# Effects of Car-related Tax Weights between Purchasing, Owning and Using Stages on Car Market Share by Engine Class, $CO_2$ Emission and Tax Revenues
## - A Modeling Approach of Choice Behavior and Car Cohort Survival -

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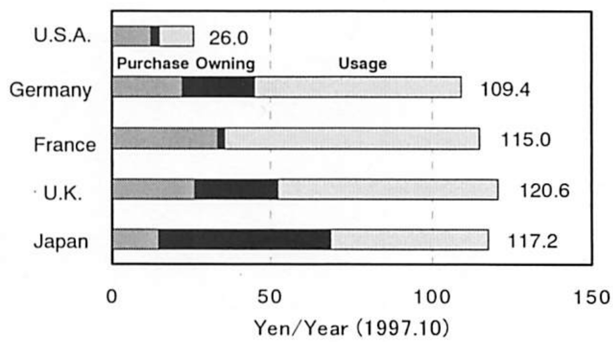
This study aims at providing a tool to examine the changes in car market configuration, the life cycle $CO_2$ emission from automobile transport and the tax revenues due to taxation policies. In order to quantitatively estimate the effects of tax policy on $CO_2$ emission, a model system that forecasts car cohort by engine class and age is developed. It contains models, which represent economic behavior when the tax rates are changed in the stages of 1) purchasing, 2) owning, and 3) using of cars. As this model system can forecast the number of existing cars by engine class and age, it makes it possible to examine the balance in taxation rates among the three stages of car ownership for reducing life cycle $CO_2$ emissions.

## 1. INTRODUCTION

In most countries, the rate of increase of $CO_2$ emission in the transport sector is considerably higher than that in the industrial sector. It is therefore necessary for the transport sector to implement substantial measures to reduce $CO_2$ emissions. 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.




Assumption: Gasoline engine, 1500cc ,1020kg,1.5 million yen (US$ 12,000)
Fuel economy:12km/l, 10,000km/year, life time: 10years

**Figure 1. International comparison of car-related tax rates.**

Car-related taxes have already been introduced in many countries. Such, though, were primarily implemented for purposes of revenue collection. It should be noted however that such scheme has also the potential to reduce $CO_2$ emission similar to that of carbon tax.

An important characteristic of car-related taxes is that it can be collected in the three stages of car ownership, namely: purchasing, owning and using. People's economic behavior in these three stages can be a determining factor in regulating $CO_2$ emission. As tax is one of the most influential components of cost, the formulation of various tax weights among the stages of car ownership may have tremendous implications in the purchasing behavior, travel pattern, and consequently the life cycle $CO_2$ emission in the process of production, usage, maintenance and disposal of cars.

Figure 1 shows the amount and 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, but the resulting mechanism on people's behavior has never been explicitly examined. The purpose of this study is to examine the effects of the change in the relative tax weights on the life cycle $CO_2$ emission and the tax revenues through assessing people's economic behavior in purchasing, owning and using cars. In Japan, "Greening of car ownership tax" was proposed at the Council for Transport Policy in 1999, and an exemption scheme for low emission cars has been introduced in Tokyo. A tax weight system on the different car ownership stages is likewise recently being studied in many European countries.

## 2. THE BASIC CHARACTERISTICS AND STRUCTURE OF THE MODEL SYSTEM

The effects of levying car-related taxes on $CO_2$ emission reduction can be classified as either *incentive* or *revenue source* effects. Incentive effect induces car owners, users, and car manufacturers to favor low $CO_2$ emission alternatives in such ways as:

1) Restraining car sales and ownership;
2) Promoting consumers' purchase and producers' research & development of low emission type of cars;
3) Restraining car driving;
4) Changing car age structure in market; and
5) 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 the following:

1) 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, respectively;
2) Reduction of $CO_2$ in disposal stage due to change in repurchasing pattern; and
3) Reduction of $CO_2$ in car usage stage due to changes in driving condition and travel distance.

Existing researches in the field of transport engineering (Ex. Sterner et al.(1992), Bunch et al.(1993), Gronau(1994), Sperling et al. (1995), Koopman et al.(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 is never conducted. 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 is called "life cycle embodied emission", which 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. 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. This concept is introduced in measuring electric vehicle performance by Delucchi et al.(1989).

