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## Conference Paper

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# Economic Impact of CO<sub>2</sub> Emissions and Carbon Tax in Electric Vehicle Society in Toyohashi City in Japan

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## **Abstract:**

In this paper, we explore the economic impact of promotion and realization of an electric vehicle society (EVS) in Toyohashi City in Japan. More concretely, this paper emphasizes a computable general equilibrium (CGE) modeling approach to evaluate the following issues: economic impacts of subsidies for promotion of an EVS, economic impacts of carbon tax in order to reduce CO<sub>2</sub> emissions, a change of industrial structure towards an EVS and modal shift towards an EVS.

Our simulation results demonstrate that after applying 5 ~ 25% up subsidies to five industries including electric vehicle (EV) manufacturing, EV transport, solar power, cogeneration and other transport, the total industrial output and city GDP increase. A large growth rate is found in industries where subsidies are introduced, but a growth can be seen in non-ferrous metal industry without subsidies as well due to a repercussion effect. Moreover, it is interesting that decreasing proportions are found in coal and petroleum, mining, heat supply and gasoline vehicle (GV) transport industries. However an increase in the total CO<sub>2</sub> emission in Toyohashi City is interpreted as a rebound effect.

All the commodity prices decrease since subsidies are given to some industries. Hence Toyohashi City's economy shows a direction where the demand for conventional vehicles and energy use are decreasing, conversely, the demands for EVs and renewable energy are increasing illustrating a different life style from the current one.

Regarding CO<sub>2</sub> emissions, we introduced a carbon tax of 1,000 yen/t-CO<sub>2</sub> for industries except the five industries mentioned above. As a result the total CO<sub>2</sub> emission decreases and the equivalent variation shows a positive value as compared with the base case. Thus introducing 5 ~ 25% subsidies and the carbon tax can really represent a realistic alternative society to EVS in Toyohashi City.

**Keywords:** CGE model, electric vehicle society, electric vehicle, solar power, Toyohashi City, Japan

## **1. Introduction**

Recently CO<sub>2</sub>, which mostly forms the largest and growing fraction of greenhouse gas (GHG) emissions from transportation sector, presents a major challenge to global climate change mitigation efforts [1]. Worldwide transportation ranks second following electric power as the largest source of emissions, contributing about 20% of the total CO<sub>2</sub> in recent trends and future projections [6].

In the case of Japan, similar to the world trend in transportation, Japan's transportation sector accounts for more than one-fifth of CO<sub>2</sub> emissions [7]. Especially, emissions generated from passenger and freight cars dominate 90% of the sector [8], while personal vehicles alone contribute 50% of transportation CO<sub>2</sub> emissions in Japan [9]. In addition, it is expected that CO<sub>2</sub> emissions will be increasing because of expanding personal vehicle fleets, particularly in the sub-urban areas like Toyohashi City in Japan (see Table 1).

Thus it is imperative to introduce a new society which is based on environmental-friendly transportation and renewable energy sources that does not negatively affect the environment. In this study, we aim to introduce an EVS hoping to shift the social demand to EVs and solar power to reduce CO<sub>2</sub> emissions. The study of EVS has been a considerably unexplored field in environmental economics despite the fact of potentially attractive and important theme though there have been little attempts for this topic in environmental economics.

For example, it would be significantly worth to examine the economic impact of both production and policy implementation for promotion and realization of an EVS. From this point, previously we applied a CGE model to investigate the economic impacts of EVs production. However, promotion of an EVS does not depend on only EVs production, but it is also required to acquaint citizens with new industries like EV transport in which small mileage is the main problem of EVs. It is expected that the spread of EVs would greatly reduce the CO<sub>2</sub> emissions, however it only depends on internalizing electricity generated from renewable sources of energy like solar. Thus, it is also imperative to consider industries like solar power generation in constructing an EVS. Moreover, cogeneration is also important to shift the energy demand to renewable energies from the conventional one. Beside, beforehand, we did not consider subsidies, but subsidies may be required to overcome the initial price difference of the new industrial productions.

Taking these backgrounds into account, this article aims to apply a CGE model similar to author's previous study concerning this field [5] to evaluate the possibility and economic impacts of an EVS taking Toyohashi City in Japan as a study region. More concretely, this paper emphasizes a CGE-modeling approach to evaluate the following contents: entire impacts of subsidies for promotion of an EVS, CO<sub>2</sub> reduction by carbon tax, the possibility of price reduction, modal shift towards an EVS, a change of industrial structure towards an EVS.

Toyohashi City is considered as a study region by three reasons: (1) the number of vehicles in the city is increasing rapidly, thus, CO<sub>2</sub> emissions show an increasing trend, (2) the city has many motor vehicle manufacturers that include the Toyota Motor Company, which is one of the world's largest automobile manufacturers by production and (3) this city is potential to generate solar energy.

The rest of the paper is organized as follows. In Section 2, the study area and method of the study are described. Section 3 explains the assumptions of the model and behaviors of the economic agents. In Section 4, simulation cases and simulation results are presented. Finally, Section 5 summarizes the conclusion.

**Table 1. Increase in the Number of Personal Vehicles and CO<sub>2</sub> Emissions in Toyohashi City in Japan**

year	increase in number of personal vehicles	increase in total emissions mt/CO <sub>2</sub>
1990	189,413	58
1995	226,839	69
2000	251,433	70
2005	264,169	71

*Source: Statistical data of Toyohashi City, 2005*

## 2. Study Area and Method of the Study

### 2.1 Study Area

Toyohashi City (see Figure 1) is located in the central part of Japan and falls in the prefectural boundary of Aichi. The Pacific Ocean is in the south of the city and the city opens onto Mikawa Bay in the west. Mikawa Port is a major port for worldwide trade, and its presence has made Toyohashi an important city as the biggest import and export hub in Japan for automobile in volume term. The area and population size of the city at founding in 1906 was 19.69 km<sup>2</sup> and 9,900 persons [10]. At present the size of the city is 261.35 km<sup>2</sup> with the population of 381,977 (density stands at 1,462 persons per km<sup>2</sup>) [11]. Attractive economic activities, especially heavy industries and a large scale sea port, are attracting migration to the city and the data of Statistics Bureau in Japan provides that 10,749 persons migrated to Toyohashi in 2008, 9,779 persons in 2009 and 8,577 persons in 2010. As a result, the

city is experiencing vertical expansion as the land area has remained unchanged since 1960 [11]. There are many motor vehicle manufacturers in Toyohashi City, including Toyota Motor Company (one of the world's largest automobile manufactures by production), Mitsubishi and Suzuki Motors.

