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**Measuring Market Damage of Automobile Related Carbon Tax  
by Dynamic Computable General Equilibrium model**

**Abstract**

*This paper tries to evaluate the market damage of automobile related carbon tax to be imposed as a control of CO<sub>2</sub> emissions. Japanese Ministry of Transport set up a target of the GHG emission level of transport sector at 2008 to 2012 as 17% increasing level from 1990 level. In order to comply with this target, Ministry of Transport has been investigating the feasibility and acceptability of automobile related carbon tax. But the economic damage of those policies is not elucidated enough. Hence we evaluate its influence on the market economy by applying the dynamic computable general equilibrium (DCGE) model. The model has characteristics of explicit formulation of the automobile related industrial and transport sector's behavior and household travel behavior.*

*With this model, we identify the automobile related carbon tax levels needed to accomplish the regulatory target of CO<sub>2</sub> emissions at transport sector for two cases with respects to the price elasticity in fuel demand. In the lower elasticity case of 0.1, the necessary carbon tax is 112[thousand yen/tC] and the associated market disbenefit is 1,810[billion yen/year]. In higher elasticity case of 0.3, the necessary carbon tax is 119[thousand yen/tC] and the market disbenefit is 2,490[billion yen/year]. In addition to above analysis, we also evaluated the subsidy policy for clean energy vehicle.*

## 1. Introduction

Issues of external diseconomies caused by automobiles have been a more serious problem. Especially, the damages suffered by Green House Gas (GHG) emissions are recognized as global warming and, at the Kyoto Protocol (COP3), the regulatory targets of GHG emissions were specified for signatory countries. The target for Japan is 6% reduction from 1990 level in the period 2008-2012, and the target of transport sector was set up by Ministry of Transport, which is 17% increasing from 1990 level. Ministry of Transport has estimated to grow the GHG emissions by 40% if no policies were performed. To reduce GHG emissions exhausted by automobiles is, therefore, an important task because the emissions of them occupy 90% of all transport sectors.

On the other hand, the policies based on market mechanism, like an environmental tax, have been proposed in order to regulate GHG emissions. The impacts exerted by executing these policies, however, are not elucidated enough. It is well known that these policies raise commodity prices through the increase of automobile user's costs, and, as result, the huge welfare loss, what is called deadweight loss, is possible to be generated. Those recognition leads to need to evaluate synthetically the economized environmental policies by calculating the deadweight loss due to executing these policies.

In this paper, we focus on the carbon tax policy imposed only to automobiles, and evaluate it with the dynamic computable general equilibrium (DCGE) model. In this DCGE modeling, the economic behaviors of household and industries, and the mechanism of market are formulated by mathematical programming, and the dynamic path is calculated. Hence the model allows us to grasp the change of agents' behaviors due to introduce the carbon tax, and measure the damage given to market economy, what is named by us the market disbenefits, by utilizing the concept of equivalent variation. Note that we ignore the social benefits generated by reducing GHG emissions, in other words we assume here that their benefits are not occurred in the studied period.

The CGE approaches have been developed to evaluate economic impacts with introducing tax policy or international trade policy, which are surveyed by Shoven and Whalley (1984). Jorgenson and Wilcoxon (1990) and Bergman (1991) applied the CGE model for the environmental policy evaluation. Such approach had been more exquisite by Ballard and Medema (1993) and Goulder et al (1999), and applied to the transport environmental problems by Borger and Swysen (1998) or Mayeres (2000). Recently, in the magazine of the review of urban & regional development studies (RURDS), a special edition on the CGE approach compiled in 2003. In there, Roson (2003) or Rana (2003) computed the economic impact of CO<sub>2</sub> emission controls.

The DCGE model of this research follows those previous CGE approaches in principle. Our model explicitly formulates, however, the automobile related industrial or transport sector's behavior and household travel behavior. Especially, the travel behavior for private tips of household is formulated by the probability choice paradigm shown by McFadden (1981).

## 2. Partial analysis

In this section, before building the theoretical model, we show the economic impacts of the carbon tax in the framework of partial equilibrium analysis on the automobile fuel market. In this context, suppose that the carbon tax is levied on the automobile fuel. In figure 1, the demand and marginal cost curve in the fuel market are drawn. Without carbon tax case, the pricing scheme yields to the market equilibrium point A. Levying the carbon tax equivalent to BF on fuel services moves the market equilibrium from point A to the point B through the shift of marginal cost curve.

This movement of market equilibrium point decreases the social surplus from CAD to EBD. In another word, the economic loss, CABE is generated. However the CFBE is the amount of paying the carbon tax which is equal to the government's gain as tax revenue. Hence the government revenue CFBE is deducted from CABE, so FAB is the net economic loss due to introduce the carbon tax. This is called to deadweight loss of taxation. In this paper, we will measure this deadweight loss by using the DCGE model.

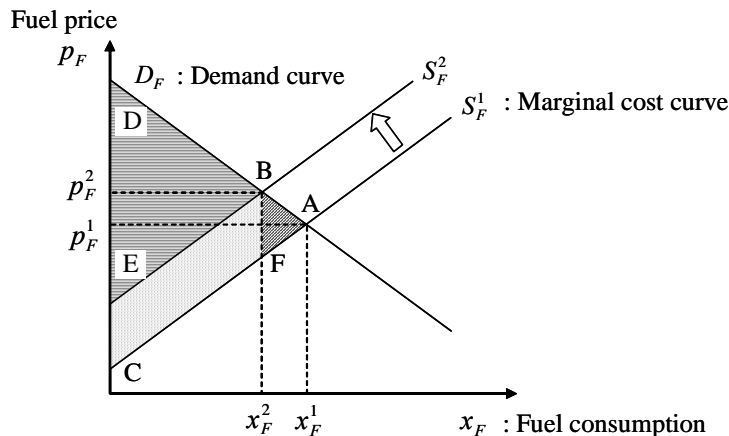


Figure 1. Impacts due to introduce the carbon tax

## 3. Structure of Dynamic Computable General Equilibrium Model

### 3.1 Assumptions

We have the following major assumptions.

- An economy consists of a representative household, industries (Eight transport sectors and five other sectors) and a central government, as illustrated in Figure 2.
- The industry provides commodities/services by inputting factors that consist of labor and capital, and intermediate goods.
- The household gains income by supplying factors and consumes commodities/services provided by industries under the budget constraint.
- We are modeled the savings behavior of household. The savings are appropriated the investment in all, by which the next period capital stock is accumulated. The decision making of savings is assumed to be done under the myopic expectation, where people consider that the present circumstance is continuous at next period.
- All transport services both of passenger and freight are supplied by the transport

sectors. However private automobile trips consumed by household are provided by his own.

- (f) Markets are considered on each commodity, labor and capital. They are assumed to be perfectly competitive.
- (g) The central government levies the carbon tax on automobile fuels, which consist of gasoline and light-oil. A part of tax revenue is appropriated the subsidy to purchasing of the clean energy vehicles, and the rest of them is done to provide the government services as general funds.

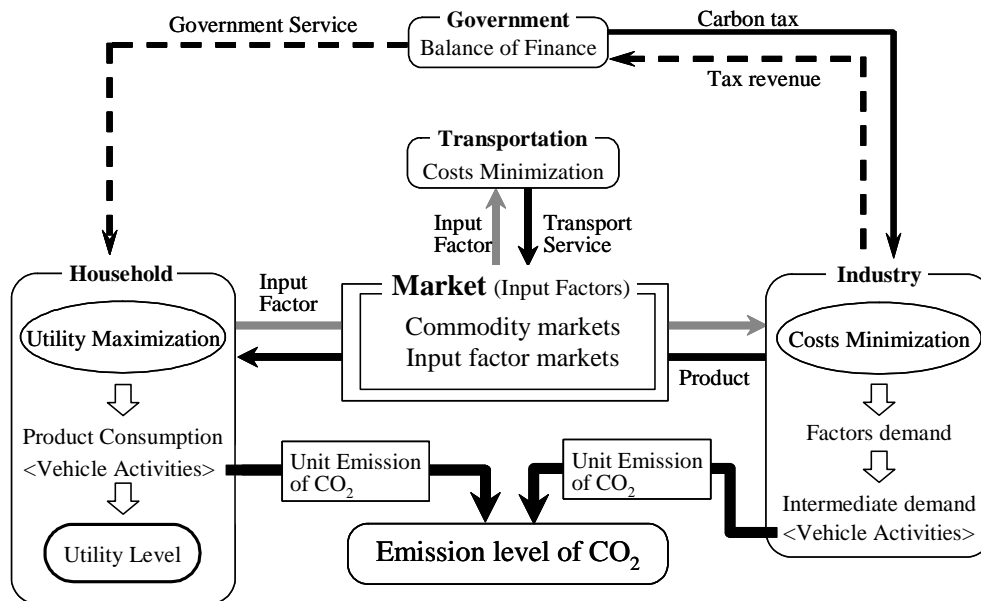


Figure 2. Framework of the dynamic computable general equilibrium model (t-period)

### 3.2 Industries' behavior

Industries produce commodities/services by inputting factors and intermediate goods. Its behavior model is built by the nested structure (in Figure 3), that is, at first, industries determine on input volume of the composite factor and each intermediate goods, and next they decide on input volume of each factor.