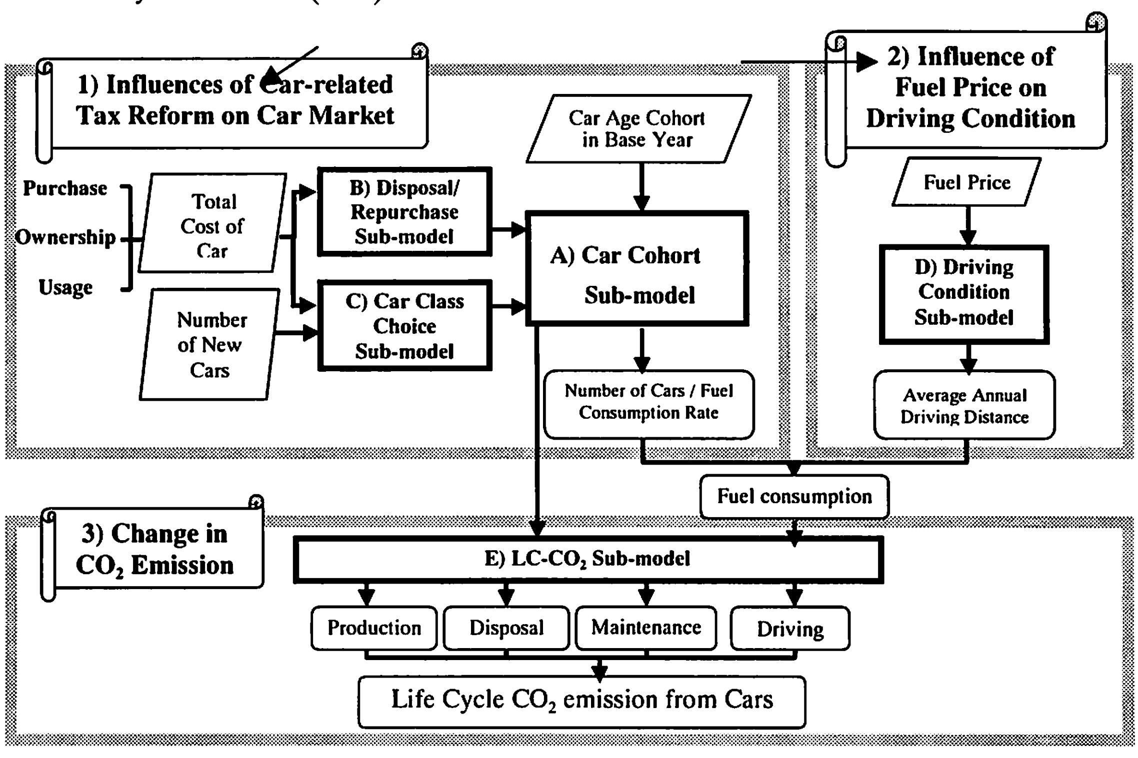
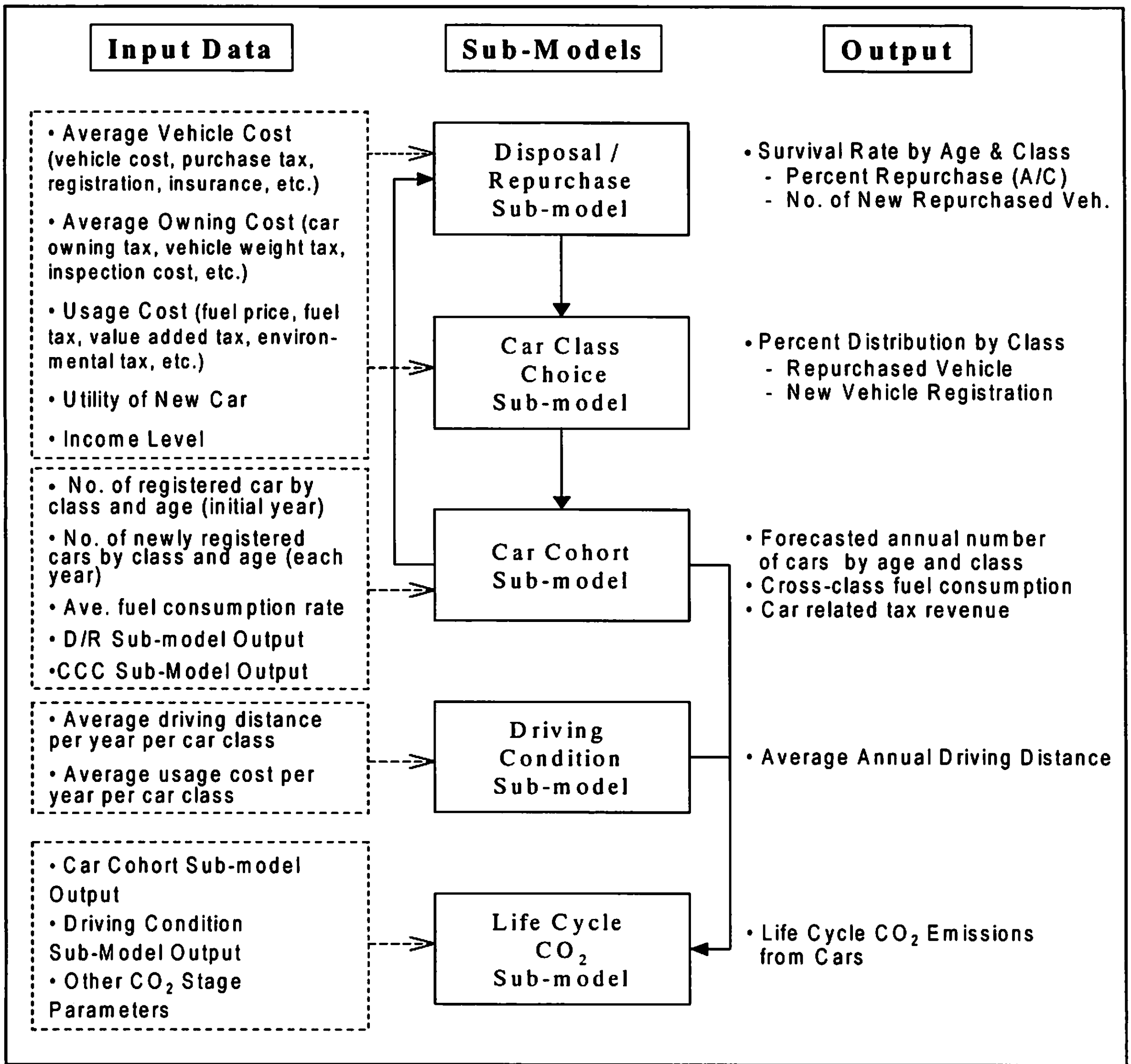