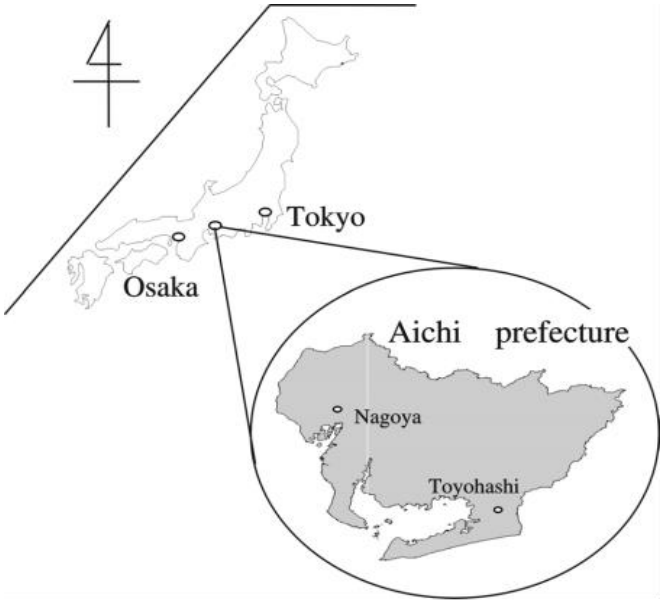


Figure 1. Location of Toyohashi City in Japan [12]

**2.2 Methodology**

The underlying approach of this study is a CGE model. In this study we apply a CGE model similar to our previous study [5] to investigate the economic impact of EVS in Toyohashi City in Japan. In constructing the model, the authors refer to the literature of Miyata and Shibusawa [2], Shoven and Whally [3] and Shibusawa and Sugawara [4]. In our model the economic agents are households, the firms in 38 industries, the government and the external sector. 40 markets are considered. They are 38 commodity markets (see Table 2), one labor market and one capital market. These are assumed to be perfectly competitive and in equilibrium in 2005.

**3. Assumptions of the Model**

**3.1 Main Assumptions**

The main assumptions made in our model are as follows:

- (1) 2005 Toyohashi City's economy is examined. The economic agents are households, the firms in 38 industries (see Table 2), the government and the external sector.
- (2) 40 markets are considered. They are 38 commodity markets, one labor market and one capital market. These are assumed to be perfectly competitive and in equilibrium in 2005.

**Table 2. Classification of Industries**

industries	industries
1. agriculture, forestry & fishery	20. aircraft
2. mining	21. other transportation equipment
3. food processing	22. precision equipment
4. textile product	23. other manufacturing
5. pulp, paper & wooden product	24. construction
6. chemical	25. electric power
7. coal & petroleum product	26. solar power
8. plastic product	27. gas supply
9. ceramic	28. heat supply
10. stone & clay product	29. cogeneration
11. iron & steel product	30. water supply & sanitary service
12. non-ferrous metal	31. commerce
13. metal product	32. financial & insurance service
14. general machinery	33. reale state
15. electrical machinery	34. GV transport
16. information & communication electronic equipments	35. EV transport
17. electronic component	36. other transport
18. gasoline vehicle (GV)	37. telecommunication & broadcasting
19. electric vehicle (EV)	38. service

### 3.2 Behavior of the Economic Agents

#### (1) Industries

In industries, intermediate goods, labor and capital are inputted to produce goods. Industries have the Cobb-Douglas technology with respect to intermediate input and labor and capital inputs, and Leontief technology for value added inputs (see Figure 2). Each firm is assumed to maximize the profit, however cost minimization is considered due to the linear homogeneity of degree one in firm's technology. Cost minimization problem can now be written as follows:

$$\min \sum_{i=1}^{38} p_i x_{ij} + (1 + tp_j)(wL_j + rK_j) \quad (j = 1, \dots, 38) \quad (1)$$

with respect to  $x_{ij}$ ,  $L_j$  and  $K_j$

subject to

$$X_j = \min \left[ \frac{1}{a_{10j}} f_j(L_j, K_j), \frac{x_{1j}}{a_{1j}}, \dots, \frac{x_{ij}}{a_{ij}}, \dots, \frac{x_{38j}}{a_{38j}} \right] \quad (2)$$

$$x'_{18j} = x_{18j}^{\alpha_{18j}} x_{19j}^{\alpha_{19j}} \quad (\alpha_{18j} + \alpha_{19j} = 1) \quad (3)$$

$$x'_{25j} = x_{25j}^{\alpha_{25j}} x_{26j}^{\alpha_{26j}} \quad (\alpha_{25j} + \alpha_{26j} = 1) \quad (4)$$

$$x'_{27j} = x_{27j}^{\alpha_{27j}} x_{28j}^{\alpha_{28j}} x_{29j}^{\alpha_{29j}} \quad (\alpha_{27j} + \alpha_{28j} + \alpha_{29j} = 1) \quad (5)$$

$$x'_{34j} = x_{34j}^{\alpha_{34j}} x_{35j}^{\alpha_{35j}} x_{36j}^{\alpha_{36j}} \quad (\alpha_{34j} + \alpha_{35j} + \alpha_{36j} = 1) \quad (6)$$

$$f_j(L_j, K_j) \equiv A_j L_j^{\alpha_j} K_j^{(1-\alpha_j)} \quad (7)$$

where

$p_i$ : price of commodity  $i$

$x_{ij}$ : intermediate input of industry  $i$ 's product in industry  $j$

$tp_j$ : net indirect tax rate imposed on industry  $j$ 's product (indirect tax rate - subsidy rate)

$w$ : wage rate

$r$ : capital return rate

$L_j$ : labor input in industry  $j$

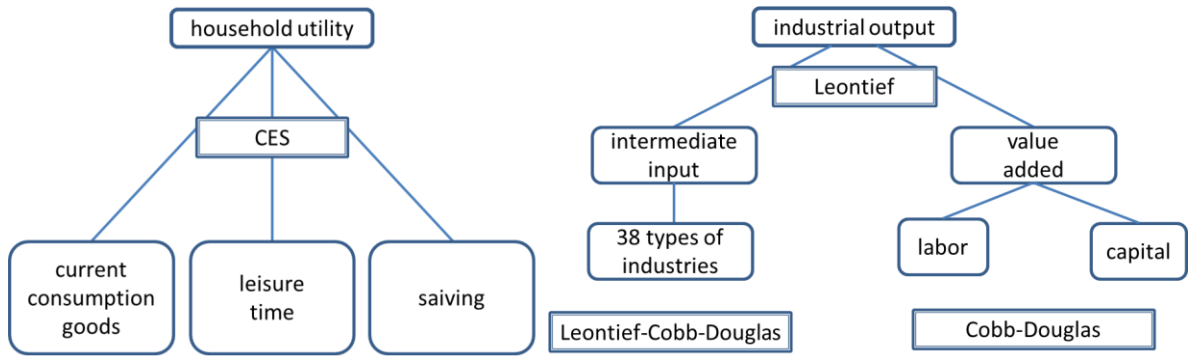
$K_j$ : capital input in industry  $j$

$X_j$ : output in industry  $j$

$a_{0j}$ : value added rate in industry  $j$

$a_{ij}$ : input coefficient

$A_{ij}$  and  $\alpha_{ij}$ : technological parameters in industry  $j$



**Figure 2. Hierarchical Structure of the CGE Model**

Conditional demands for intermediate goods, labor and capital in the production process are as follows:

$$x_{ij} = a_{ij}X_j \quad (8)$$

$$x_{18j} = \frac{\alpha_{18j}}{p_{18}} \left[ \frac{p_{18}}{\alpha_{18j}} \right]^{\alpha_{18j}} \left[ \frac{p_{19}}{\alpha_{19j}} \right]^{\alpha_{19j}} a'_{18j} X_j \quad (9)$$

$$x_{19j} = \frac{\alpha_{19j}}{p_{19}} \left[ \frac{p_{18}}{\alpha_{18j}} \right]^{\alpha_{18j}} \left[ \frac{p_{19}}{\alpha_{19j}} \right]^{\alpha_{19j}} a'_{18j} X_j \quad (10)$$

$$x_{25j} = \frac{\alpha_{25j}}{p_{25}} \left[ \frac{p_{25}}{\alpha_{25j}} \right]^{\alpha_{25j}} \left[ \frac{p_{26}}{\alpha_{26j}} \right]^{\alpha_{26j}} a'_{25j} X_j \quad (11)$$

$$x_{26j} = \frac{\alpha_{26j}}{p_{26}} \left[ \frac{p_{25}}{\alpha_{25j}} \right]^{\alpha_{25j}} \left[ \frac{p_{26}}{\alpha_{26j}} \right]^{\alpha_{26j}} a'_{25j} X_j \quad (12)$$

$$x_{27j} = \frac{\alpha_{27j}}{p_{27}} \left[ \frac{p_{27}}{\alpha_{27j}} \right]^{\alpha_{27j}} \left[ \frac{p_{28}}{\alpha_{28j}} \right]^{\alpha_{28j}} \left[ \frac{p_{29}}{\alpha_{29j}} \right]^{\alpha_{29j}} a'_{27j} X_j \quad (13)$$

$$x_{28j} = \frac{\alpha_{28j}}{p_{28}} \left[ \frac{p_{27}}{\alpha_{27j}} \right]^{\alpha_{27j}} \left[ \frac{p_{28}}{\alpha_{28j}} \right]^{\alpha_{28j}} \left[ \frac{p_{29}}{\alpha_{29j}} \right]^{\alpha_{29j}} a'_{27j} X_j \quad (14)$$

$$x_{29j} = \frac{\alpha_{29j}}{p_{29}} \left[ \frac{p_{27}}{\alpha_{27j}} \right]^{\alpha_{27j}} \left[ \frac{p_{28}}{\alpha_{28j}} \right]^{\alpha_{28j}} \left[ \frac{p_{29}}{\alpha_{29j}} \right]^{\alpha_{29j}} a'_{27j} X_j \quad (15)$$

$$x_{34j} = \frac{\alpha_{34j}}{p_{34}} \left[ \frac{p_{34}}{\alpha_{34j}} \right]^{\alpha_{34j}} \left[ \frac{p_{35}}{\alpha_{35j}} \right]^{\alpha_{35j}} \left[ \frac{p_{36}}{\alpha_{36j}} \right]^{\alpha_{36j}} a'_{34j} X_j \quad (16)$$

$$x_{35j} = \frac{\alpha_{35j}}{p_{35}} \left[ \frac{p_{34}}{\alpha_{34j}} \right]^{\alpha_{34j}} \left[ \frac{p_{35}}{\alpha_{35j}} \right]^{\alpha_{35j}} \left[ \frac{p_{36}}{\alpha_{36j}} \right]^{\alpha_{36j}} a'_{34j} X_j \quad (17)$$

$$x_{36j} = \frac{\alpha_{36j}}{p_{36}} \left[ \frac{p_{34}}{\alpha_{34j}} \right]^{\alpha_{34j}} \left[ \frac{p_{35}}{\alpha_{35j}} \right]^{\alpha_{35j}} \left[ \frac{p_{36}}{\alpha_{36j}} \right]^{\alpha_{36j}} a'_{34j} X_j \quad (18)$$

$$LD_j = \left[ \frac{(1-\alpha_j)r}{\alpha_j w} \right]^{a_j} \frac{a_{0j} X_j}{A_j} \quad (19)$$

$$KD = \left[ \frac{a_j w}{(1-a_j)r} \right]^{(1-a_j)} \frac{a_{0j} X_j}{A_j} \quad (20)$$

where

$LD_j$ : conditional demand for labor in industry  $j$

$KD_j$ : conditional capital demand in industry  $j$

Zero profit condition is realized in the industries under the perfect competition.

$$profit = p_j X_j - \sum_{i=1}^{38} p_i x_{ij} - (1 + t p_j)[w \cdot LD_j + r \cdot KD_j] = 0 \quad (21)$$

## (2) Households

Households in Toyohashi City are assumed to be homogeneous with the fixed number of households. Thus one can consider that households share an aggregate single utility function. Households share a CES utility function of the current and future goods. Here the current good is defined as a CES composite of current consumption goods and leisure time, while the future good is derived from saving.

Each household chooses a bundle of the current and future goods so as to maximize the utility function with a budget constraint. Then the current good is divided into a composite consumption good and a leisure time (labor supply).

Household income consists of full wage income, which is obtained when households supply their full labor endowment, capital income after capital depreciation, current transfers from the government, labor income, property income and other current transfers from the external sector. A part of household wage income and capital income is transferred to the external sector.

Household direct tax is imposed on the after-current-transfers income. Then households are assumed to allocate their after-direct-tax income on current and future goods. Here direct tax is supposed to include all current transfers from households to the government for simplicity.

To explain the household behavior, first, derivation of future good is described here. The future good implies the future consumption which derived from household saving, however, the saving formulates capital investment. Therefore capital good can be regarded as saving good. Investment is made by using produced goods, and let their

portions in investment be denoted by  $b_i$ . Denoting the price of investment good by  $p_b$ ,  $p_I I = \sum_{i=1}^{38} p_i I_i$  is realized.

Then the price of investment good is expressed as  $p_I = \sum_{i=1}^{38} b_i p_i$ . This can be regarded as the price of saving good  $p_s$ .

Since the capital returns after direct tax by a unit of capital injection is expressed by  $(1-t_y)(1-k_o)(1-k_r)r\delta$ , the expected return rate of the price of saving good  $p_s$ , that is, the expected net return rate of household saving  $r_s$  is written as follows:

$$r_s = (1-t_y)(1-k_o)(1-k_r)r\delta / p_s \quad (22)$$

where

$t_y$ : direct tax rate imposed on households

$k_o$ : rate of transfer of property income to the external sector

$k_r$ : capital depreciation rate

$\delta$ : ratio of capital stock measured by physical commodity unit to that by capital service unit.

