A model system for the assessment of the effects of car and fuel green taxes on CO₂ emission

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Abstract

This study aims at developing a model system to examine the changes in the car market configuration, the life cycle CO₂ emission from automobile transport and the tax revenues due to different taxation policies. The model system specifically determines the effect of varying the weights of the tax components in the stages of a) car purchasing, b) car owning, and c) car using to the changes in the car class and age mix and the car users' driving pattern and behavior towards car class choice and decommissioning. Five sub-models comprise the model system, formulated using car ownership related data in Japan from 1980 to 1994. Performance tests conducted against the sub-models generally yielded encouraging results. The sensitivity analysis identified car usage tax as the most significant parameters in reducing CO₂. An increase in, ownership tax, on the other hand, significantly results to a shift to smaller cars, while the propensity to decommission and repurchase can be reduced by increasing the purchase tax and can be decreased by increasing the ownership tax. The model system was utilized to determine the impact of the 1989 tax reform and to forecast future scenarios using different taxation schemes. The model system is being further developed for possible future application in other countries. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Tax weight balance; Emission reduction; Car ownership; Choice models; Green tax

1. Introduction

In most countries, energy consumption and pollutant emissions from the transportation sector has been considerably increasing in the past decade. In Japan, for instance, fuel consumption and CO₂ emissions in the transportation sector significantly increased by 16% from 1990 to 1995. Given such steady increase, emission level in the transportation sector is expected to rapidly in-
crease by 40% by 2010 based from the 1990 level. In the midst of a growing concern on global warming, this alarming rate of increase calls for energy efficiency and emission reduction measures in the entire transportation system. Among other emission reduction schemes, economic measures recently attract a great deal of attention as they result to direct emission reduction, as well as indirect reduction through giving incentives to develop low-emission engines (Hayashi et al., 1999).

Car-related taxes have the potential to reduce CO₂ emissions similar to carbon tax. This idea of greening the taxation system has been recently the subject of political concern among legislators in Japan. The Council for Transport Policy under the Ministry of Transport, for instance, has started to conduct examinations on the possible greening of the car taxation system in 1996. The study however did not prosper, as the Council of Taxation under the Ministry of Finance did not accept the proposal.

An important characteristic of car-related taxes is that it can be collected in the different stages of car taxation, namely: purchasing, owning and using. Tax collection in purchasing, basically involves the payment of the consumption tax while tax collection in owning stage includes the payment of annual license fee and annual taxes for ownership and compensation to road and infrastructure damage. Using stage, on the other hand, basically includes the fuel taxes. Among the stages of car ownership are various choices for car users to decide on. People’s responses to these choices as dictated by their economic behavior affect the factors which determine CO₂ emission. Tax is one of the most influential components of cost. The formulation of various tax weights among the stages of car ownership, therefore, may have tremendously affected the purchasing behavior, travel pattern, and consequently the life cycle CO₂ emission in the process of production, usage, maintenance and disposal of cars.

Fig. 1 shows the amount of weight of car-related tax per private car in developed countries. Although the total amount of tax is almost the same among most of the countries except USA, the weight among tax components varies differently. There are various theoretical discussions on tax weight balance. In Japan however, the resulting mechanism on people’s behavior has never been

![Figure 1: International comparison of car-related tax rates](image)

Fig. 1. International comparison of car-related tax rates (Assumption: Gasoline engine, 1500 cubic centimeter, 1020 kg, 1.5 million yen (US$13,500). Fuel economy: 12 km/l, 10,000 km/year, life time: 10 years).
explicitly examined. The “Greening of car ownership tax” was proposed at the Council for Transport Policy in 1999 while an exemption scheme for low emission cars has been introduced in Tokyo. Recently, many European countries have likewise been studying the tax weight system on the different stages of car ownership.

Prior to 1989, cars, particularly big passenger cars have been regarded in Japan as luxury items with a high tax rate added to its purchase and owning costs. Tax rates however were considerably changed due to the tax reform in 1989 when consumption tax was introduced to goods, including cars, and services (see Fig. 2). Before 1989, passenger cars were classified into big passenger cars (whose displacement is roughly over 2000 cubic centimeter “namely, class A”) and small passenger cars “namely, class B”. Tax rates for purchasing and owning of big passenger cars were about twice as high as those of small passenger cars were. But, after the tax reform, the tax rates for purchasing and owning for both classes became almost equal. As a result, the number of purchase of big passenger cars increased drastically. This study aims to examine the effects of the change in the relative tax weights, due to the 1989 Tax Reform, on the life cycle CO2 emission and the tax revenues by assessing people’s economic responses in the purchase, ownership and use of cars.