**Figure 2a. Structure of the model system**




| SUB-MODELS | Input | | Output | |
|---|---|---|---|---|
| | Parameters | Remarks | Parameters | Remarks |
| Disposal / Repurchase | Ave. Vehicle Cost<br>Other Purchase Cost<br>Owning Cost<br>Usage Cost<br>Utility of New Car | Assumed Class Ave.<br>Registration, Insurance<br>Tax, Inspection<br>Fuel Price, Fuel Tax<br>Other Advantages | Survival Rates (Age/Class)<br>Percent Repurchase<br>No. of Repurchased Veh.<br>New Vehicle | Annual & Over-time Rates<br>Renewal with New Vehicle<br>To be derived using Reg.<br>35% of Repurchased |
| Car Class Choice | Ave. Vehicle Cost<br>Other Purchase Cost<br>Owning Cost<br>Usage Cost | Assumed Class Ave.<br>Registration, Insurance<br>Tax, Inspection<br>Fuel Price, Fuel Tax | % Distribution by Class<br>% Dist. of Repurchased<br>% Dist. of New Vehicle | Using Choice Probability<br>Choice Prob. Results<br>Assume same to Repur. |
| Car Cohort | Vehicle Registration<br>Ave. Fuel Consumption<br>Survival Rates (Age/Class)<br>New Vehicle Class % Mix | Initial Year:by Class/Age<br>Rate in l/km by veh. class<br>Annual & Over-time Rates<br>Repurchased and New | Number of cars per Year by Class and Age<br>Car Fuel Consumption per Cross Classification | Using Car Cohort Table<br>Using class average fuel Consumption |
| Driving Condition | Ave. Fuel Consumption<br>Fuel Price<br>Change in Drivin Distance | Rate in l/km by veh. class<br>Uniform Price per Liter<br>Influence of Fuel Price | Annual Average Driving Distance by Class | Based on Fuel Consump-tion and Fuel Elasticity |
| Life-Cycle CO2 | Fleet Composition per Fuel Consumption<br>Annual Driving Distance<br>Other CO2 Emission Stage Parameters | Annual Number of Vehicle By Class & Age<br>In km/veh type/year<br>CO2 Rate per Veh: Production, Disposal | Total CO2 Life Cycle Emission from Cars | Usage CO2 plus others |

**Figure 2b. Simplified Model Framework**

**Table 1. Car cohort by age and car class**

| | 0 (NEW) | 1 | 2 | 3 | ••• | Total |
|---|---|---|---|---|---|---|
| 1997 | $C^K_{0,97}$ | $C^K_{1,97}$ | $C^K_{2,97}$ | $C^K_{3,97}$ | | $\sum_a C^K_{a,97}$ |
| 1998 | $C^K_{0,98}$ | $C^K_{1,98}$ | $C^K_{2,98}$ | $C^K_{3,98}$ | | $\sum_a C^K_{a,98}$ |
| 1999 | $C^K_{0,99}$ | $C^K_{1,99}$ | $C^K_{2,99}$ | $C^K_{3,99}$ | | $\sum_a C^K_{a,99}$ |
| 2000 | $C^K_{0,00}$ | $C^K_{1,00}$ | $C^K_{2,00}$ | $C^K_{3,00}$ | | $\sum_a C^K_{a,00}$ |
| 2001 | $C^K_{0,01}$ | $C^K_{1,01}$ | $C^K_{2,01}$ | $C^K_{3,01}$ | | $\sum_a C^K_{a,01}$ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |

Annual Survival Rate: $L^k_{a,t} = C^k_{a,t} / C^K_{(a+1),(t+1)}$

## 3. THE MODEL SYSTEM

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 Framework of the Model System

The structure of the model system is illustrated in Figure 2a. The model system 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 out put parameters of each sub-models is presented in Figure 2b.

**Table 2. Cost components considered in formulation of the model (Time Series Data)**

<u>A: Data for Cohort Submodel</u>

1. Number of registered cars by car-class and age for each year
2. Number of newly registered cars by car-class for each year
3. Number of disposed cars by car-class for each year
4. Average fuel consumption rate

* Car-class should be categorized by tax rate and fuel consumption rate

<u>B: Data for Disposl/Repurchase Submodel and Car-Class Choice Subm</u>odel

5. Purchase cost by car-class for each year
   - a) vehicle price
   - b) purchase tax (car purchase tax and/or value added tax)
   - c) surrounding cost in purchase (registration, insurance cost)
6. Owning cost by car-class for each year
   - d) ownership tax (car owning tax, vehicle weight tax)
   - e) inspection cost
   - f) insurance cost
7. Usage cost by car-class for each year
   - g) fuel price
   - h) fuel tax (including value added tax and environmental tax)

<u>C: Data for Driving Condition Submodel</u>

8. Average driving distance per year by car-class for each year

### 3.2 Specification of the Influencing Mechanism of Car-related Tax Reform on the Car Market

*Car Cohort Survival Sub-model*

Car cohort survival model is the core part of the model system. This method is adopted in a model forecasting the share of diesel engine car by Morisugi et al.(1996). It basically generates the number of cars cross-classified by class and age using a mathematical formulation as illustrated in Table 1. 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 using the survival rate generated in the Disposal/Repurchase Choice sub-model. In this study, the increase rate of new cars used is 35% of the number of disposed cars referring to the market trend in Japan. The car class mix is assumed to be that of the repurchased cars.