It is assumed that the expected returns of saving finance the future consumption. Regarding the price of the current consumption good as the price of future good under the myopic expectation, and denoting the household real saving by  $S$ , the following equation holds.

$$p \cdot H = (1-t_y)(1-k_o)(1-k_r)r\delta \cdot S \quad (23)$$

This yields  $[p_s p / (1-t_y)(1-k_o)(1-k_r)r\delta] H = p_s S$ , and we set the price of future good  $p_H$  associated with the real saving  $S$  as;

$$p_H = p_s p / (1-t_y)(1-k_o)(1-k_r)r\delta \quad (24)$$

Then  $p_s S = p_H H$  is realized. Employing the above-mentioned future good and its price, household utility maximization problem is now specified in the following. Regarding the current good, it will be described in a later part.

$$\max_{G,H} u(G,H) \equiv \{ \alpha^{1/v_1} G^{(v_1-1)/v_1} + (1-\alpha)^{1/v_1} H^{(v_1-1)/v_1} \}^{v_1/(v_1-1)} \quad (25)$$

subject to

$$p_G \cdot G + p_H \cdot H = (1-t_y)FI - TrHO \quad (26)$$

$$FI \equiv (1-l_o)w \cdot E + LI + (1-k_o)(1-k_r)r \cdot KS + KI + TrGH + TrOH \quad (27)$$

where

$\alpha$ : share parameter

$v_1$ : elasticity of substitution between the current good and future good

$G$ : household present consumption

$H$ : household future consumption

$p_G$ : price of current good

$p_H$ : price of future good

$FI$ : household full income

$TrHO$ : current transfers from households to the external sector



$l_o$  : rate of labor income transferred to the external sector

$E$  : household initial labor endowment, which is set up as the double of real working time. This is based on the actual working time and leisure time in Toyohashi City.

$LI$  : labor income transferred from the external sector to households (exogenous variable)

$KS$  : initial capital stock endowed by households

$KI$  : property income transferred from the external sector to households (exogenous variable)

$TrGH$  : current transfers from the government to households

$TrOH$  : current transfers from the external sector to households

Solving this utility maximization problem, demand functions for current and future goods are obtained yielding a household saving function.

$$G = \frac{\alpha[(1-ty)FI - TrHO]}{p_G^{v_1} \cdot \Delta} \quad (28)$$

$$H = \frac{(1-\alpha)[(1-ty)FI - TrHO]}{p_H^{v_1} \cdot \Delta} \quad (29)$$

$$S = p_H H / p_s \quad (30)$$

$$\Delta \equiv \alpha p_G^{1-v_1} + (1-\alpha) p_H^{1-v_1} \quad (31)$$

Then we describe the derivation of demands for composite consumption and leisure time from the current good  $G$ . The current good  $G$  is a composite of consumption and leisure time, and  $G$  is obtained from the following optimization problem.

$$\max_{C,F} G \equiv \{ \beta^{1/v_2} C^{(v_2-1)/v_2} + (1-\beta)^{1/v_2} F^{(v_2-1)/v_2} \}^{v_2/(v_2-1)} \quad (32)$$

subject to

$$p \cdot C + (1-ty)(1-l_o)w \cdot F = (1-ty)FI - TrHO - SH \quad (33)$$

where

$\beta$  : share parameter

$v_2$  : elasticity of substitution between composite consumption and leisure time

$C$  : composite consumption

$F$  : leisure time

$p$  : price of composite consumption good

$SH$  : household nominal saving ( $=P_s \cdot S$ )

Solving this utility maximization problem, demand functions for composite consumption, leisure time and labor supply are obtained.

$$C = \frac{\beta[(1-ty)FI - TrHO - SH]}{p^{v_2} \cdot \Omega} \quad (34)$$

$$F = \frac{(1-\beta)[(1-ty)FI - TrHO - SH]}{[(1-ty)(1-l_o)w]^{v_2} \cdot \Omega} \quad (35)$$

$$LS = E - F \quad (36)$$

$$\Omega = \beta p^{(1-v_2)} + (1-\beta)[(1-ty)(1-l_o)w]^{(1-v_2)} \quad (37)$$

where  $LS$ : household labor supply

Substituting composite consumption (34) and leisure time (35) into (32), the price index of the current good is derived as follows:

$$P_G = \{\beta p^{1-v_2} + (1-\beta)[(1-ty)(1-l_o)w]^{1-v_2}\}^{1/(v_2-1)} \quad (38)$$

Moreover, composite consumption good is disaggregated into produced goods through the maximization of a Cobb-Douglas sub-sub utility function given the household income and leisure time.

$$\max C \equiv \prod_{i=1}^{38} C_i^{\gamma_i} \quad (\sum_{i=1}^{38} \gamma_i = 1) \quad (39)$$

subject to

$$\sum_{i=1}^{38} p_i \cdot C_i = (1-ty)Y - TrHO - SH \quad (40)$$

where

$C_i$ : household consumption good produced by industry  $i$

$p_i$ : price of good  $i$

$Y$ : household income ( $= (1-l_o)w \cdot LS + LI + (1-k_o)(1-k_r)r \cdot KS + KI + TrGH + TrOH$ )

From this optimization problem, consumption good  $i$  is derived.

$$C_i = \frac{\gamma_i}{p_i} [(1-ty)Y - TrHO - SH] \quad (i = 1, \dots, 38) \quad (41)$$

The price of composite consumption is calculated as follows:

$$P = \prod_{i=1}^{38} \left[ \frac{p_i}{\gamma_i} \right]^{\gamma_i} \quad (42)$$

### (3) The Government

The government sector in this study consists of the national and local governmental activities in Toyohashi City. Thus, the concept of the government corresponds to the definition of SNA framework. The government obtains its income from direct and net indirect taxes of Toyohashi City, and current transfers from the external sector, and then it spends the income on government consumption, current transfers to households, and current transfers to the external sector. The difference between income and expenditures is saved. Nominal consumption expenditures on commodities/services are assumed to be proportional to the government revenue with constant sectorial share. These are denoted by the following balance of payment.

$$\sum_{i=1}^{38} p_i \cdot CG_i + TrGH + TrGO + SG = ty \cdot Y + \sum_{i=1}^{38} tp_i (w \cdot LD_i + r \cdot KD_i) + TrOG \quad (43)$$

where

$CG_i$ : government consumption expenditures on commodity  $i$

$TrGH$ : current transfers to households

$TrGO$ : current transfers to the external sector

$SG$ : government savings

$TrOG$ : current transfers from the external sector

#### (4) The External Sector

The external sector gains its income from Toyohashi City's imports, current transfers from the government, labor income transfers and property income transfers. Then, it spends the income on Toyohashi City's exports, current transfers to households and the government, labor and property income transfers. These are also expressed by the following balance of payment.

$$\sum_{i=1}^{38} p_i \cdot EX_i + TrOH + TrOG + KI + LI + SO = \sum_{i=1}^{38} p_i \cdot EM_i + TrHO + TrGO + KIO + LIO \quad (44)$$

where

$EX_i$ : export of commodity  $i$

$EM_i$ : import of commodity  $i$

$SO$ : savings of the external sector (= city current surplus)

$LIO$ : labor income transfers to the external sector (=  $l_o \cdot w \cdot LS$ )

$KIO$ : property income transfers to the external sector (=  $k_o \cdot r \cdot KS$ )

#### (5) Balance of Investment and Savings

Household, government, the external sector's savings and the total capital depreciation determine the total investment.

$$\sum_{i=1}^{38} p_i \cdot I_i = SH + SG + SO + \sum_{i=1}^{38} DR_i \quad (45)$$

where

$I_i$ : demand for commodity  $i$  by investment

$DR_i$ : capital depreciation in industry  $i$

#### (6) Commodity Prices

From the zero profit condition in the industries, commodity prices can be determined by the following equation.