2. The basic characteristics and structure of the model system

The effects of levying car-related taxes on CO2 emission reduction can be classified as either incentive or revenue source effects. Incentive effect induces car owners, users, and car manufac-
turers to favor low CO$_2$ emission alternatives in such ways as: restraining car sales and ownership; promoting consumers’ purchase and producers’ research and development of low emission type of cars; restraining car driving; changing car age structure in market; and inducing proper car maintenance. Revenue source effect, on the other hand, promotes improvement measures on the environment by appropriating car-related tax revenues.

This study basically features the incentive effects, which are composed of: (a) the reduction of CO$_2$ in production and maintenance stages due to sales mix shift and change in fleet composition in terms of vehicle age and class; (b) the reduction of CO$_2$ in disposal stage due to change in decommissioning pattern; and (c) the reduction of CO$_2$ in car usage stage due to changes in driving condition and travel distance.

Changes in volume of production, car maintenance and disposal also bring the change in induced CO$_2$ emission in other related sectors. Such series of emission being referred to as “life cycle embodied emission”, can be measured by the concept of Life Cycle Assessment (LCA). The LCA is an environmental impact assessment tool and a component of the International Standard Organization 14000 Series. Existing researches in the field of transport engineering (e.g. Sterner et al., 1992; Bunch et al., 1993; Gronau, 1994; Sperling et al., 1995; Koopman, 1995; Kurani et al., 1996) mainly evaluate the reduction of CO$_2$ in car usage stage through simulations with respect to driving distance and fuel economy. However, assessment on CO$_2$ reduction during vehicle production, maintenance, and disposal were never conducted. In this study, the sum of life cycle embodied CO$_2$ and driving CO$_2$, which is called “Extended Life Cycle CO$_2$ (ELC-CO$_2$)” of car, is estimated. DeLuchi et al. (1989) introduce this concept in measuring electric vehicle performance in 1989.

3. The model system

The model system as illustrated in Fig. 3 is composed of five sub-models that will comprise three main processes:

1. Examination of the influence of car-related tax reform on the car market by tracing the change in car cohort over time considering the process of “disposal” and “car class choice” in repurchasing;
2. Estimation of the influence of fuel tax reform on driving distance as a function of fuel cost; and
3. Consequently, the total CO$_2$ emission, considering the life cycle CO$_2$ emission of cars.

A simplified flowchart highlighting the input and output parameters of each sub-models and a supplementary input and output table for all sub-models are presented in Fig. 4 in Table 1, respectively. This model is calibrated by the data of passenger cars in Japan, which generated 42% of the total CO$_2$ emission in transport sector in 1991.

3.1. Car cohort survival sub-model

Car cohort survival model is the core part of the model system. This method is adopted from a model developed by Morisugi and Ohno (1996), which is designed to forecast the share of diesel engine car. It basically generates the number of cars cross-classified by class and age using a mathematical formulation as illustrated in Table 2. The total number of new vehicle for each year
is based on the number of disposed cars, implying a repurchase, plus the number of new cars purchased by the new car owners, representing an increase in car ownership. The number and class mix of repurchased cars are determined in the disposal/repurchase choice sub-model using the survival rate models as shown in Eqs. (1) and (2). In this study, the increase rate of new cars used is 35% of the number of disposed cars as based to the market trend in Japan. The car class mix is assumed to be that of the repurchased cars. Survival rate over time is obtained from the number of registered cars in the initial year and the annual survival rate.

Annual survival rate: $L$

$$C_{a,t}^k = L_{a,t}^k e^{-k_{(a-1),(t-1)}};$$  

(1)

where $C_{a,t}^k$ is the number of existing cars of age $a$ and class $k$ in year $t$.