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

| | Class A | Class B | Class C | Class D |
|---|---|---|---|---|
| **Constant** | 2.97 (9.3) | 1.12 (3.0) | 0.677 (2.2) | 0.940 (3.6) |
| **Difference in Purchase Cost ($x_1$)** | -0.647 (-1.9) | -1.16 (-1.2) | -2.76 (-2.0) | -5.54 (-3.5) |
| **Owning Cost - Value of Current Car ($x_2$)** | -2.93 (-17.2) | -6.60 (-17.5) | -10.9 (-20.0) | 12.8 (-21.1) |
| **Difference in Driving Cost ($x_3$)** | 10.6 (0.8) | -- | -- | 14.2 (0.4) |
| **Logsum Utility of New Car ($x_4$)** | -0.453 (-3.9) | -0.101 (-0.7) | -0.0471 (-0.5) | -0.151 (-1.6) |
| | | | | |
| **$R^2$-Value** | 0.78 | 0.70 | 0.74 | 0.79 |
| **No. of Samples** | 124 | 142 | 144 | 144 |

( ) : t-value

* Difference in Purchase Cost = ((new car price incl.tax)-(price when purchased current car)) / per capita income

The basic equations are as follows:

Annual Survival Rate: $L$

$$C^k_{a,t} = L^k_{a,t}\, C^k_{(a-1),(t-1)} \qquad (1)$$

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

Survival Rate Over Time: $S$

$$S^k_{a,t} = C^k_{a,t} / C^k_{0,(t-a)} = \prod_{i=1,a} L^k_{i,(t-a+i)} \qquad (2)$$

Survival Rate Over Time is obtained from the number of registered cars in the initial year and the annual survival rate. 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 of the Ministry of Transport. The cars are classified

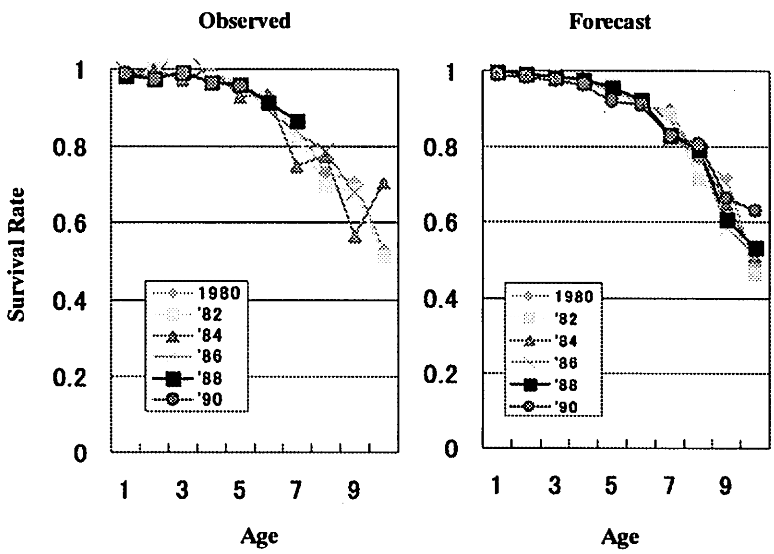



**Figure 3. The goodness of fit represented by comparison of observed and forecasted values of survival rate over time**

according to engine size as follows:

**Class A**: 2,001 cc or bigger
**Class B**: 1,501 cc - 2,000 cc
**Class C**: 1,001 cc - 1,500 cc
**Class D**: 1,000 cc or smaller

**Table 4. Estimated result of car class choice sub-model**

| | Class A / Class B | Class A / Class C | Class A / Class D |
|---|---|---|---|
| Constant | 1.38 (8.2) | 2.42 (4.2) | 27.9 (12.6) |
| Difference in Purchase Cost ($x_1$) | -0.495 (-1.1) | -1.22 (-1.2) | -9.87 (-4.3) |
| Difference in Owning Cost ($x_2$) | -24.5 (-12.7) | -17.9 (-2.9) | -59.2 (-3.7) |
| Difference in Usage Cost ($x_3$) | -- | -11.5 (-0.5) | -73.2 (-0.2) |
| | | | |
| $R^2$-Value | 0.99 | 0.96 | 0.96 |
| No. of Samples | 12 | 12 | 12 |

( ) : t-value

***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 follows:

$$L = exp(U_{cur})/\{exp(U_{cur}) + exp(U_{new})\} = 1/(1+exp(U_{new}-U_{cur})) \quad (3)$$

where

$U_{new}-U_{cur}= a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4$

$U_{cur}$: Utility gained by continuing to use the current car
$U_{new}$:Utility gained by disposing the current car and purchasing a new car
$x_1$: Difference in purchase costs between current car and new car
$x_2$: Difference between owning cost of current car and its remaining value
$x_3$: Difference in using cost between current car and new car
$x_4$: Additional utility by purchasing a new car; and
$a_n$: Parameter estimates

The components of cost for purchasing, owning and using, as employed in policy analysis, are shown in Table 2.

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. The value of car is assumed to diminish linearly to reach 0 (zero) in 10 years because the scrapping rate is highest in 9-year-old and 11-year-old cars based on statistical data of car registration in Japan.

Table 3 shows the estimated result of parameters using the data of 0-10 year-old cars registered in 1980-1994 with a reasonably high goodness of fit.

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 in driving cost is not significant. This means that fuel tax does not influence so much on disposal/repurchase choice.

Figure 3 compares the actual and the calculated data of survival rate over time in the case of car class C. This shows the model traces quite acceptably the actual data through the given time. The rate of change between data points as calculated by the model 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 two-year inspection interval. The result of the model though is good enough for the purpose of assessing $CO_2$ emissions over-time.