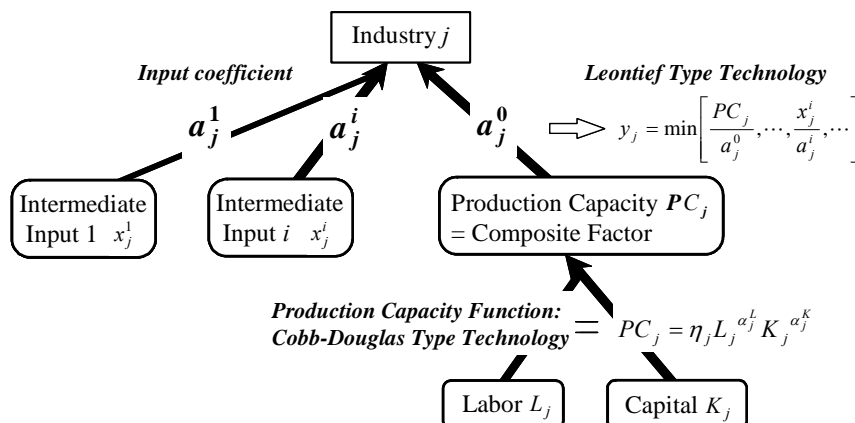


Figure 3. Outline of industries' behavior

At first step, the industries' behaviors inputting the composite factor and intermediate goods are formulated as minimization of production costs under Leontief type technology constraint.

$$C_j = \min_{PC_j, x_j^i} c_j \cdot PC_j + \sum_i p_i x_j^i \quad (1a)$$

$$\text{s.t. } y_j = \min \left[ \frac{PC_j}{a_j^0}, \dots, \frac{x_j^i}{a_j^i}, \dots \right] \quad (1b)$$

Where,  $PC_j$ : production capacity (input volume of composite factor),  $x_j^i$ : intermediate goods input volume from industry  $i$  to industry  $j$ ,  $y_j$ : output volume,  $c_j$ : unit cost of composite factor,  $p_i$ : the price of commodity  $i$ ,  $a_j^0$ : production capacity rate [production capacity for the unit output],  $a_j^i (i \neq 0)$ : input coefficient in Leontief Matrix and  $C_j$ : product cost.

Solving the programming in (1), we obtain production capacity  $PC_j$  and intermediate goods input volume  $x_j^i$ , respectively.

$$PC_j = a_j^0 y_j \quad (2a)$$

$$x_j^i = a_j^i y_j \quad (2b)$$

Substitution of the (2) into the (1) gives the product cost  $C_j$  in industry  $j$ ,

$$C_j = \left[ a_j^0 c_j + \sum_i a_j^i p_i \right] y_j \quad (3)$$

At second step, industries decide on input volume of each factor. The behavior is formulated as minimization of the cost for input factors under Cobb-Douglas type technology constraint.

$$c_j = \min_{L_j, K_j} p_L L_j + p_K K_j \quad (4a)$$

$$\text{s.t. } PC_j = \eta_j L_j^{\alpha_j^L} K_j^{\alpha_j^K} = 1 \quad (4b)$$

Where,  $L_j, K_j$ : labor and capital input volume, respectively,  $p_L, p_K$ : labor wage and capital rent, respectively and  $\eta_j, \alpha_{L_j}, \alpha_{K_j}$ : parameters [ $\alpha_{L_j} + \alpha_{K_j} = 1$ ].

The solution of cost minimization programming for input factors in (4) yields to the input volume of each factor demand function  $D_{L_j}, D_{K_j}$  for unit  $PC_j$ .

$$\text{Labor input: } D_{L_j} = \frac{1}{\eta_j} \left[ \frac{\alpha_j^L p_K}{\alpha_j^K p_L} \right]^{\alpha_j^K} \quad (5a)$$

$$\text{Capital input: } D_{K_j} = \frac{1}{\eta_j} \left[ \frac{\alpha_j^K p_L}{\alpha_j^L p_K} \right]^{\alpha_j^L} \quad (5b)$$

Substituting (5) into the (4), we obtain the unit cost of composite input factor  $c_j$ ,

$$c_j = \frac{1}{\eta_j} \left[ \left( \frac{\alpha_j^L}{\alpha_j^K} \right)^{\alpha_j^K} + \left( \frac{\alpha_j^K}{\alpha_j^L} \right)^{\alpha_j^L} \right] p_L^{\alpha_j^L} p_K^{\alpha_j^K} \quad (6)$$

### 3.3 Price vector of products

The price [ $p_j$ ] of commodity  $j$  is led through the zero profit condition in industry  $j$ .

The substituting (6) into (3) yields to the product costs of industry  $j$ ,

$$C_j = \left[ a_j^0 c_j(p_L, p_K) + \sum_i a_j^i p_i \right] y_j. \quad (7)$$

The carbon tax and the subsidy for the clean energy vehicle are assumed to be imposed/provided on input factor cost  $c_j$ . So  $C_j$  is represented like this.

$$C_j = \left[ a_j^0 c_j(p_L, p_K) \{1 + \tau_j\} + \sum_i a_j^i p_i \right] y_j. \quad (8)$$

Where,  $\tau_j$ : tax/subsidy rate.

The subsidy rate  $\tau_j$  may be considered as negative tax.

We can have the profit of industry  $j$  from (8) as below,

$$\pi_j = p_j y_j - \left[ a_j^0 c_j(p_L, p_K) \{1 + \tau_j\} + \sum_i a_j^i p_i \right] y_j. \quad (9)$$

Where,  $\pi_j$ : profit of industry  $j$ .

The (9) is linear type for  $y_j$ , so the market equilibrium solutions exist under the zero profit condition. Its condition gives the commodity price  $p_j$ ,

$$p_j = a_j^0 c_j(p_L, p_K) \{1 + \tau_j\} + \sum_i a_j^i p_i. \quad (10)$$

By arranging (10), we obtain a price vector of commodity,

$$\mathbf{p}' = \mathbf{c}' \cdot [\mathbf{I} - \mathbf{A}]^{-1}. \quad (11)$$

Where,  $\mathbf{p}$ : price vector of commodity,  $\mathbf{c}$ : product vector of composite factor unit cost by production capacity rate,  $\mathbf{I}$ : unit matrix,  $\mathbf{A}$ : input coefficient matrix and  $'$ : transposed matrix.

### 3.4 Behavior of clean energy vehicle product industry

In Japan, the clean energy vehicle is beginning to be diffused. Though its product price is higher than the one of general vehicles, it is expected that the accumulation of them may decrease its price by learning effects in its product industry. In this paper, we will grasp the leaning effects through the next formulation of clean energy vehicle industry's product behavior, in which an additional fix cost is introduced. Its cost is assumed to depend on the product volume  $\left\{ \sum_{s=1}^{s=t-1} y_C^s \right\}$  of clean energy vehicle accumulated by previous period and decrease with increasing of  $\sum_{s=1}^{s=t-1} y_C^s$ . The product behavior of clean energy vehicle is described like below,

$$C_C = \min_{x_C^i, PC_C} c_C \cdot PC_C + \sum_i p_i x_C^i + FC(Y_C^{t-1}) \cdot y_C \quad (12a)$$

$$\text{s.t. } y_C = \min \left[ \frac{PC_C}{a_C^0}, \dots, \frac{x_C^i}{a_C^i}, \dots \right] \quad (12b)$$

Where, subscript  $C$ : clean energy vehicle product industry,  $FC$ : additional fix cost,  $Y_C^{t-1}$ : accumulated volume of clean energy vehicle product  $\left\{ = \sum_{s=1}^{s=t-1} y_C^s \right\}$ .