Survival rate over time: $S$

$$S_{a,t}^k = C_{a,t}^k / C_{0,(t-a)}^k = \prod_{i=1}^{t-a} L_{i,(t-a+i)}^k.$$  

(2)

In classifying cars, we introduce four categories to consider the different rates of ownership tax. The average car purchasing price and fuel consumption rates are calculated from the car purchasing price, engine size, and fuel consumption rate by car model (such as Honda Accord, Toyota Corolla, etc.) derived from the car registration data on the Ministry of Transport. The cars are classified according to engine size as follows:

*Class A*: 2001 cubic centimeter or bigger.

*Class B*: 1501–2000 cubic centimeter.
Class C: 1001–1500 cubic centimeter.
Class D: 1000 cubic centimeter or smaller.

3.2. Disposal/repurchase choice sub-model

The choice process whether to continue the use of the current car or to repurchase is formulated as an aggregate binary logit model by car class as shown in Eq. (3). The components of cost for purchasing, owning and using, as employed in policy analysis, are shown in Table 1. Each cost includes tax and is normalized by per capita GDP in each year. These cost variables are also used in car class choice model. In the absence of a calibrated car value depreciation model for the case of Japan, the value of car is assumed to diminish, for simplicity, linearly to reach 0 (zero) in 10 years. The theoretical life span of 10 years is based on statistical data of car registration in Japan which shows that the scrapping rate is highest among 9-year-old and 11-year-old cars. Table 3
<table>
<thead>
<tr>
<th>Sub-models</th>
<th>Input Parameters</th>
<th>Remarks</th>
<th>Output Parameters</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disposal/repurchase</td>
<td>Average vehicle cost</td>
<td>Calculated class average</td>
<td>Survival rates</td>
<td>Annual &amp; over-time calculated rates</td>
</tr>
<tr>
<td></td>
<td>Other purchase cost</td>
<td>Registration and purchase tax</td>
<td>Percent repurchase</td>
<td>Renewal with new vehicle</td>
</tr>
<tr>
<td></td>
<td>Owning cost</td>
<td>Insurance cost and owning tax</td>
<td>No. of repurchased vehicle</td>
<td>To be derived using Reg. 35% of repurchased vehicle</td>
</tr>
<tr>
<td></td>
<td>Usage cost</td>
<td>Inspection, fuel price and tax</td>
<td>New vehicle</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Utility of new car</td>
<td>Benefits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car class choice</td>
<td>Average vehicle cost</td>
<td>Cost class average</td>
<td>% Distribution by class</td>
<td>Using choice probability</td>
</tr>
<tr>
<td></td>
<td>Other purchase cost</td>
<td>Registration, purchase tax</td>
<td>% Distribution of repurchased car</td>
<td>Choice probability results</td>
</tr>
<tr>
<td></td>
<td>Owning cost</td>
<td>Insurance cost, owning tax</td>
<td>% Distribution of new vehicle</td>
<td>Assume same as Repurchased</td>
</tr>
<tr>
<td></td>
<td>Usage cost</td>
<td>Inspection fuel price,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>fuel tax</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car cohort</td>
<td>Vehicle registration</td>
<td>Initial year: by class/age</td>
<td>Number of cars per year by class and age</td>
<td>Using car cohort table</td>
</tr>
<tr>
<td></td>
<td>Average fuel consumption</td>
<td>Rate in 1/km by veh. class</td>
<td>Car annual fuel consumption per cross classification</td>
<td>Using class average fuel consumption</td>
</tr>
<tr>
<td></td>
<td>Survival rates</td>
<td>Annual &amp; over-time</td>
<td>Annual &amp; over-time survival rates</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(age/class)</td>
<td>survival rates</td>
<td>Repurchased and new cars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>New vehicle class % mix</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driving condition</td>
<td>Average fuel consumption</td>
<td>Rate in 1/km by veh. class</td>
<td>Annual average driving distance by class</td>
<td>Based on fuel consumption and fuel elasticity</td>
</tr>
<tr>
<td></td>
<td>Fuel price</td>
<td>Annual average price per liter</td>
<td>Influence of fuel price</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Change in driving distance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Life-cycle CO₂</td>
<td>Fleet composition</td>
<td>Annual number of vehicle</td>
<td>Total CO₂ life cycle emission from cars</td>
<td>Usage CO₂ plus others</td>
</tr>
<tr>
<td></td>
<td>Fuel consumption</td>
<td>By class &amp; age</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Annual driving distance</td>
<td>In km/veh. type/year</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other CO₂ emission</td>
<td>CO₂ rate per veh.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stage parameters</td>
<td>Production, disposal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
shows the best set of resulting parameter estimates using the data of 0–10 year-old cars registered in 1980–1994 with a reasonably high goodness of fit.