***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 formulated as follows:

$$P_i=exp(U_i)/\Sigma_{j=1,4}exp(U_j) \quad (4)$$

where, the choice set is categorized into four classes: A, B, C and D
$P_i$: Choice probability of class $i$
$U_i$: Utility of class $i$

Equation (4) is denoted as follows:

$P_D/P_i = exp(U_D-U_i)$
and
$ln(P_D/P_i) = U_D-U_i = b_0 + b_1x_1 + b_2x_2 + b_3x_3$

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).

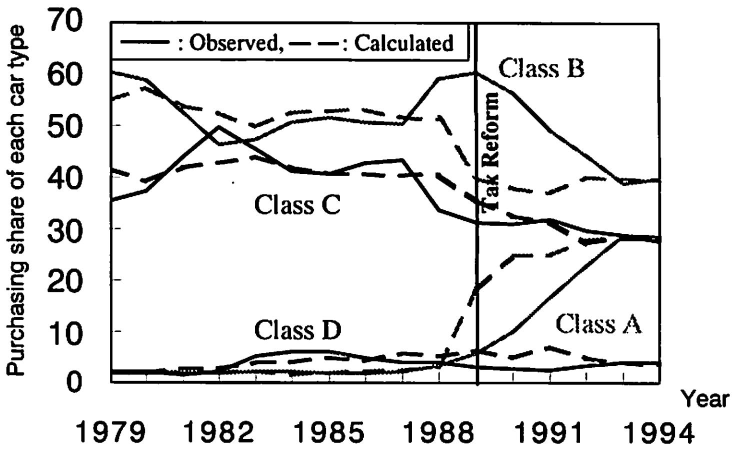



**Figure 4. Validity test of car class choice sub-model**

The model parameters 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 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.

Figure 4 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.

### 3.3 Specification of Influencing Mechanism of Fuel Price on Driving Condition

*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. Hence, it can be 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 $P_i$ and driving distance $D_i$ 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

In Japan, car-related tax rates were considerably changed due to the tax reform in 1989 when consumption tax was introduced. (See Figure 5.) Before 1989, passenger cars were classified into big passenger cars (whose displacement is roughly over 2,000cc <namely, class A>) and small passenger cars. 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.

The developed model was applied in analyzing the 1988 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 Figure 6.