The optimal solutions of (12) are the same with previous obtained solutions of other

industries. But the product cost is increased by the additional fix cost.

$$C_C = \left[ a_C^0 c_C(p_L, p_K) \{1 + \tau_C\} + \sum_i a_C^i p_i + FC(Y_C^{t-1}) \right] y_C \quad (13)$$

And the clean energy vehicle's price is led as below,

$$p_C = a_C^0 c_C(p_L, p_K) \{1 + \tau_C\} + \sum_i a_C^i p_i + FC(Y_C^{t-1}) \quad (14)$$

From this result, even if the clean energy vehicle product industry has the same technology with another general automobile product industry, the price of them is risen up by additional fix cost  $FC$ . However, as being increased the number of them,  $FC$  is decreased less and the difference of price between the clean energy vehicle and another general vehicle is gradually shortened.

In figure 4, we show the actual values of accumulated vehicles and its selling price on the case of T type produced by the Ford, and we estimate the additional fix cost function  $FC(Y_C^{t-1})$  based on their values. But  $FC(Y_C^{t-1})$  in Figure 4 is adjusted by the actual data of the clean energy vehicle's price and the number of accumulated one of Japan in 1995.

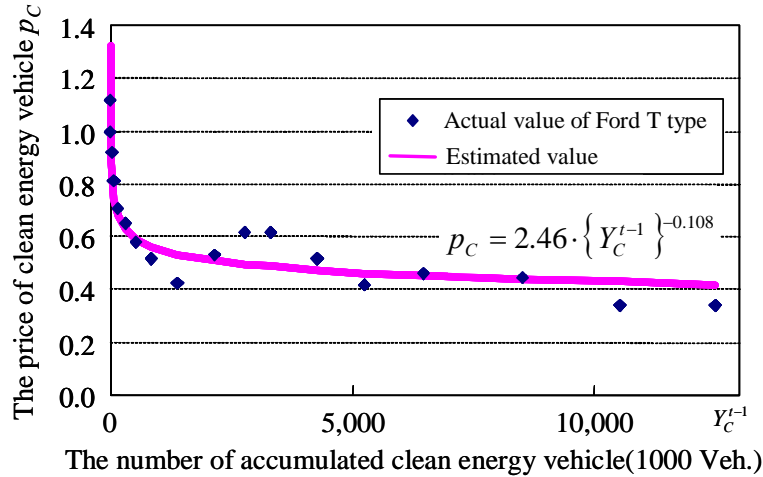


Figure 4. Estimated price of clean energy vehicle

### 3.5 Household behavior

#### (1) Outline of model

Household gains income by providing the input factors which consist of labor and capital, and determines the consuming volume of commodities/services so as to maximize his utility under the budget constraint. Hence the consuming behavior of the household should be illustrated in a nested structure, as shown in figure 5. This structure has been proposed by Shoven and Whalley(1992).

#### (2) Formulation of consuming behavior

At first stage, the household determines consumption levels of present goods  $H$  and savings  $C_F$ , and, at second stage, ones of composite goods, leisure time and total passenger trips, and, at third stage, ones of each commodity and total freight transport services, and, at fourth stage, ones of each traffic mode on freight transport. The choice models on passenger trips are formulated in more detail by using the nested logit model that will be explained at next section.

From the first stages to fourth one, household behaviors are formulated by general

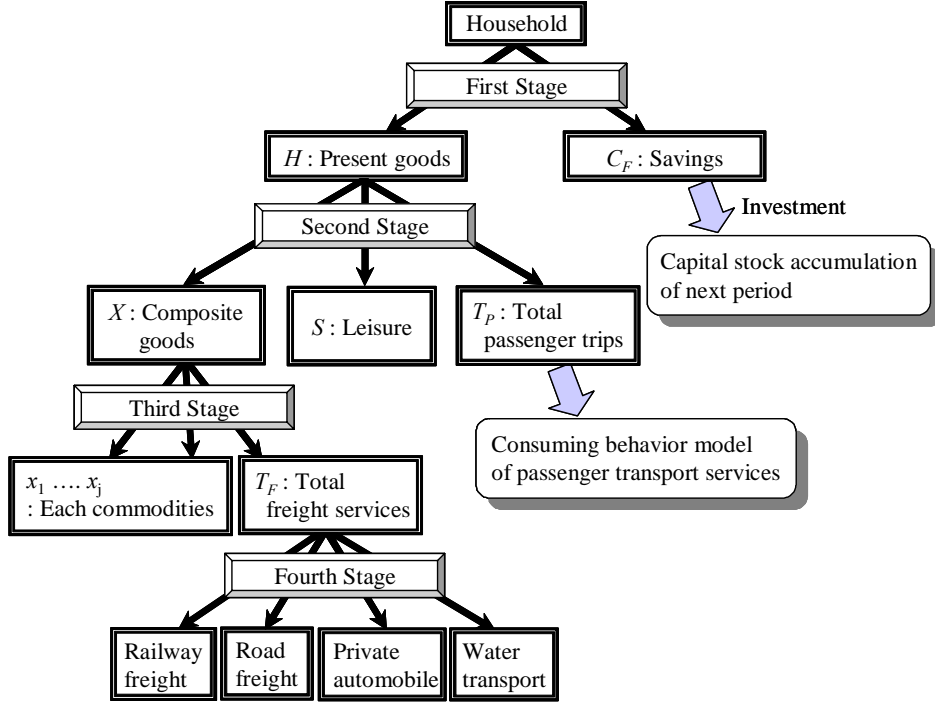


Figure 5. Outline of household nested consuming behavior

utility maximize programming as below,

$$V^l = \max_{x_j^l} U^l(x_j^l) \quad (15a)$$

$$\text{s.t. } \sum_j p_j^l x_j^l = M^l \quad (15b)$$

Where, superscript  $l$ : number of stage, superscript  $j$ : commodity or service,  $U^l$ : direct utility function,  $x_j^l$ : consuming volume of commodity/service  $j$ ,  $p_j^l$ : price of commodity/service  $j$ ,  $M^l$ : income,  $V^l$ : utility level.

Corresponding this utility maximization program to the nested consuming behavior shown in figure 5, the specified forms of household behavior as table 1 is obtained. The utility functions of the first, second and fourth stage, are adopted the CES type, and at the third state, it is done the Cobb-Douglas type. And the optimal solutions of those mathematical programming are also expressed in table 1.

In this model, household's income is defined by full income included the time concept that implies endowment of time. The endowment of time is given like this.

$$\Omega = L_S + S + \sum_m t_m x_m^P \quad (16)$$

Where,  $\Omega$ : endowment of time,  $L_S$ : labor providing time,  $S$ : leisure time,  $t_m$ : required time of traffic mode  $m$ ,  $x_m^P$ : consuming volume of passenger trips by mode  $m$ .

By being introduced the time concept into model, the utility maximizing program yields to the distribution of time consumption as well as the one for each commodities /services.

Substituting the optimal solutions solved in (15) into its objective function, we obtain utility level  $V^l$ .