\[ L = \exp(U_{\text{cur}}) / \{ \exp(U_{\text{cur}}) + \exp(U_{\text{new}}) \} = 1 / (1 + \exp(U_{\text{new}} - U_{\text{cur}})), \]

where \( U_{\text{new}} - U_{\text{cur}} = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 \), \( U_{\text{cur}} \) the utility gained by continuing to use the current car, \( U_{\text{new}} \) the utility gained by disposing the current car and purchasing a new car, \( x_1 \) the difference in purchase costs between current car and new car, \( x_2 \) the difference between owning cost of current car and its remaining value, \( x_3 \) the difference in using cost between current car and new car, \( x_4 \) the additional utility by purchasing a new car; and \( a_n \) are the parameter estimates.

The \( t \)-value for the parameter for \( x_2 \) (the difference in owning cost and value of current car) is the largest and it increases, as the car-class gets smaller. This means that the owners of smaller cars are more sensitive to the owning cost. The high value of the constant for Class A means that this class has peculiar attractiveness and that their owners’ sensitivity to cost is low. The difference

\[ a \]

\[ b \]

\[ c \]

\[ d \]

Table 2
Car cohort by age and car class

<table>
<thead>
<tr>
<th>Year</th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
<th>Class D</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>2.97 (9.3)</td>
<td>1.12 (3.0)</td>
<td>0.677 (2.2)</td>
<td>0.940 (3.6)</td>
</tr>
<tr>
<td>2000</td>
<td>-0.647 (1.9)</td>
<td>-1.16 (1.2)</td>
<td>-2.76 (2.0)</td>
<td>-5.54 (3.5)</td>
</tr>
<tr>
<td>1999</td>
<td>-2.93 (17.2)</td>
<td>-6.60 (17.5)</td>
<td>-10.9 (20.0)</td>
<td>12.8 (21.1)</td>
</tr>
<tr>
<td>1998</td>
<td>10.6 (0.8)</td>
<td>-</td>
<td>-</td>
<td>14.2 (0.4)</td>
</tr>
<tr>
<td>1997</td>
<td>-0.453 (3.9)</td>
<td>-0.101 (0.7)</td>
<td>-0.0471 (0.5)</td>
<td>-0.151 (1.6)</td>
</tr>
</tbody>
</table>

Table 3
Estimated result of disposal/repurchase choice sub-model

<table>
<thead>
<tr>
<th></th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
<th>Class D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>2.97 (9.3)</td>
<td>1.12 (3.0)</td>
<td>0.677 (2.2)</td>
<td>0.940 (3.6)</td>
</tr>
<tr>
<td>Difference in purchase cost (( x_1 ))</td>
<td>-0.647 (1.9)</td>
<td>-1.16 (1.2)</td>
<td>-2.76 (2.0)</td>
<td>-5.54 (3.5)</td>
</tr>
<tr>
<td>Owning cost-value of current car (( x_2 ))</td>
<td>-2.93 (17.2)</td>
<td>-6.60 (17.5)</td>
<td>-10.9 (20.0)</td>
<td>12.8 (21.1)</td>
</tr>
<tr>
<td>Difference in driving cost (( x_3 ))</td>
<td>10.6 (0.8)</td>
<td>-</td>
<td>-</td>
<td>14.2 (0.4)</td>
</tr>
<tr>
<td>Logsum utility of new car (( x_4 ))</td>
<td>-0.453 (3.9)</td>
<td>-0.101 (0.7)</td>
<td>-0.0471 (0.5)</td>
<td>-0.151 (1.6)</td>
</tr>
<tr>
<td>Adj. ( R^2 )-value</td>
<td>0.78</td>
<td>0.70</td>
<td>0.74</td>
<td>0.79</td>
</tr>
<tr>
<td>No. of samples</td>
<td>124</td>
<td>142</td>
<td>144</td>
<td>144</td>
</tr>
</tbody>
</table>

\( a \) The \( t \)-values are given in parenthesis.
\( b \) Difference in purchase cost = ((new car price incl. tax) – (price when purchased current car))/per capita income.
in driving cost for classes B and C are not significant and are not included, as consumption rates do not vary that much in a 10-year span of usage. This shows that fuel tax does not influence so much on disposal/repurchase choice.