$$p_j X_j = \sum_{i=1}^{38} p_i x_{ij} + (1 + tp_j)[w \cdot LD_j + r \cdot KD_j] \quad (46)$$

Given a wage and a capital return rates, we can calculate the commodity prices as follows:

$$P = (I - A')^{-1}[(1 + tp_j)(w \cdot ld_j + r \cdot kd_j)] \quad (47)$$

where

$P$ : vector of commodity prices

$A'$ : transposed matrix of industries' input coefficients

$[\cdot]$ : column vector whose elements in the brackets are  $ld_j \equiv LD_j / X_j$  and  $kd_j \equiv KD_j / X_j$

#### (7) Derivation of Equilibrium

The equilibrium condition in the model can be summarized as follows:

##### Commodity Market

$$\begin{bmatrix} X_1 \\ \vdots \\ X_{38} \end{bmatrix} = \begin{bmatrix} a_{11} & \cdots & a_{138} \\ \vdots & \ddots & \vdots \\ a_{381} & \cdots & a_{3838} \end{bmatrix} \begin{bmatrix} X_1 \\ \vdots \\ X_{38} \end{bmatrix} + \begin{bmatrix} C_1 \\ \vdots \\ C_{38} \end{bmatrix} + \begin{bmatrix} CG_1 \\ \vdots \\ CG_{38} \end{bmatrix} + \begin{bmatrix} I_1 \\ \vdots \\ I_{38} \end{bmatrix} + \begin{bmatrix} EX_1 \\ \vdots \\ EX_{38} \end{bmatrix} - \begin{bmatrix} EM_1 \\ \vdots \\ EM_{38} \end{bmatrix} \quad (48)$$

## Labor Market

$$LS = \sum_{j=1}^{38} LD_j \quad (49)$$

## Capital Market

$$KS = \sum_{j=1}^{38} KD_j \quad (50)$$

## 4. Simulation Cases and Simulation Results

### 4.1 Simulation Cases

First of all, Base Case is defined as a case which assumes the existence of electric vehicle production, solar power generation, cogeneration and EV transport in Toyohashi City. The penetration rates of these activities are as follows:

- 1) EV production: 15 % of the total vehicle production
- 2) Solar power generation: 10% of the electric power generation
- 3) Cogeneration: 10% of gas and heat supply
- 4) EV transport: 15% of road transport

Simulation cases are set up as in Table 3 to analyse economic impacts of additional subsidies (net indirect tax rate) and the introduction of carbon tax.

**Table 3. Simulation Cases**

	net indirect tax rate		carbon tax	net indirect tax rate
Case 1	95%	Case I	¥1,000/t-CO <sub>2</sub>	no subsidy
Case 2	90%	Case II	¥1,000/t-CO <sub>2</sub>	95%
Case 3	85%	Case III	¥1,000/t-CO <sub>2</sub>	90%
Case 4	80%	Case IV	¥1,000/t-CO <sub>2</sub>	85%
Case 5	75%	Case V	¥1,000/t-CO <sub>2</sub>	80%
		Case VI	¥1,000/t-CO <sub>2</sub>	75%

### 4.2 Simulation Results

In this section, we explain the simulation results by referring to some important economic variables as mentioned below.

#### (1) Industrial Outputs

The change rates in industrial outputs in cases relative to Base Case are shown in Figures 3 and 4. In the cases where only the subsidies are introduced, industries with large output are found in service, commerce, GV manufacturing and construction sectors. Large industrial outputs can be seen in automobile related industries in Toyohashi City because Toyota Motor Company (one of the world's largest automobile manufacturers by production) is located in the neighboring area. The shares of outputs in the new industries are small. Large increments are found in industries including solar power generation (0.35% ~ 1.79% in Case 1 ~ Case 5), cogeneration (0.21% ~ 1.07%), EV transport (0.20% ~ 1.00%), other transport (0.18% ~ 0.91 %), non-ferrous metal (0.14% ~ 0.68%) and EV manufacturing (0.11% ~ 0.58%).

Growth rates in industrial outputs depend on the subsidy policy. The reason behind large increment in non-ferrous metal is the high demand for producing batteries used in EV, since non-ferrous metal is necessary to produce batteries used in EV. Thus, the rise in non-ferrous metal production is indirectly caused by the subsidy policy

on EV production. Decreasing tendency is found in some industries, for instance, coal and petroleum product (-0.03% ~ -0.16%), mining (-0.01 ~ -0.07%), heat supply (-0.07 ~ -0.38%) and the GV transport (-0.02 ~ -0.12%). And these results are considered as a positive factor for realization of an environmental-friendly city. The reason behind the large decrease in coal and petroleum product industry is due to an increase in share of EV, solar power and cogeneration. Moreover, falling trend in mining relates to a reduction in coal and petroleum production. And a decline in the heat supply industry is found because of growing share of cogeneration. The total industrial output increases ranging from 0.02% to 0.08% across different cases.

Figure 4 shows the results where the carbon tax is introduced. In Case I that does not take additional subsidies into account, the outputs in industries of EV manufacturing, EV transportation and other transportation decreases even the carbon tax is not imposed. However, the some industrial outputs are increased by introducing additional subsidies. A large increase rates are found in industries including solar power generation (1.50% ~ 3.31% in Case I to Case VI), EV transport (0.08% ~ 1.08%) other transport (-0.28% ~ 0.62%), EV manufacturing (-0.21% ~ 0.36%). The total industrial output decreases by -0.16% (5.344 billion yen) in Case VI.

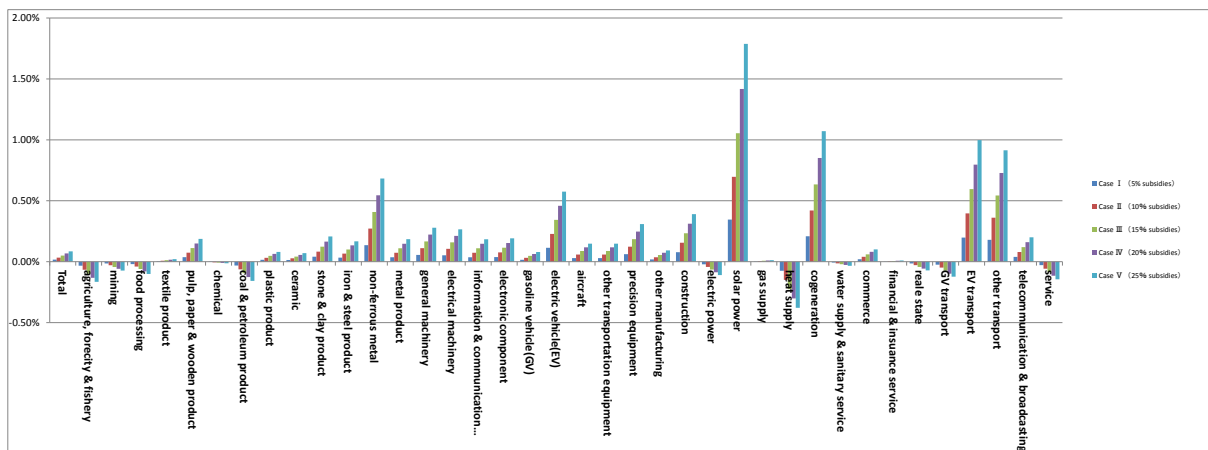


Figure 3. Change Rates in Industrial Outputs (Case 1 to Case 5)