Table 1. Formulation of household consuming behavior

	Utility maximizing program	Consuming volume of commodities
First stage ( $l=1$ )	$V = \max_{H, C_F} \left[ \beta_H^{\frac{1}{\sigma_1}} H^{\sigma_1} + (1 - \beta_H)^{\frac{1}{\sigma_1}} C_F^{\sigma_1} \right]^{\frac{1}{\sigma_1}}$ $\text{s.t. } p_H H + p_F C_F = p_L \Omega + p_K K (\equiv M^1)$	<p>Present goods: <math>H = \frac{\beta_H M^1}{p_H^{\sigma_1} \Delta_1}</math></p> <p>Savings: <math>C_F = \frac{(1 - \beta_H) M^1}{p_F^{\sigma_1} \Delta_1}</math></p> <p>Where, <math>\Delta_1 = \beta_H p_H^{(1 - \sigma_1)} + (1 - \beta_H) p_F^{(1 - \sigma_1)}</math></p>
	<p><math>p_H</math>: present goods price, <math>p_F</math>: saving price, <math>\Omega</math>: endowment of time, <math>K</math>: endowment of capital, <math>M^1</math>: full income, <math>\beta_H</math>: parameter, <math>\sigma_l</math>: elasticity of substitution, <math>v_l := (\sigma_l - 1) / \sigma_l</math>, <math>V</math>: utility level.</p>	
First stage ( $l=2$ )	$H = \max_{X, S, T_P} \left[ \gamma_X^{\frac{1}{\sigma_2}} X^{\sigma_2} + \gamma_S^{\frac{1}{\sigma_2}} S^{\sigma_2} + \gamma_P^{\frac{1}{\sigma_2}} T_P^{\sigma_2} \right]^{\frac{1}{\sigma_2}}$ $\text{s.t. } p_X X + p_L S + p_{TP} T_P = M^2$	<p>Composite goods: <math>X = \frac{\gamma_X M^2}{p_X^{\sigma_2} \Delta_2}</math></p> <p>Leisure: <math>S = \frac{\gamma_S M^2}{p_L^{\sigma_2} \Delta_2}</math></p> <p>Total passenger trips: <math>T_P = \frac{\gamma_P M^2}{p_{TP}^{\sigma_2} \Delta_2}</math></p> <p>Where, <math>\Delta_2 = \gamma_X p_X^{(1 - \sigma_2)} + \gamma_L p_L^{(1 - \sigma_2)} + \gamma_{TP} p_{TP}^{(1 - \sigma_2)}</math></p>
	<p><math>p_X</math>: Composite goods price, <math>p_{TP}</math>: Total passenger transport price, <math>M^2 := M^1 - p_F^* C_F^*</math>, <math>\gamma_X, \gamma_L, \gamma_P</math>: parameters, <math>H</math>: Utility level gotten from consuming volume of present goods.</p>	
Third stage ( $l=3$ )	$X = \max_{x_j, T_F} \prod_j x_j^{\zeta_j} \cdot T_F^{\zeta_F}$ $\text{s.t. } \sum_j p_j x_j + p_{TF} T_F = M^3$ <p>(<math>j</math>: each commodity except automobile, fuel and freight transport)</p>	<p>Each commodity <math>j</math>: <math>x_j = \frac{\zeta_j}{p_j} M^3</math></p> <p>Total freight transport: <math>X_F = \frac{\zeta_F}{p_{TF}} M^3</math></p>
	<p><math>p_j</math>: each commodity price, <math>p_{TF}</math>: total freight transport price, <math>M^3 := M^2 - p_X^* X^* - p_{TP}^* T_P^*</math>, <math>\zeta_j, \zeta_F</math>: parameters, <math>X</math>: Utility level gotten from consuming volume of composite goods.</p>	
Fourth stage ( $l=4$ )	$X_F = \max_{x_j} \left[ \sum_j \chi_j^{\frac{1}{\sigma_4}} x_j^{\sigma_4} \right]^{\frac{1}{\sigma_4}}$ $\text{s.t. } \sum_j p_j x_j = M^4 \quad (j: \text{freight transport})$	<p>Freight transport consumption of each traffic mode <math>j'</math>: <math>x_j = \frac{\chi_j M^4}{p_j^{\sigma_4} \Delta_4}</math></p> <p>Where, <math>\Delta_4 = \sum_j \chi_j p_j^{(1 - \sigma_4)}</math></p>
	<p><math>p_j</math>: freight transport price, <math>M^4 := M^3 - \sum_j p_j^* x_j^*</math>, <math>\chi_j</math>: parameters, <math>X_F</math>: Utility level gotten from consuming volume of freight transport services.</p>	

$$V^l = V^l(p_j^l, M^l) \quad (17)$$

The commodity/service price at the  $l$ th stage is led through transforming the result of (17) and the budget constraint equation at the same stage as below.

$$p_i^l = p_j^l(p_j^{l-1}) \quad (18)$$

Table 2. Specified utility level of household and commodity price

	Utility level	Commodity price
First stage ( $l=1$ )	$V = M^1 \cdot (\Delta_1)^{\frac{1}{\sigma_1-1}}$	Present goods: $p_H = (\Delta_2)^{\frac{1}{1-\sigma_2}}$
Second stage ( $l=2$ )	$H = M^2 \cdot (\Delta_2)^{\frac{1}{\sigma_2-1}}$	Composite goods: $p_X = \prod_j \left( \frac{p_j}{\zeta_j} \right)^{\zeta_j} \left( \frac{p_{TF}}{\zeta_F} \right)^{\zeta_F}$
Third stage ( $l=3$ )	$X = M^3 \cdot \prod_j \left( \frac{\zeta_j}{p_j} \right)^{\zeta_j} \left( \frac{\zeta_F}{p_{TF}} \right)^{\zeta_F}$	Total freight transport: $p_{TF} = (\Delta_4)^{\frac{1}{1-\sigma_4}}$
Fourth stage ( $l=4$ )	$X_F = M^4 \cdot (\Delta_4)^{\frac{1}{\sigma_4-1}}$	

We show the results of solved  $V^l$  and  $p^l$  in table 2. Here, we want to emphasize that the nested utility maximizing behaviors become to be consistent by leading the relation among prices of each stage as (18).

Next, we explain the saving behavior of household. The savings are led under the balance of returns and loss generated by investing all savings to accumulation of capital stock. The return of investment is given as capital rent dividend. Supposing the myopic expectation in this model, the household consider next period's rent the same as present one. So such rent dividend is expressed as

$$p_K I \quad (19)$$

Where,  $I$ : investment volume, that corresponds with accumulation of capital stock.

$$I = \Delta K \quad (20)$$

On the other hand, the loss of investment is yielded as value of the present good consumption that has been given up by investing. This consumption is defined as the future goods  $C_F$  that is formulated at first stage in table 1. Assuming myopic expectation, the price of  $C_F$  is equivalent to the present composite good's price.

From these result, the balance equation (21) between return and loss of investment, is to be constructed.

$$p_K I = p_X C_F \quad (21)$$

Here assuming  $p_I$  to investment price, which will be introduced in (25) at next paragraph. Hence  $p_I I$  indicates the amount value of investment and implies also the one of saving. The (21) is modified by introducing the  $p_I$ .

$$p_I I = \left( \frac{p_I p_X}{p_K} \right) C_F \quad (22)$$

The coefficient of  $C_F$  is defined as  $p_F$ .

$$p_F \equiv \frac{p_I p_X}{p_K} \quad (23)$$

The  $p_F$  can be considered as the price of future goods,  $C_F$ . Obtaining the numerical  $p_F$  by (23), we can solve the utility maximize programming at the first state. The optimal solutions of its programming give also the value of future goods that implies

amount of investment from equation of (22). The investing amount is appropriated to purchasing invest goods to accumulate the capital stock. The purchasing volume of them is given as below.

$$x_j^I = \frac{\xi_j \cdot p_I I}{p_j} \quad (24)$$

Where,  $x_j^I$  : purchasing volume of investment goods,  $\xi_j$  : expenditure share of investment goods.

From the definition of  $\xi_j$ , the investment price,  $p_I$  is obtained as

$$p_I = \sum_j \xi_j p_j \cdot \quad (25)$$

### (3) Formulation of passenger trip consuming behavior

In this section, we try to introduce the modal choice for the consumption of total passenger trips,  $T_p$  (see  $l=2$  in table 1).

At first, the household is divided into two types, which are one owning the private automobile by previous period and not owning (see figure 6). The household of automobile owner chooses the traffic mode from the railway, bus, airplane and private automobile. On the other hand, the household of non-automobile owner decides whether he purchases the private automobile or not. The household, who determines to purchase a new automobile, chooses the used fuel type from the gasoline, diesel and clean energy. The household purchasing a new automobile decides on modal choice from traffic modes including its automobile, and the household not purchasing it does from modes except automobile.