Fig. 5 compares the actual and the calculated data of survival rate over time in the case of car class C. This shows that the model traces quite acceptably the actual data through the given time. The rate of change between data points as calculated by the model however is not as defined as the actual change. This can be attributed to the 2-year interval of the car inspection regulation. In the model the cost factors did not adopt the 2-year inspection interval. The result of the model though is good enough for the purpose of assessing CO₂ emissions over time.

### 3.3. Car class choice sub-model

As it is observed that people choose a car class which gives the highest utility, we employ the aggregate multinominal logit modeling technique for the car class choice model. It is as formulated in Eq. (4) denoted as: 

\[ \frac{P_i}{P_j} = \exp(U_i - U_j) \quad \text{and} \quad \ln \left( \frac{P_i}{P_j} \right) = U_i - U_j = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3, \]

where \( b_0, b_1, b_2, b_3 \) are model parameter estimates; and \( x_1, x_2, x_3 \), are given by the same data as used in disposal/repurchase sub-model (see Table 2).

\[
P_i = \frac{\exp(U_i)}{\sum_{j=1,4} \exp(U_j)},
\]

where the choice set is categorized into four classes: A, B, C and D. \( P_i \) is the choice probability of class \( i \) and \( U_i \) is the utility of class \( i \).

The model parameter estimates are generated using the same data as used in disposal/repurchase sub-model, excluding the data during the transition period strongly influenced by the tax
Table 4
Estimated result of car class choice sub-modela

<table>
<thead>
<tr>
<th></th>
<th>Class A/B</th>
<th>Class A/C</th>
<th>Class A/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1.38 (8.2)</td>
<td>2.42 (4.2)</td>
<td>27.9 (12.6)</td>
</tr>
<tr>
<td>Difference in purchase cost (x_1)</td>
<td>(-0.495 , (-1.1))</td>
<td>(-1.22 , (-1.2))</td>
<td>(-9.87 , (-4.3))</td>
</tr>
<tr>
<td>Difference in owning cost (x_2)</td>
<td>(-24.5 , (-12.7))</td>
<td>(-17.9 , (-2.9))</td>
<td>(-59.2 , (-3.7))</td>
</tr>
<tr>
<td>Difference in usage cost (x_3)</td>
<td>(-)</td>
<td>(-11.5 , (-0.5))</td>
<td>(-73.2 , (-0.2))</td>
</tr>
<tr>
<td>Adj. (R^2)-value</td>
<td>0.99</td>
<td>0.96</td>
<td>0.96</td>
</tr>
<tr>
<td>No. of samples</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

The \(t\)-values are given in parenthesis.

reform (from 1989 to 1992). Table 4 shows the resulting parameter estimates. The absolute value (namely, sensitivity) of each \(x_2\) (difference in owning cost) is 6–50 times more than that of \(x_1\) (difference in purchase cost) while the \(x_3\) (difference in usage cost) shows to be statistically insignificant. The constant parameters have high significance, thus indicating that the peculiar attractiveness of each car class dominates the preference of the consumers. Sensitivity to cost change of the low class cars is higher than that of the high class.

Fig. 6 shows the result of the time-series validity test of the result of the car class choice model. The curve generated by the model corresponds to the observed time-series changes fairly well. However, just after tax reform in 1989, model forecast generally yields a higher rate of change as compared to the actual. Nevertheless, as the final level is well forecasted, the sub-model can be considered adequate in forecasting the changes in number of registered car-by-car classification.

