a decrease in the number of vehicles owned, the travel distance, and the total travel distance.

[4] According to an estimation in Nagata (1995), the price elasticity of vehicle transport (passenger-kilometer) is 0.2179 and that of vehicle transport (ton-km) is 0.1114.

[5]Imahashi (1995) indicated the need to correct disparities between different oil or vehicle types.

[6]Several models have been developed, both in Japan and worldwide, to analyze the effects of automobile taxation revision. For example, in Japan, such models have been developed in studies by Kanamoto, Hasuike, and Fujiwara (2006); Ueda, Mutou, and Morisugi (1998); Morisugi (2002); and Kashima, Tanishita, Miyoshi, and others (2003). The Automobile Tax System Assessment Model developed by the GENDAI Advanced Studies Research Organization is an improved version of the model by Kashima, Tanishita, Miyoshi, and others (2003). The model is also broader than those developed in earlier studies because it includes distributors (trucks) as well as vehicle acquisition and ownership behaviors for both passenger cars and trucks. It should be noted that the model explicitly deals with the effects of road improvement by earmarked tax revenues for road construction while we did not use this function in simulation. In Europe, the TREMOVE model (http://www.tremove.org/) has been developed under the Auto-Oil Program. This model has succeeded in describing separate traffic demands for inner cities and inter-city areas and for different time zones. It also includes other forms of transport, such as marine and air transport, and it enables us to analyze the effects of policy changes, including changes to the taxation system.

[7]A household has 12 option when it decides to buy a vehicle (3 types of passenger cars × 4 ages), while it has 78 options when it decides to buy two vehicles (${}_{12}C_2$ (number of options where type

and/or the age of two vehicles are different) + 12 (number of options where type and age of two vehicles are the same)). Hence, in all, a household has 91 options, including 1 option where no vehicle is bought.

[8]In the comparative case, the tax revenue neutrality is realized only in the base year. Since the behavior of each sector will change with a revision of the taxation system, tax revenue neutrality will not be secured after the base year.

[9]Douro toushi no hyouka ni kannsuru sisin kentou iinnkai (Exploratory committee of guide for evaluation of road investments) (2000) p. 81.

[10]Douro toushi no hyouka ni kannsuru sisin kentou iinnkai (Exploratory committee of guide for evaluation of road investments) (2000) p. 80.

[11]It should be noted that the automobile acquisition tax is imposed only upon the acquisition of new vehicles.

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