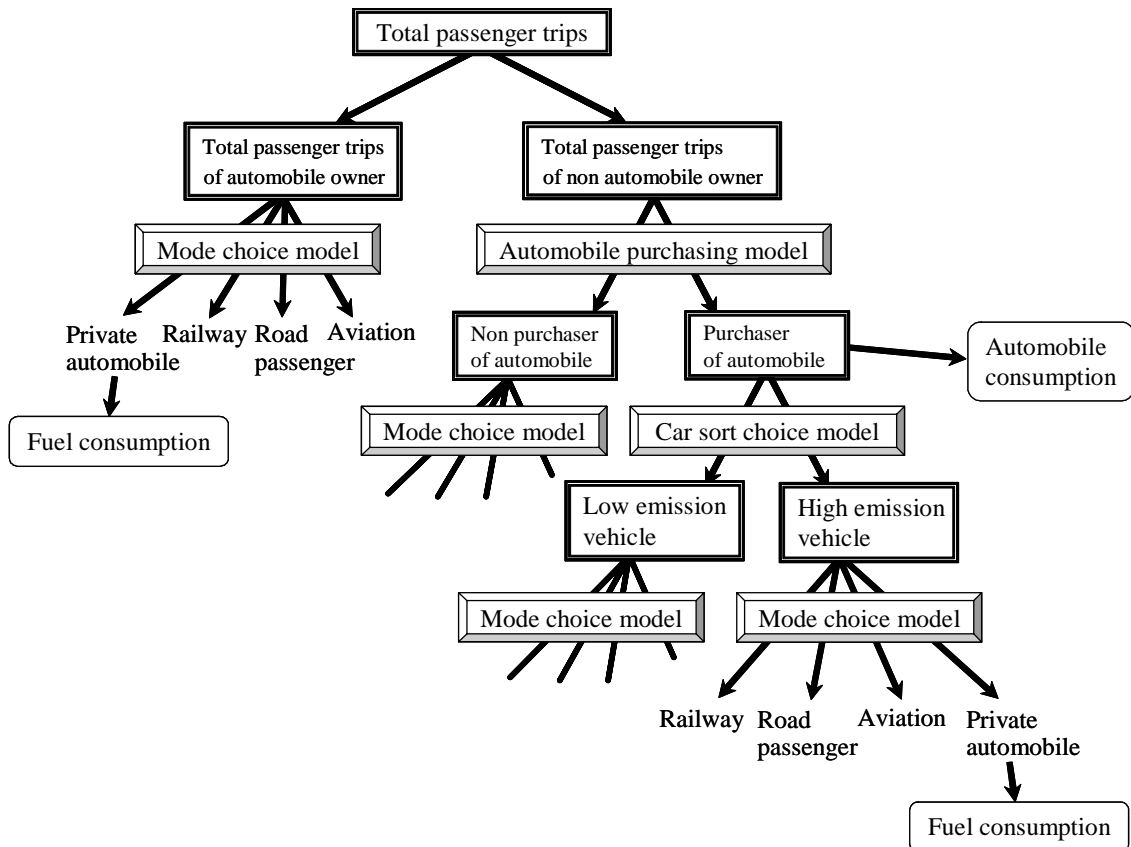


Figure 6. Outline of passenger transport service consuming behavior

We model those passenger trips consuming behavior of household in the framework of nested logit model. The behavior model at one level is formulated as well as Miyagi(1986) like below,

$$q_h = \max_{P_m^l} \left[ \sum_m P_m^l q_m - \frac{1}{\theta^l} \sum_m P_m^l \ln P_m^l \right] \quad (26a)$$

$$\text{s.t. } \sum_m P_m^l = 1 \quad (26b)$$

Where, superscript  $l$ : number of level, subscript  $m$ : traffic mode of passenger transport (example),  $P_m^l$ : choice probability of mode  $m$ ,  $q_m$ : generalized transport price and  $\theta^l$ : logit parameter.

The programming in (26) yields to the probability functions expressed by the logit model.

$$P_m^l = \frac{\exp(\theta^l q_m)}{\sum_m \exp(\theta^l q_m)} \quad (27)$$

Substituting (27) into objective function of (26), we obtain inclusive expected generalized transport price  $q_h$  as logsum variable.

$$q_h = \frac{1}{\theta^l} \ln \sum_m \exp(\theta^l q_m) \quad (28)$$

Corresponding this expected transport cost minimization program in (26) to the nested transport choice behavior illustrated in figure 6, we can get the specified model shown in table 3. The optimal programming is indicated on the left side of table 3, and the logit models and logsum variables obtained by being solved its programming is done on the right side. The logsum variable is equivalent to the cost function of upper choice model. Though the automobile owning probability is not led as logit model and the logsum variable also can not be obtained, the total passenger transport price,  $p_{TP}$  is given by the weighted average of its probability.

### 3.6 Government behavior

The government levies the carbon tax for CO<sub>2</sub> emissions on automobile fuel consumption. A part of tax revenue is appropriated the subsidy to diffuse of the clean energy vehicles, and the rest of them is done to provide the government services as general funds. When the government service is supplied, it consumes some commodities. Its government consumption is given as

$$x_j^G = \frac{\varsigma_j [\Psi^T + \Psi^S]}{p_j} \quad (29)$$

Where,  $x_j^G$ : volume of government consumption,  $\varsigma_j$ : expenditure share of government consumption,  $\Psi^T$ : tax revenue of carbon tax,  $\Psi^S$  ( $\Psi^S \leq 0$ ): subsidy for clean energy vehicle.

The household utility has been increased by providing the government service. The benefit of utility increasing is assumed simply to be equivalent to the amount of expenditure to government service,  $[\Psi^T + \Psi^S]$ .

Table 3. Formulation of transport choice model on the passenger trips

Level	Optimal programming	Choosing probability and logsum variables
Modal choice of automobile owner	$q_h = \min_{P_m^M} \left[ \sum_m P_m^M q_m - \frac{1}{\theta^M} \sum_m P_m^M \ln P_m^M \right]$ $\text{s.t. } \sum_m P_m^M = 1$ <p>The generalized transport price of each traffic mode</p> <p>Non-automobile: <math>q_m = p_m + p_L t_m</math></p> <p>Automobile: <math>q_{m'}^h = \kappa_h p_F^h + p_L t_h</math></p>	<p>Choosing probability of mode <math>m</math>:</p> $P_m^M = \frac{\exp(\theta^M q_m)}{\exp(\theta^M q_{m'}^h) + \sum_m \exp(\theta^M q_m)}$ <p>The average generalized transport price of automobile owning or purchasing household (logsum variable):</p> $q_h = \frac{1}{\theta^M} \ln \left[ \exp(\theta^M q_{m'}^h) + \sum_m \exp(\theta^M q_m) \right]$
	<p>Subscript <math>m</math>: traffic mode (<math>m'</math>: automobile), subscript <math>h</math>: fuel type of automobile, <math>p_m</math>: passenger transport service price, <math>t_m</math>: required time of mode <math>m</math>, <math>\kappa_h</math>: ratio of spending fuel for unit trip, <math>p_F^h</math>: fuel price of fuel type <math>h</math>, <math>t_h</math>: required time of automobile, <math>\theta^M</math>: logit parameter.</p>	
Fuel type choice at purchasing automobile	$q_B = \min_{P_h^S} \left[ \sum_h P_h^S \left\{ \frac{p_A^h}{x_{m'}^h} + q_h \right\} - \frac{1}{\theta^S} \sum_h P_h^S \ln P_h^S \right]$ $\text{s.t. } \sum_h P_h^S = 1$	<p>Fuel type choosing probability:</p> $P_h^S = \frac{\exp \left( \theta^S \left\{ \frac{p_A^h}{x_{m'}^h} + q_h \right\} \right)}{\sum_h \exp \left( \theta^S \left\{ \frac{p_A^h}{x_{m'}^h} + q_h \right\} \right)}$ <p>The average passenger transport price of household purchasing new automobile (logsum variable):</p> $q_B = \frac{1}{\theta^S} \ln \sum_h \exp \left[ \theta^S \left\{ \frac{p_A^h}{x_{m'}^h} + q_h \right\} \right]$
	<p><math>p_A^h</math>: automobile product price, <math>x_{m'}^h</math>: automobile consuming volume, <math>\theta^S</math>: logit parameter.</p>	
Purchasing choice of a new automobile	$q_{\bar{H}} = \min_{P_o^B} \left[ \sum_o P_o^B q_o - \frac{1}{\theta^B} \sum_o P_o^B \ln P_o^B \right]$ $\text{s.t. } \sum_o P_o^B = 1$	<p>Purchasing probability of a new automobile:</p> $P_B^B = \frac{\exp(\theta^B q_B^B)}{\exp(\theta^B q_B^B) + \exp(\theta^B q_{\bar{B}}^B)}$ <p>The average passenger transport price of non-automobile owner (logsum variable):</p> $q_{\bar{H}} = \frac{1}{\theta^B} \ln \sum_o \exp(\theta^B q_o)$
	<p>Subscript <math>o</math>: implying to purchase (<math>B</math>) or not purchase (<math>\bar{B}</math>), superscript <math>\bar{H}</math>: non-automobile owner, <math>\theta^B</math>: logit parameter.</p>	
Automobile owning probability	<p>Automobile owning probability:</p> $P^H = \frac{Z^{t-1}(1-\delta) + x_z}{N}$	
	<p><math>Z^{t-1}</math>: Number of automobile owned at previous period, <math>\delta</math>: depreciation rate of automobile, <math>x_z</math>: purchasing volume of new automobiles, <math>N</math>: number of population.</p>	