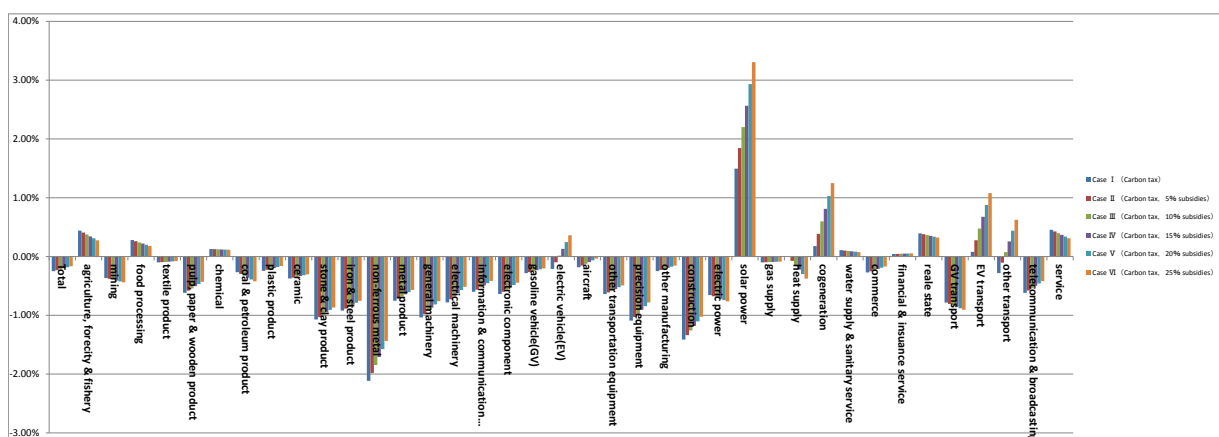


Figure 4. Change Rates in Industrial Outputs (Case I to Case VI)

## (2) City GDP

Figures 5 and 6 show the change rates in city GDP in cases relative to Base Case. Net indirect taxes are reduced by the subsidy policy. Industrial GDP with high decrease rates are found in solar power generation (-0.43 ~ -2.24% in Case 1 ~ Case 5), EV manufacturing (-0.23 ~ -1.14%), cogeneration (-0.12 ~ -0.62%), EV transport (-

0.22 ~ -1.10%), other transport (-0.25% ~ -1.27%) and heat supply (-0.07% ~ -0.38%) where additional subsidies are introduced. Conversely an increasing trend is found in industries including non-ferrous metal (0.14% ~ 0.68 %) and construction (0.08% ~ 0.39%). Moreover from Case I to Case VI, GDP with high decrease rates are found in solar power (1.49% ~ -0.784%), other transport (-0.28% ~ 1.56%), EV manufacturing (-0.21% ~ -1.35%) and EV transport (-0.08% ~ -1.02%). Large increase rates are found in industries including real estate (0.39% ~ 0.32%), service (0.45% ~ 0.31%) and so on.

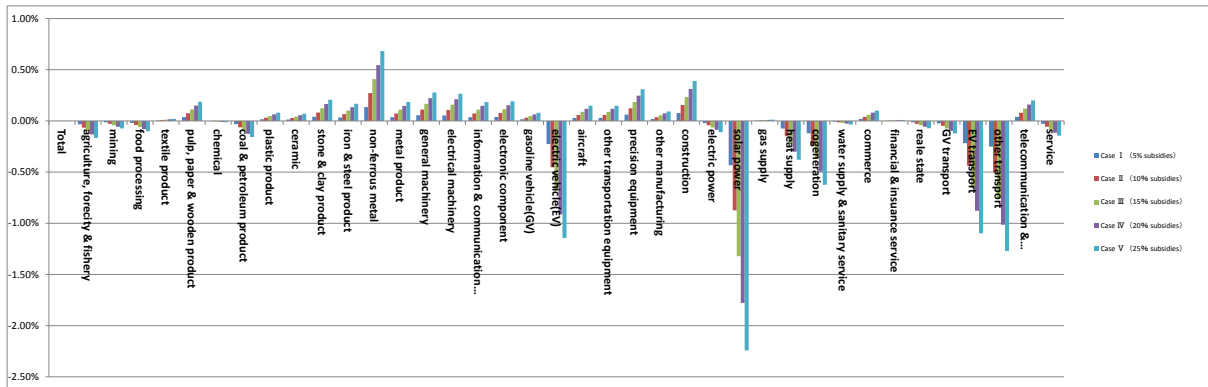


Figure 5. Change Rates in City GDP (Case 1 to Case 5)

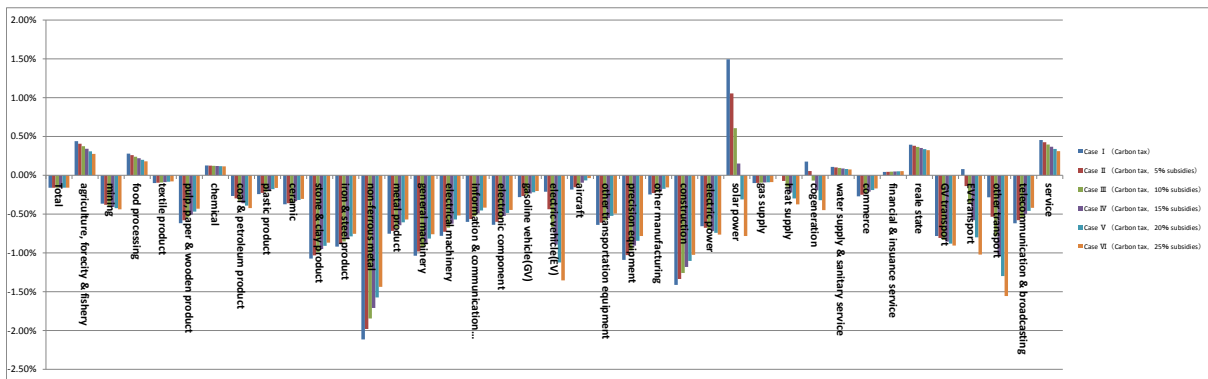


Figure 6. Change Rates in City GDP (Case I to Case VI)

### (3) Commodity Prices

The commodity prices are determined by the prices of the production factors. Since the numerare is set up as labor in this model, the capital return rate is adjusted to equilibrate the capital market. Because the benchmark data set is not equilibrated in this model, all prices do not become unity in Base Case. The capital return rate is determined so as to equilibrate the total capital supply and demand. Commodity prices decrease with additional subsidies. That is, the prices of solar power generation (-0.38 ~ -1.92%), other transport (-0.27 ~ -1.36%), EV manufacturing (-0.11 ~ -0.53%), EV transport (-0.25 ~ -1.25%) and cogeneration (-0.23 ~ -1.15%) largely decrease in Figure 7. The price of GV transport decreases by -0.03 ~ -0.15% due to a fall in the price of other transport. The decreasing trends in all commodity prices are found due to introduction of subsidies in some industries, leading to a fall in the consumer price index. In the cases with carbon tax, the commodity prices in the industries emitting large amount of CO<sub>2</sub> increase. For instance it is observed that 2.18% ~ 2.11% in electricity (Case I to Case VI), iron and steel product (1.48% ~ 1.42%) and stone and clay product (1.15% ~ 1.09%).