3.4. Driving condition sub-model

If the fuel price increases, car users may save fuel consumption by reducing its driving distance and changing its driving pattern to lower fuel consumption. In this study, this phenomenon is
described simply as a change in driving distance wherein it is assumed that driving distance fluctuation is as equal to the price elasticity of gasoline. The price elasticity of gasoline is estimated to be \(-0.23\), using the data in Japan from 1981 to 1989, when gasoline price suffered a sharp fluctuation. With this value, the relationship between gasoline price \(P_t\) and driving distance \(D_t\) at any year \(i\) is expressed as follows:

\[
D_{t+1} = (1 + 0.23(1 - P_{t+1}/P_t))D_t.
\]

(5)

4. Policy analysis

4.1. Post analysis of the effect of tax reform in 1989 on CO\(_2\) emission

The developed model was applied in analyzing the 1989 tax reform in order to test how the model estimates the (a) changes in car class share; (b) the amount of CO\(_2\) emission; and (c) the amount of car-related tax revenue due to the tax reform. The result shows that, if the tax reform had not been executed, the shift from Class B to Class A (big passenger cars) cars had not occurred, and that the ELC-CO\(_2\) emission from all passenger cars in 2010 could have been lower by 8%. Accordingly, the tax revenue would have been higher by 10%. The calculated result is presented in Fig. 7.

4.2. Sensitivity analysis

To compare the elasticity of an incremental increase in each tax category (purchase, ownership, usage), to the changes in car class share and CO\(_2\) emission, a sensitivity analysis was conducted.

Fig. 7. Forecast in the cases of keeping current tax rate and resetting the rate at the rate before the 1989 tax reform.
based on every 10,000 yen (approx. US$90)/car equivalent extra charge. Here, the amounts of purchase tax and ownership tax are set to be linearly proportional to the engine displacement. Figs. 8(a)–(c) and 9 show the corresponding changes in car class share and changes in the ELC-CO₂ emission per car-by-car engine class in 2010 due to the incremental increase in each tax categories. The changes per tax category are summarized below.

**Purchase tax.** An additional charge of 10,000 yen/year in every class corresponds to an equivalent of 40% increase in purchase tax. The effect of car class share (Fig. 8(a)) is observed only as slight increase in class A. Emission from car production is reduced by 0.2% in class A and by 1% in the other classes.

**Fig. 8.** Effects of increasing each tax by an equivalent increment of 10,000 yen/car (approx. US$90). (a) Strengthening purchase tax; (b) strengthening ownership tax; (c) strengthening usage tax.

**Fig. 9.** Change in CO₂ emission in 2010 due to 10,000 yen/car (approx. US$90) incremental tax increase from 1995 to 2010.
Ownership tax. An additional charge of 10,000 yen/year in every class is equivalent to 15.0% increase in ownership tax. In effect, the share of class A decreases while the shares of classes B and C increase, as shown in Fig. 8(b). This indicates that the incremental increase in ownership tax is more influential than that of purchase tax. CO2 emission from production increases because the lifetime of cars is shortened due to the lowering of relative cost of purchasing against owning. On the other hand, the total CO2 emission from driving in all car-classes decreases in the long run because of the shift to lower class cars when repurchasing.

Usage tax (fuel tax). An additional charge by 10,000 yen/year in every class is equivalent to an average increase of 20.6% in usage tax. The result, as presented in Fig. 8(c) shows that the share of each car class changes a little as usage tax is not so significant to the purchase behavior as indicated in the estimation of the purchase sub-model. On the other hand, the reduction rate of CO2 emission is at the highest among the other taxes as this result to shorter trips and more efficient driving practices.

In total, usage tax can reduce CO2 emission most by a unit incremental burden, equivalent to 10,000 yen/year per car. Most of reduction comes from the decrease in driving distance while only a little shift in car class share to smaller class is observed. On the other hand, ownership tax makes a fairly large shift to smaller car class while purchase tax has a very little effect.

4.3. Spiral rating of ownership tax according to engine displacement size

The minimal effect of an increase in ownership tax on the reduction of CO2 emission is due to the fact that each car class is allocated a tax increase, which is linearly proportional to the engine displacement. However, if tax rate is set in proportion to fuel efficiency or CO2 emission rate, a bigger effect is expected since the taxation scheme will be indirectly promoting the shift to lower emission cars. In this section, forecasting was conducted using different tax weight combinations for each engine type. This is referred to as the spiral tax rating scheme. The different scenarios are as presented below:

Policy 0: Keep the current tax rates.
Policy 1: Doubling ownership tax rate for only class A from 1995.
Policy 2: Doubling ownership tax rate for classes A and B from 1995.
Policy 3: Doubling ownership tax rate for all classes from 1995.