### 3.7 Market equilibrium conditions

The markets in this model are considered on each commodity, labor and capital. So the market equilibrium conditions of them are formalized as

$$\text{Commodity market: } \mathbf{y} = [\mathbf{I} - \mathbf{A}]^{-1} \mathbf{x} \quad (30a)$$

$$\text{Labor market: } \sum_j L_j = L_s \quad (30b)$$

$$\text{Capital market: } \sum_j K_j = K_s. \quad (30c)$$

Where,  $y$ : vector of domestic product volume,  $x$ : vector of domestic final demand.

The domestic final demand  $x$  consists of the consuming demands of household  $x_j$ , investment  $x_j^I$  and government  $x_j^G$ . The Consuming demands of household are obtained from table 1 and 3, the one of investment is done in (24) and the one of government is done in (29).

$L_j, K_j$  are labor and capital demand at industry  $j$ , respectively, and  $L_s, K_s$  are labor supply and endowment of capital at the period, respectively. Concretely,  $L_j, K_j$  is led below as

$$L_j = a_j^0 y_j D_{L_j} \quad (31a)$$

$$K_j = a_j^0 y_j D_{K_j}. \quad (31b)$$

Where,  $D_{L_j}, D_{K_j}$  are yielded from (5) and  $y_j$  is done from (30a).

On the other hand, labor supply  $L_s$  is obtained from the difference between the endowment of time and the time spent for leisure and passenger trip as (32).

$$L_s = \Omega - S^* - \sum_m t_m x_m^{P*} \quad (32)$$

And the endowment of capital is led by adding capital accumulation to capital stock at previous period, from which capital consumption is deducted.

$$K_s^t = \Delta K_s^{t-1} + (1 - \delta) K_s^{t-1} \quad (33)$$

Where,  $\delta$ : capital consumption ratio.

#### 4. Estimation of CO<sub>2</sub> emission and definition of market disbenefit

The CO<sub>2</sub> emissions are estimated by multiplying the CO<sub>2</sub> emission's coefficients to the consuming volume of automobile fuel. Here, the CO<sub>2</sub> emission's coefficient of gasoline is adopted 643 [gC/l] and the one of light-oil is done 721 [gC/l], which were proposed by Kondo and Moriguchi (1997).

The market disbenefit is measured by the concept of equivalent variation (EV). The EV in this dynamic model should be defined by the household utility level gotten from only present goods consumption, where the utility generated by savings is not included. Because the savings at the period is actualized in the future, and to include into the benefit of its period becomes double count.

The utility level of consuming present goods has been obtained at the second stage of table 2 as  $H$ . Hence the definition of EV based on the  $H$  is indicated as

$$H^t(p_X^B, p_L^B, p_{TP}^B, M^{2B} + EV_t) = H^t(p_X^A, p_L^A, p_{TP}^A, M^{2A}) \quad (34)$$

Where, superscript  $A, B$ : expressing with carbon tax and without, respectively.

The EV of (34) is led below by using the specified form of  $H$  in table 2.

$$EV_t = \frac{\left(\Delta_2^A\right)^{\frac{1}{\sigma_2-1}} M^{2A} - \left(\Delta_2^B\right)^{\frac{1}{\sigma_2-1}} M^{2B}}{\left(\Delta_2^B\right)^{\frac{1}{\sigma_2-1}}} + (\Psi^T + \Psi^S) \quad (35)$$

The second term of RHS (35) is added as result of household's utility increasing with being provided the government service.

Total EV is obtained by summing the present value of  $EV_t$  in (35).

$$TEV = \sum_t \frac{EV_t}{(1+i)^t} \quad (36)$$

Where.  $i$  : social discount rate.

## 5. Measuring market disbenefit of carbon taxation

### 5.1 Parameter setting

As for setting the parameters of each function in the DCGE model, we adopt the calibration method following Shoven and Whalley(1992). The calibration method is the way in which the parameters are determined under the condition reproducing the benchmark equilibrium data set. Here, we set the benchmark year in 1995. The data set is basically constructed by using the input-output table in 1995 and the national accounts. And basing on the data set, the parameters of the product and utility function are determined. The result of estimated parameters is shown in table 4 and 5.

We build data set on transport sectors by referring the "Road traffic economic survey" as well as the input-output table or the national accounts. Using the data set on transport sector, logit parameters can be determined. Here, the parameters has been estimated by giving the price elasticity of automobile fuel demand as well as reproducing the data in 1995.

The setting the price elasticity allows us to execute the simulating analysis according to the sensitivity with introducing carbon tax. Actually, the logit parameter is obtained by solving the simultaneous equation below as (37).

$$\varepsilon = \theta_1^l q_m \{1 - P_m^l\} \quad (37a)$$

$$P_m^{1995} = \frac{\exp(\theta_1^l \cdot q_m^{1995} + \theta_2^l)}{\sum_m \exp(\theta_1^l \cdot q_m^{1995} + \theta_2^l)}. \quad (37b)$$

Where,  $\varepsilon$  : price elasticity of automobile fuel demand, superscript 1995 : data in 1995.

The parameters on each level of passenger transport consuming behavior in table 3, are estimated as result like table 6. Where, we pick up two elasticity setting cases that  $\varepsilon$  are 0.3 and 0.1.

### 5.2 Result of simulation in the BAU case

The simulating results of future are shown in figure from 7 to 10 without introducing the automobile related carbon tax, in the other words business as usual (BAU) case. As for the results on passenger trips, the estimated dynamic path of passenger-km is indicated by dividing the case into  $\varepsilon = 0.3$  and  $\varepsilon = 0.1$ . Seeing this results carefully, it becomes known that automobile passenger-km in the case of  $\varepsilon = 0.3$  is estimated upper level than in the case of  $\varepsilon = 0.1$ . The reason leading such results can be understood from figure 11, in which the fact declining the automobile fuel price relatively toward the future is expressed. The difference of estimated automobile passenger-km generated the

Table 4. Parameters of product function

	Scale parameter $\eta$	Share parameter		Product capacity ratio $a^0$
		Labor $\alpha_L$	Capital $\alpha_K$	
Agriculture/Manufacture	335.99	0.7448	0.2552	0.3402
Gasoline automobile industry	627.54	0.8171	0.1829	0.1787
Diesel automobile industry	627.54	0.8171	0.1829	0.1787
CEV industry	627.54	0.8171	0.1829	0.1787
Gasoline product industry	44.10	0.5274	0.4726	0.5156
Light-oil product industry	44.10	0.5274	0.4726	0.5156
Electric/gas/water	61.56	0.5616	0.4384	0.4457
Commerce	618.43	0.8154	0.1846	0.6681
Finance/insurance	224.46	0.6997	0.3003	0.6118
Real estate	0.35	0.0811	0.9189	0.8030
Railway passenger	487.29	0.7874	0.2126	0.3756
Road passenger	2007.02	0.9683	0.0317	0.7346
Private automobile passenger	0.00	0.0000	0.0000	0.0000
Aviation transport	2381.18	0.9987	0.0013	0.3151
Railway freight	1996.07	0.9674	0.0326	0.4140
Road freight	1658.06	0.9404	0.0596	0.6429
Private automobile Freight	0.00	0.0000	0.0000	0.0000
Water transport	840.15	0.8523	0.1477	0.3569
Communication	407.79	0.7668	0.2332	0.5867
Official	2364.47	0.9969	0.0031	0.6609
Service	588.82	0.8096	0.1904	0.5592