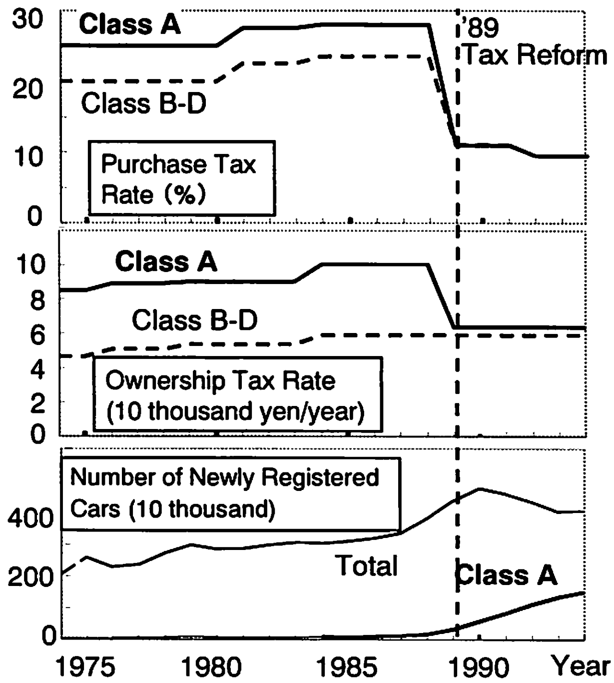



**Figure 5. Increase in the share of Class A due to the different car-related tax**

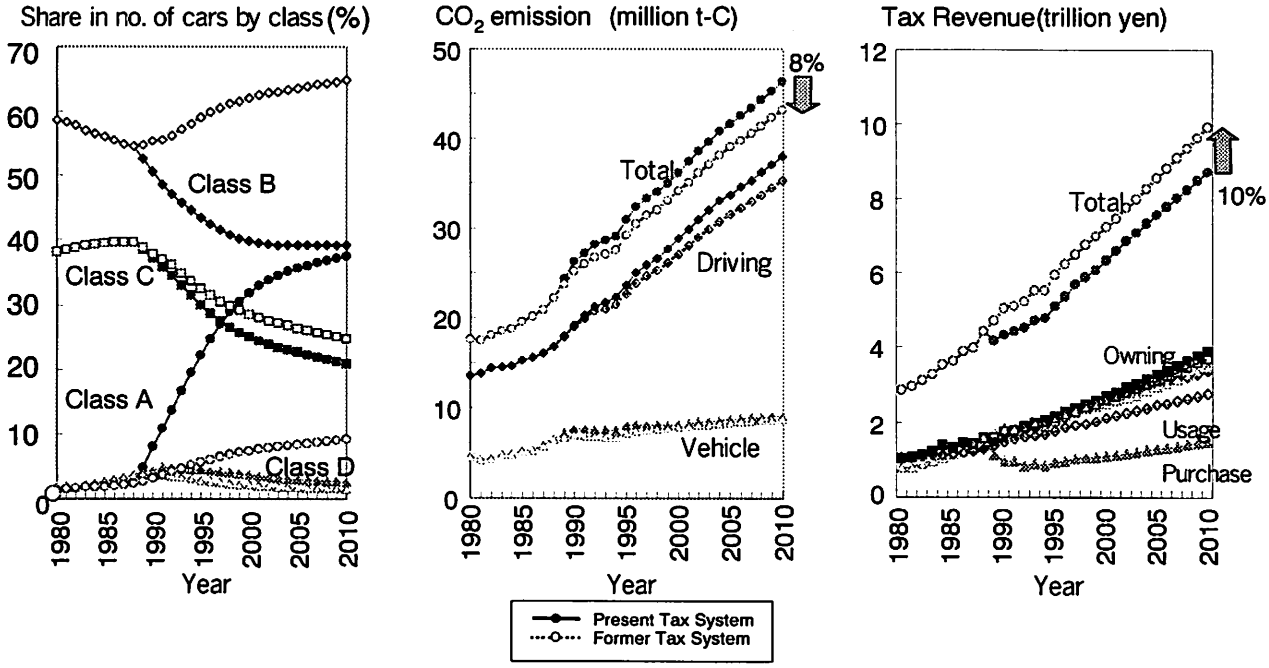



**Figure 6. Forecast in cases of keeping current tax rate and resetting the rate at the rate before 1989 tax reform**

### 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 based on every 10,000 yen (approx. US$100)/car equivalent extra charge. Here, the amounts of purchase tax and ownership tax are set to be linearly proportional to the engine displacement. Figures 7-(a), (b), (c) and 8 show the corresponding changes in car-class share and changes in the ELC-$CO_2$ emission per car by car engine class in 2010 due to the incremental increase in each tax categories. The changes per tax category are presented in the following sections.

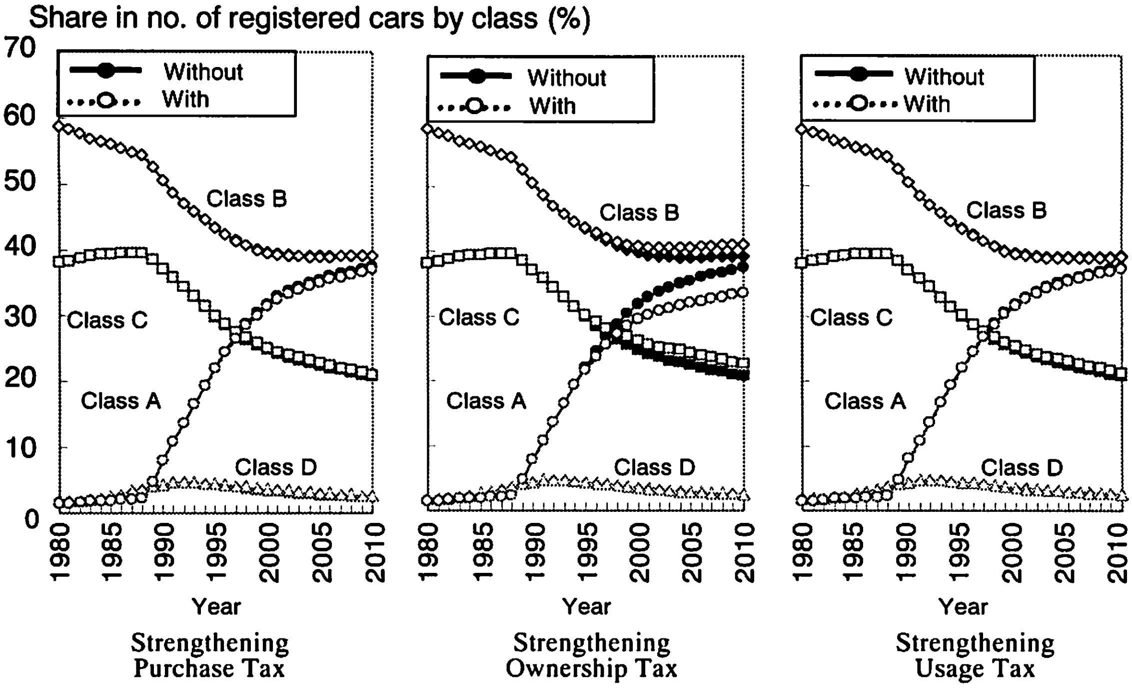



**Figure 7-(a)** **Figure 7-(b)** **Figure 7-(c)**

**Figure 7. Effects of increasing each tax by an equivalent increment of 10,000yen/car (approx. US$100)**

1) 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 on car-class share (Figure 7-(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.

*2) Ownership Tax*

An additional charge by 10,000 yen/year in every class is equivalent to 15.0% increase in ownership tax. As shown in Figure 7-(b), the share of Class A decreases while the shares of classes B and C increase. The incremental increase in ownership tax is more influential than that of purchase tax. $CO_2$ emission from production increases because the lifetime of

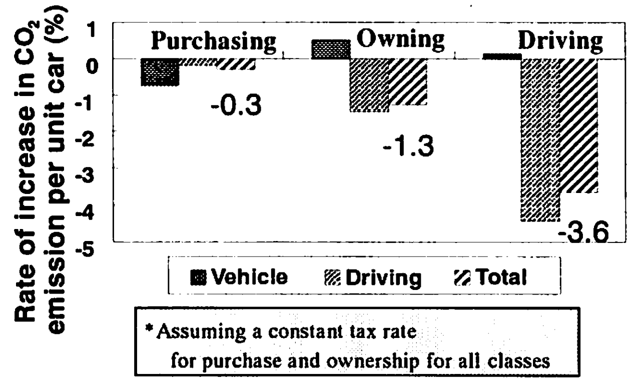



**Figure 8. Changes in $CO_2$ emission in 2010 due to 10,000yen/car (approx. US$) incremental tax increase from 1995 to 2010**

cars is shortened due to lowering of relative cost of purchasing against owning. On the other hand, the total $CO_2$ emission from driving all car-classes decreases in the long run because of the shift to lower class cars when repurchasing.