The result of these policies are summarised as follows:

Policy 1: Doubling ownership tax rate only for class A from 1995. The share of class A will decrease reaching the level of that in 1980 by the year 2003 when almost all cars will finish one cycle of disposal and will be repurchased (Fig. 10(a)). The decrease in class A is mainly due to a shift to class B and slightly to a shift a class C. This will result to a 6% decrease of CO2 emission from driving as compared to that in Policy 0 (continuation of current tax rate). CO2 from production, maintenance and disposal of vehicles will not have a significant change (Fig. 10(b)). The revenue will first increase due to the rise of tax rate but later turn to decrease due to the shift to smaller class cars of which ownership tax rate is lower (Fig. 10(c)).

Policy 2: Doubling ownership tax rate for classes A and B from 1995. In the case of Policy 2, the share of classes A and B decreases while that of classes C and D will increase to 80% of the class mix in 2010 (Fig. 11(a)). In 2010, car emission is forecasted to be 20% lower compared to Policy 0,
due to 25% CO₂ reduction due to change in driving and 5% due to change in vehicle (Fig. 11(b)). The revenue is forecasted to decrease by 13% by 2010 (Fig. 11(c)).

Policy 3: Doubling ownership tax rate for all classes from 1995. In the case when the owning tax rate is doubled for all classes, CO₂ emission decreases by 10% and revenue increases by 30%. This means that the increase in ownership tax on higher classes is more effective than the case of a taxation scheme yielding an equal increase across all classes and the case where in additional burden is equal on all classes, and can even yield a lower total tax increase.

5. Summary and conclusion

A model system designed to evaluate the effect of car-related taxation scheme on the total Life Cycle CO₂ emission and the total tax revenue was developed. The system basically determines the effects of changing the weight balance of the car-related tax components on the changes in the car class mix, the car users’ driving pattern, and the individual’s behavior towards purchasing and decommissioning a car. The model system comprises of five sub-models, namely: (a) the car class
choice; (b) the disposal/repurchase choice; (c) the car cohort sub-model; (d) driving condition sub-model; and (e) the life-cycle CO₂ sub-models.

The choice and car cohort sub-models were generated using car ownership and car market related data in Japan from 1980 to 1994, capturing the 1989 tax reform, while the driving condition sub-model was based from the gasoline price elasticity. The life cycle CO₂ sub-model on the other hand was adopted from an established procedure derived from a component of ISO 14000 Series.

The results of the performance tests that were conducted on the choice and car cohort sub-models are encouraging, yielding a generally good correspondence between the calculated and the observed values. Some deviations between the calculated and observed values for the overtime survival rate are attributed to the difference in the time plotting interval. However, deviations between the car class choice results, particularly within the tax reform implementation period, may be significant but can be considered good enough for macro analysis, as the final car class mix were well forecasted.

Fig. 11. Effects of Policy 2: Doubling ownership tax rate for only class A and B.
Sensitivity analysis was conducted based on an incremental increase of 10,000 yen (approx. US$90) for each tax category. The result shows that most of the CO₂ reduction can be attributed to the car usage tax which results to a decrease in driving distance. Ownership tax on the other hand has significant incentive effects to a shift to smaller cars while the purchase tax has no significant effect.

Further analysis were conducted using several other tax weight combinations yielding the following general conclusions:
1. The choice of disposal/repurchase and the choice of car class for repurchase is not much influenced by usage tax but by purchase and ownership taxes.
2. CO₂ emission due to production and disposal of vehicles is proportional to the number of disposal/repurchase cases. The propensity to decommission and repurchase can be reduced by increasing the purchase tax and can be encouraged by decreasing the ownership tax. The change in CO₂ emission by production and disposal however is less significant as to the change in CO₂ due to driving.
3. The decrease in CO₂ emission due to driving is strongly influenced by the strengthening of usage tax. Spiral taxation rate based on the car class rate of emission will spiral to engine size or emission rate effect in CO₂ emission.
4. Varying the balance of the car related taxes can be a useful means not only to reduce CO₂ emission but also to increase the government revenues.

Currently, the model system is being further polished for possible application to other countries through the conduct of continuing research make an added reduction in cooperation with the OECD Project on Environmentally Sustainable Transport (EST). The conceptual framework of the model system is believed to be general enough to be suitable to whatever data, concepts and other information that is readily available.

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