Table 5. Parameters of utility, investment and government consumption functions

First stage			Investment $\xi_j$			Government $\zeta_j$		
elasticity of substitution	$\sigma^1$	1.113	Agriculture/Manufacture	0.815	0.010			
Share parameter(Present goods)	$\beta_H$	0.787	Gasoline automobile industry	0.033	0.000			
(Savings)	$1 - \beta_H$	0.213	Diesel automobile industry	0.006	0.000			
Second stage			CEV industry	0.000	0.000			
elasticity of substitution	$\sigma^2$	0.8	Gasoline product industry	0.000	0.000			
Share parameter(Composite goods)	$\gamma_X$	0.617	Light-oil product industry	0.000	0.000			
(Leisure)	$\gamma_S$	0.252	Electric/gas/water	0.000	0.024			
(Total passenger trip)	$\gamma_P$	0.130	Commerce	0.075	0.000			
Third stage			Finance/insurance	0.000	0.000			
Share parameter(Agri./Manu.)	$\zeta_1$	0.144	Real estate	0.000	0.000			
(Electric/gas/water)	$\zeta_2$	0.015	Railway passenger	0.000	0.000			
(Commerce)	$\zeta_3$	0.198	Road passenger	0.000	0.000			
(Finance/insurance)	$\zeta_4$	0.015	Private automobile passenger	0.000	0.000			
(Real estate)	$\zeta_5$	0.134	Aviation transport	0.000	0.000			
(Total freight transport)	$\zeta_F$	0.021	Railway freight	0.000	0.000			
(Communication)	$\zeta_6$	0.009	Road freight	0.005	0.000			
(Official)	$\zeta_7$	0.102	Private automobile Freight	0.000	0.000			
(Service)	$\zeta_8$	0.361	Water transport	0.000	0.000			
Fourth stage			Communication	0.000	0.000			
elasticity of substitution	$\sigma^F$	0.8	Official	0.000	0.361			
Share parameter(Railway freight)	$\chi_T$	0.0053	Service	0.066	0.605			
(Road transport)	$\chi_R$	0.7683				Endowment of time $\Omega$	291,807	[Million hour]
(Private auto freight)	$\chi_A$	0.0000				Capital Stock in 1995 $K_S^{1995}$	932,235,000	[Billion yen]
(Water transport)	$\chi_S$	0.2265				Capital consumption ratio $\delta_K$	0.09734	

Table 6. Parameters of passenger transport service consuming model

	The case of $\varepsilon = 0.3$			The case of $\varepsilon = 0.1$		
	Purchasing $\theta^B$	Fuel choice $\theta^S$	Modal Choice $\theta^M$	Purchasing $\theta^B$	Fuel choice $\theta^S$	Modal Choice $\theta^M$
Logit parameter	-0.00995	-0.00995	-0.550	-0.00995	-0.00995	-0.190
Constant term	0.298	-3.558	1.627	0.298	-3.558	-0.734

one of CO<sub>2</sub> emissions gotten in the both case of  $\varepsilon = 0.3$  and  $\varepsilon = 0.1$ . The estimated increasing rate of CO<sub>2</sub> emissions in 2010 comparing with 1990 is 43.0% in the case of  $\varepsilon = 0.3$ , and is 39.0% in the case of  $\varepsilon = 0.1$ .

### 5.3 Result of simulation for introducing the carbon tax

The carbon tax levied on CO<sub>2</sub> emissions is indicated as t [yen/gC]. Using the coefficients of CO<sub>2</sub> emissions that of gasoline is 643 [gC/l] and of light-oil is 721 [gC/l], the imposed amounts of carbon tax are obtained as 643t [yen] and 721t [yen],



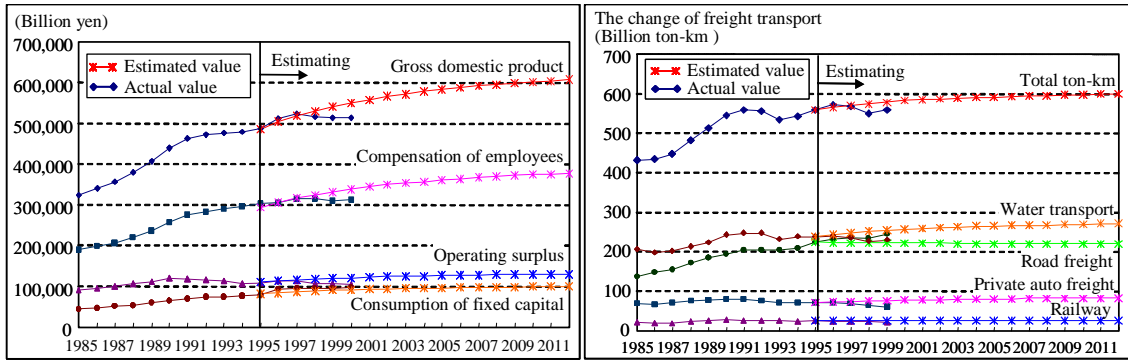


Figure 7. Future estimation of GDP and freight transport

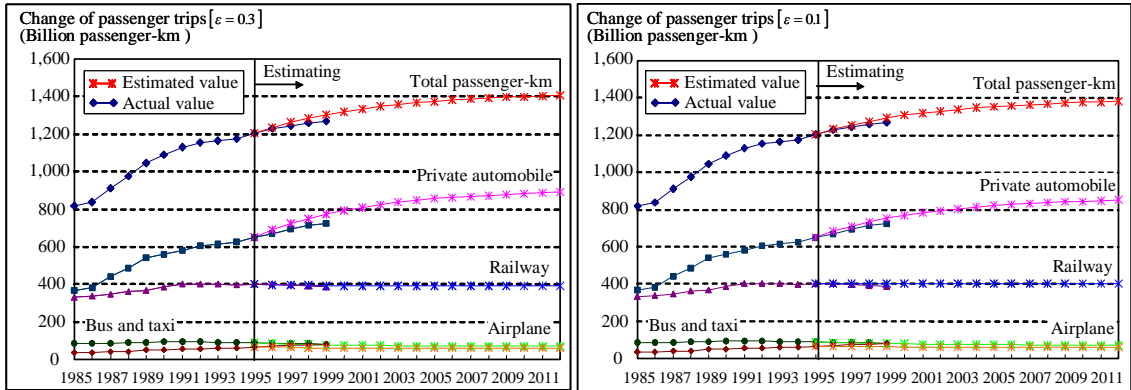


Figure 8. Future estimation of passenger transport

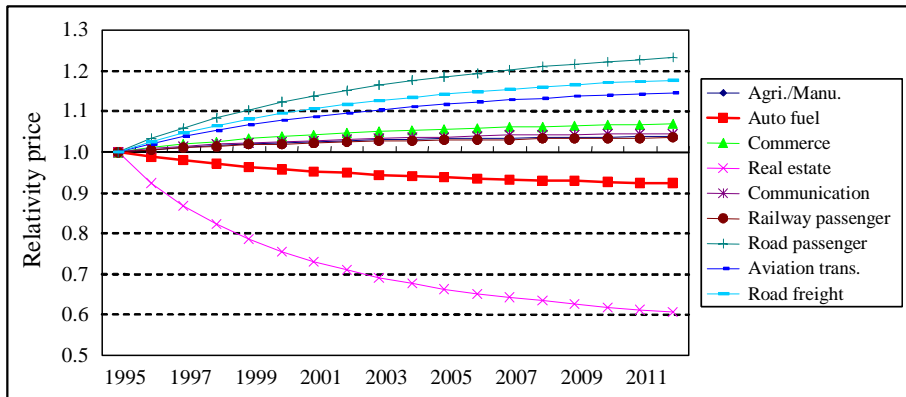


Figure 9. Change of commodity price

respectively. We simulate the market disbenefit with DCGE model by changing the tax rate  $t$  (yen/gC). Where, the carbon tax policy is introduced from 2003 and the tax rate do not change after introducing policy. Executing the numerical simulation, the relation of carbon tax  $t$  and the increasing rate of CO<sub>2</sub> emissions are shown in figure 10.