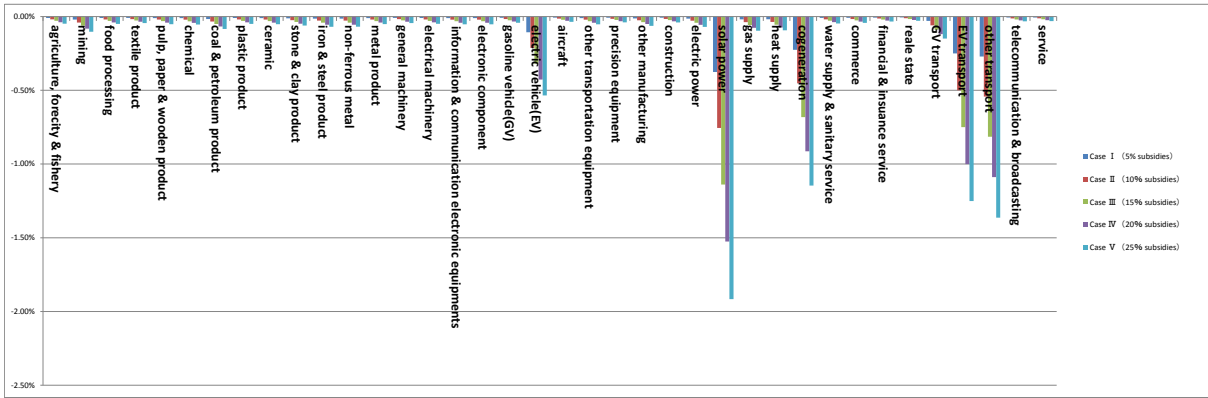


Figure 7. Change Rates in Commodity Prices (Case 1 to Case 5)

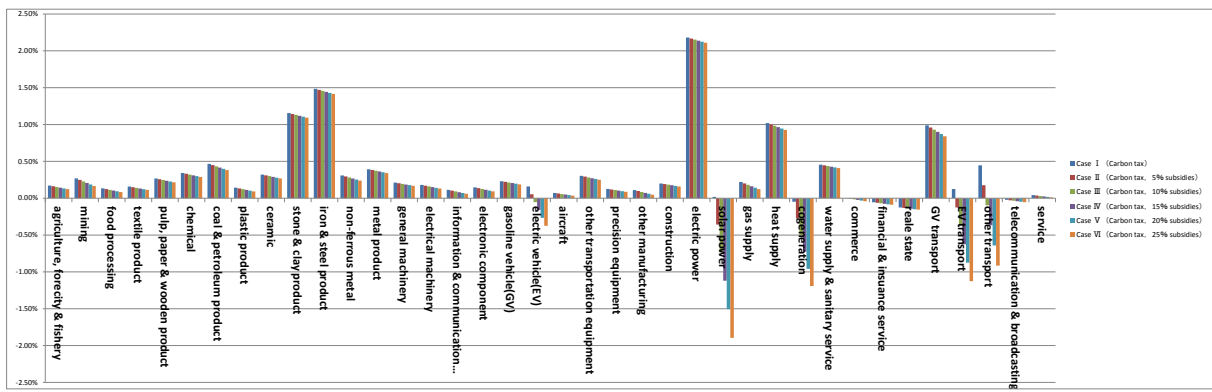


Figure 8. Change Rates in Commodity Prices (Case I to Case VI)

#### (4) CO<sub>2</sub> Emissions

Looking at the changes in CO<sub>2</sub> emissions by sector in Figures 9 and 10, it can be seen that changes in CO<sub>2</sub> emissions by industries correspond to the expense of the public subsidies. As a result decreasing trends in CO<sub>2</sub> emissions are found in heat supply (-0.07% ~ -0.38% in Case 1 ~ Case 5), coal and petroleum product (-0.03% ~ -0.16%) and GV transport (-0.02% ~ -0.12%). Decreases in CO<sub>2</sub> emissions in these industries are attributed to increases in industrial outputs including cogeneration, solar power and EV transport. However large increase rates in CO<sub>2</sub> emissions are seen in other transport (0.18% ~ 0.91%), non-ferrous metal (0.14% ~ 0.68%), EV manufacturing (0.11% ~ 0.58%) and construction (0.08% ~ 0.39%). These industries correspond to the industries where industrial outputs increase. The total CO<sub>2</sub> emission eventually increases by 2,323 t-CO<sub>2</sub> (0.06%) in Case 5. By popularization of EV, CO<sub>2</sub> emissions by heat supply and coal and petroleum product were reduced, but the industrial productions which emit more CO<sub>2</sub> such as other transport and non-ferrous metal increase. Thus the total CO<sub>2</sub> emission is increased.

This can be interpreted as a rebound effect. The rebound effect implies a secondary effect caused by improvement of energy and/or production efficiency. The rebound effect is a phenomenon to cancel a part of or all of CO<sub>2</sub> reduction expected by improvement of energy and/or production efficiency.

CO<sub>2</sub> emissions decrease in many industries after imposition of carbon tax in Case I to Case VI. Industries reducing much CO<sub>2</sub> emissions include, for example, nonferrous metals (-2.12% ~ 1.44% in Case I to Case VI), construction (-1.41% ~ 1.03%) and stone and clay (-1.07% ~ 0.87%). The total CO<sub>2</sub> emission is decreased by 23,041 t-CO<sub>2</sub> (-0.58%) in Case VI. This is attributed to the fact of decreases in industrial outputs with large CO<sub>2</sub> emissions.

Moreover, CO<sub>2</sub> emissions from EV manufacturing and other transport decrease in Case I where additional subsidies are not introduced, but CO<sub>2</sub> emissions from those industries increase as the subsidy rate rises. Industries with a large increment in CO<sub>2</sub> emissions include other transport (-0.28% ~ 0.62%), EV manufacturing (-0.21% ~ 0.36%) and services (0.45% ~ 0.31%). It is observed that CO<sub>2</sub> emissions from coal and petroleum decrease as the subsidy rate increases.

Comparing the total CO<sub>2</sub> emissions in Cases I and VI with that in Base Case, decreases of -25,348 t-CO<sub>2</sub> (-0.64%) and -23,041 t-CO<sub>2</sub> (-0.58%) are observed respectively.