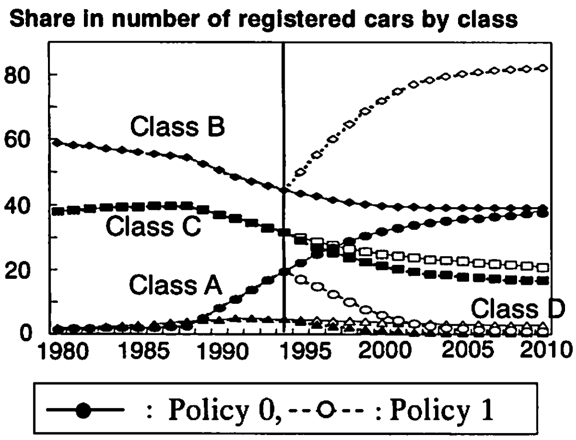



**Figure 9-(a) Effects of Policy 1:**
**Doubling ownership tax rate for only Class A**
**-Car ownership share-**

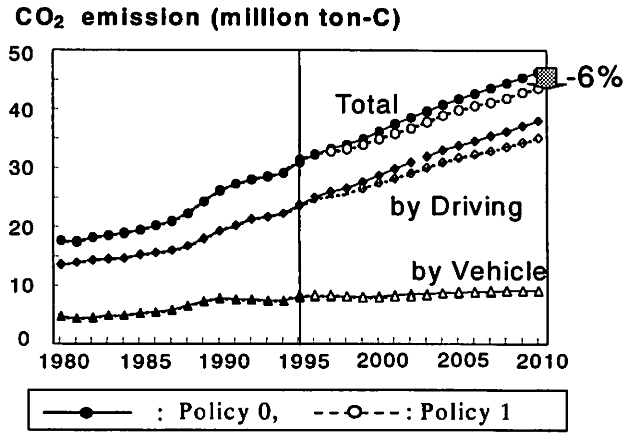



**Figure 9-(b) Effects of Policy 1:**
**Doubling ownership tax rate for only Class A**
**-ELC-$CO_2$-**

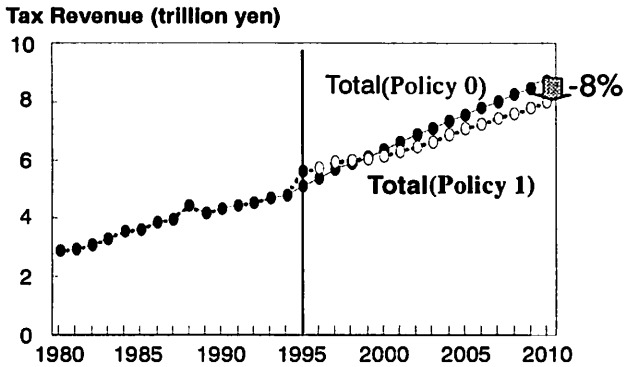



**Figure 9-(c) Effects of Policy 1:**
**Doubling ownership tax rate for only Class A**
**-Tax revenue-**

*3) Usage Tax (Fuel Tax)*

An additional charge by 10,000 yen/year in every class is equivalent to 20.6% increase in usage tax in average. According to Figure 7-(c), the share of each car class changes a little as usage tax is not so significant to the purchase behavior as seen in the estimation of the purchase sub-model. On the other hand, the reduction rate of $CO_2$ emission is at the highest among the other taxes as this result to a shorter trips and more efficient driving practices.

*4) Comparison of effectiveness of incremental tax burden on $CO_2$ emission reduction between three taxes*

Usage tax can reduce $CO_2$ emission most by a unit incremental burden equivalent to 10,000 yen/year per car. Most of reduction comes from 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 $CO_2$ 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 $CO_2$ 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 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