The carbon taxes requested to accomplish the CO<sub>2</sub> emissions regulatory target at transport sector are 112 [thousand yen/tC] in the case of  $\varepsilon = 0.3$  and 119 [thousand yen/tC] in the case of  $\varepsilon = 0.1$ . The results express that the carbon tax level is the case of  $\varepsilon = 0.3$  is higher than in the case of  $\varepsilon = 0.1$ . Though the case of  $\varepsilon = 0.3$  is more sensitive for introducing the policy, the reason led such results is considered that the CO<sub>2</sub> emissions of BAU case is more increasing in the case of  $\varepsilon = 0.3$  than  $\varepsilon = 0.1$ .

In figure 10, the relation between the carbon tax and automobile fuel price of gasoline

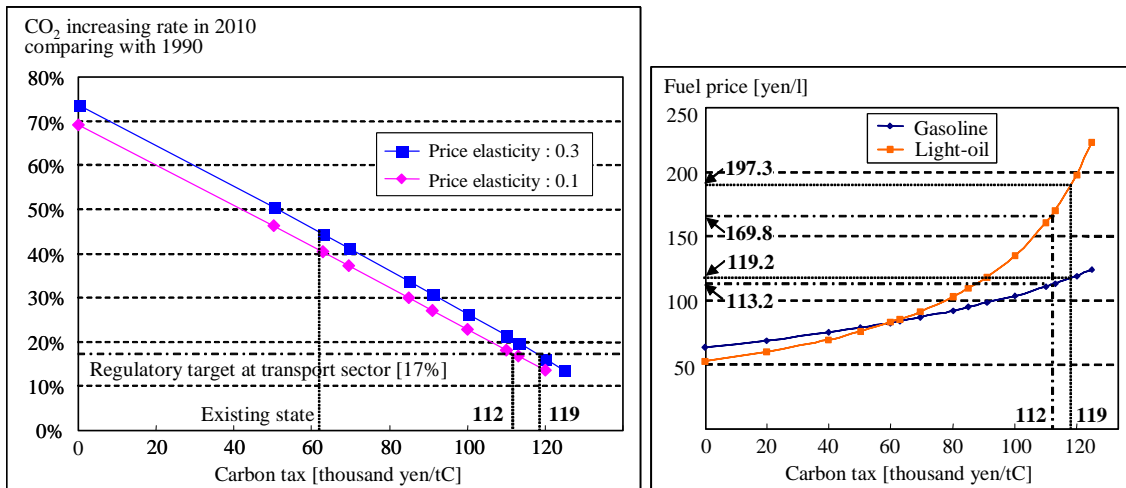


Figure 10. Carbon tax and CO2 increasing rate, and fuel price

and light-oil is also drawn. Seeing this graph, it is indicated that rising rate of light-oil price for increasing carbon tax is higher than the one of gasoline price. From this figure, the fuel prices when introducing the carbon tax policy to accomplish the regulatory target, become clear that the gasoline and light-oil prices are 113.2(yen/l) and 169.8(yen/l) respectively in the case of  $\varepsilon = 0.3$ , and those are 119.2(yen/l) and 197.3(yen/l) respectively in the case of  $\varepsilon = 0.1$ .

Next, the measured results of market disbenefit are shown in figure 11. They are 1,810(Billion yen) in the case of  $\varepsilon = 0.3$  and 2,490(Billion yen) in the case of  $\varepsilon = 0.1$ . Here, in the figure 11, the point that the market disbenefit becomes zero implies the role as the carbon tax of the fuel tax levied at present. Hence it is calculated that the increasing rates of carbon tax to accomplish the regulatory target are 83.1% in the case of  $\varepsilon = 0.3$ , and 95.1% in the case of  $\varepsilon = 0.1$ .

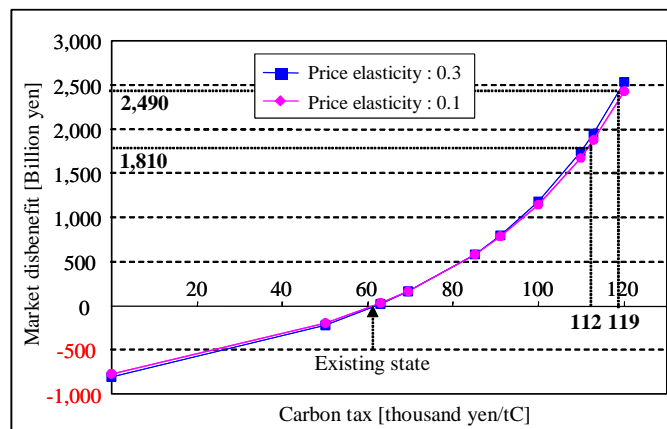


Figure 11. Carbon tax and market disbenefit

#### 5.4 Result of simulation for the subsidy to the clean energy vehicle

As for the subsidy to the clean energy vehicle, we simulate the change of increasing rate of CO2 emissions and the market disbenefit with introducing the subsidy policy and obtain the result shown in figure 12. Where, the price elasticity is set  $\varepsilon = 0.1$  and carbon tax level is done  $t = 112$ [thousand yen/tC].

The result in figure 12 indicates that the increasing rate of CO2 has been reducing

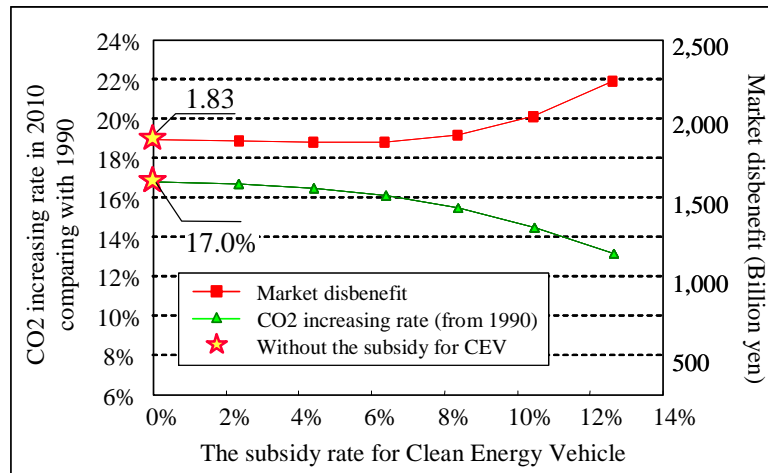


Figure 12. Subsidy rate for CEV and CO2 increasing rate or market disbenefit

less for raising the subsidy rate, and the market disbenefit has been generating more. As for the impact that the subsidy gives to market disbenefit, it is thought the effect by being declined the price of clean energy vehicle and negative effect by being decreased the carbon tax revenue through the government service. From the result, we are known that the reducing the CO2 emissions can be done by 6.4% of subsidy rate without generating more market disbenefit.

## 6. Conclusion

In this paper, the impacts with introducing the automobile related carbon tax have been evaluated by using the dynamic computable general equilibrium (DCGE) model. Here, setting the difference price elasticity in the fuel demand, the reducing volume of CO2 emissions and market disbenefit have been computed for each case. Those results are concluded as below.

- i) The case of price elasticity  $\varepsilon = 0.3$ : The carbon tax requested to accomplish the CO2 emissions regulatory target at transport sector (to control CO2 emissions by 17% increasing in 2010 comparing with 1990) is 112[thousand yen/tC]. However, in which the present fuel tax is included, hence its carbon tax level is equivalent to the raising tax rate 83.1% comparing with present situation. With introducing this carbon tax policy, the market disbenefit is generated 1,810[Billion yen] and the GDP is declined by 0.5%.
- ii) The case of price elasticity  $\varepsilon = 0.1$ : The requested carbon tax of this case is 119[thousand yen/tC], and the raising tax rate is 95.1%. With introducing this policy, the market disbenefit is 2,490[Billion yen] and the GDP is declined by 0.56%.

From these results, it has been known that the difference of fuel price elasticity does not give so serious impact to the reduction of CO2 emissions. The reason is thought that the effects decreasing CO2 emissions with policy is possible to cancel out by changing the CO2 emissions in BAU case, if the price elasticity is set to difference case.

However, in this study, we could not analyze the impacts by changing the fuel price elasticity of transport industry sectors. And it is remained as future tasks that are the reconsideration of myopic expectation or the analysis introducing the carbon tax for industrial sector except automobile sector.

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