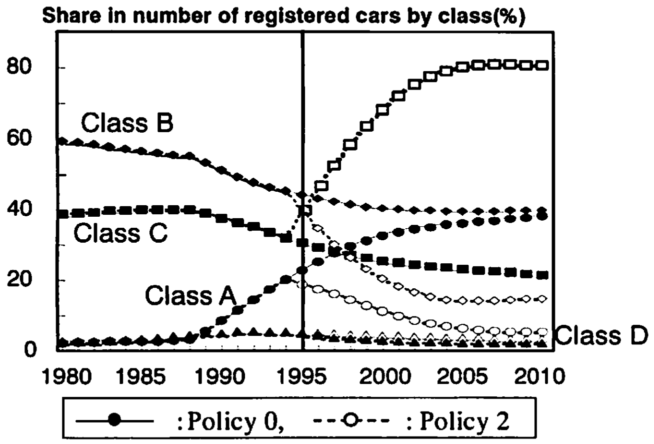



**Figure 10-(a) Effects of Policy 2: Doubling ownership tax rate for only Class A and B -Car ownership share-**

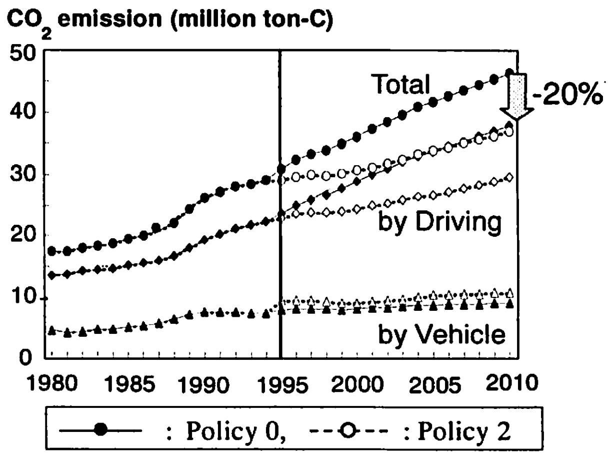



**Figure 10-(b) Effects of Policy 2: Doubling ownership tax rate for only Class A and B -ELC-$CO_2$-**

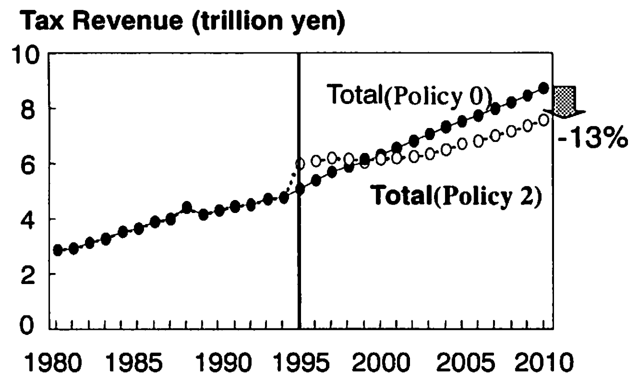



**Figure 10-(c) Effects of Policy 2: Doubling ownership tax rate for only Class A and B -Tax revenue-**

<Policy 1: Doubling ownership tax rate only for class A from 1995>

The share of class A will decrease reaching the level of that in1980 by the year 2003 when almost all cars will finish one cycle of disposal and will be repurchased (Figure 9-(a)). The decrease in Class A is mainly due to a shift to Class B and slightly to a shift to Class C. This will result to a 6% decrease of $CO_2$ emission from driving as compared to that in Policy 0 (continuation of current tax rate). $CO_2$ from production, maintenance and disposal of vehicles will not have a significant change (Figure 9-(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 (Figure 9-(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 (Figure 10-(a)). In 2010, car emission is forecasted to be 20% lower compared to Policy 0, due to 25% $CO_2$ reduction due to change in driving and 5% due to change in vehicle (Figure 10-(b)). The revenue is forecasted to decreases by 13% by 2010 (Figure 10-(c)).

*<Policy 3: Doubling ownership rate for all classes from 1995>*

In the case when the owning tax rate is doubled for all classes, $CO_2$ 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 additional burden in equal on all classes, and can even yield a lower total tax increase.

## 5. SUMMARY OF RESULTS AND RECOMMENDATIONS

### 5.1 The Model System and Results of Performance Analysis

A model system designed to evaluate the effect of car-related taxation scheme to the total Life Cycle $CO_2$ emission and the total tax revenue was developed. The system basically determines the effect of changing the weight of the tax components of the different stages of car ownership, to the changes in the car class mix and the car users' driving pattern and behavior towards car class purchasing choice and decommissioning. The model system is comprised of five sub-models, namely: (1) the car class choice; (2) the disposal / repurchase choice; (3) the car cohort sub-model; (4) driving condition sub-model; and (5) the life-cycle $CO_2$ sub-models.

The choice and car cohort sub-models were generated using car ownership and car market related data 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 $CO_2$ sub-model on the other hand was adopted from an established procedure derived from a component of ISO 14000 Series and is being used being used in Japan.

### 5.2 Analysis of Results

The results of the performance tests conducted on the choice and car cohort sub-models are encouraging, yielding a generally good correspondence between the expected and the observed values. Some deviations between the expected 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.

Sensitivity analysis was conducted based on an incremental increase of 10,000 yen (approx. US$100) for each tax category. The result shows that most of the $CO_2$ reduction can be attributed to the car usage tax which results to a decrease in driving distance. Ownership tax on the other hand significantly results to a shift to smaller cars while the purchase tax has no significant effect. Further analyses 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) $CO_2$ 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 decreased by increasing the ownership tax. The change in $CO_2$ emission by production and disposal however is less significant as to the change in $CO_2$ due to driving.

3) The decrease in $CO_2$ 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 effectively reduce $CO_2$ emission.
4) Varying the balance of the car related taxes can be a useful means not only to reduce $CO_2$ emission but also to increase the government revenues.

### 5.3 Recommendations for Further Development

The present state of the model system however is still far from being perfect. The adopted 4-car classification system, for instance, may not be adequate to accurately represent car fuel consumption rate due to other unaccounted vehicle and engine performance characteristics. The driving condition sub-model likewise, may require the incorporation of other transport planning parameters in addition to the fuel cost that is currently being used. Established results of driving pattern studies may also be integrated in the model system in the near future. Further, the transferability of the model system for possible application to other countries should likewise be conducted.

The constraints, weaknesses and limitations of the current model system can be generally attributed to the limited parameters available from the existing data gathering system. The time series data requirement and the lack of adequate historical records capturing different cases of tax reform events further limited the model formulation and the conduct of performance testing analyses. The current model system however is further polished through the conduct of continuing research. The availability of data, as well as the emergence of other related models that can be incorporated into the model system, are expected to further improve the accuracy and expand the applications of the model system.

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