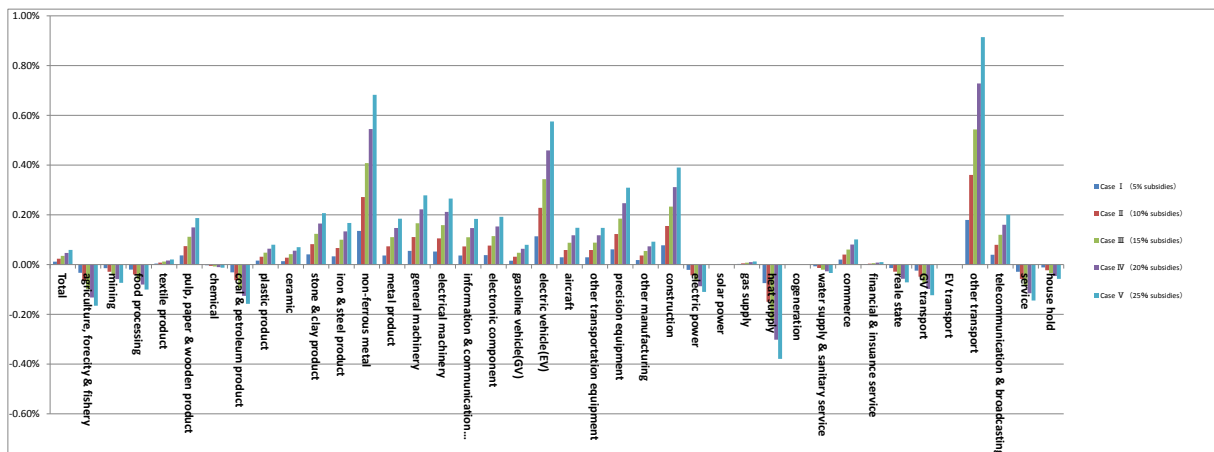


Figure 9. Change Rates in CO<sub>2</sub> Emissions (Case 1 to Case 5)

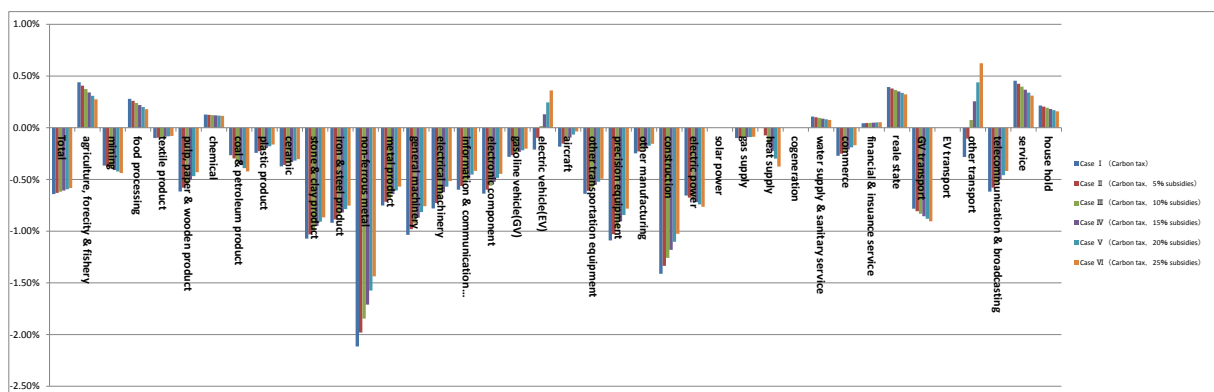


Figure 10. Change Rates in CO<sub>2</sub> Emissions (Case I to Case VI)

### (5) Other Variables

Looking at Figures 11 and 12 to see changes in other variables comparing with those in Base Case, large increase rates are found in EV purchase by households (0.08 ~ 0.42% in Cases 1 to 5), the total investment (0.07% ~ 0.36%) and labor supply (0.02% ~ 0.11%). Many variables decrease in other variables. A decrease in net indirect tax revenue in the government sector results in reduction in government income, government consumption expenditure and government saving. This decrease also causes a fall in the current transfers from the government to households resulting in a decline in household income.

On the other hand in Cases I to VI, government income, government consumption expenditure and government saving show increases since the carbon tax is introduced. Household income also grows because the current transfers from the government to households are expanded.



The equivalent variation shows a negative value of -1,255 million yen in Case 5 as Base Case is set up as the base line. This value implies the per capita equivalent variation of -3,354 yen in Toyohashi City. In Case VI, the equivalent variation depicts a welfare gain of 2,208 million yen meaning the per capita equivalent variation of 5,901 yen.

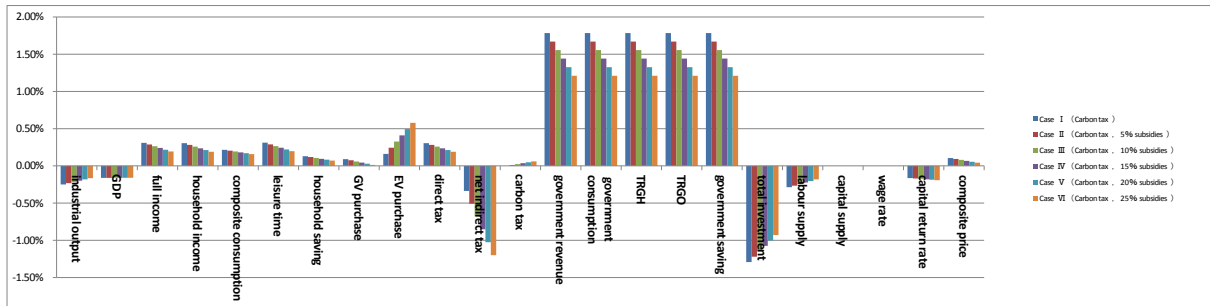


Figure 11. Change Rates in Other Variables (Case 1 to Case 5)

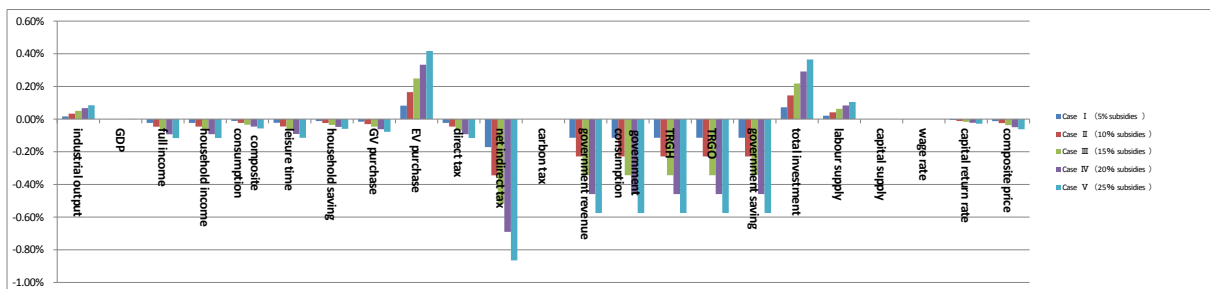


Figure 12. Change Rates in Other Variables (Case I to Case VI)

## 5. Concluding Remarks

The conversion of Toyohashi City towards the electric vehicle society by subsidy policy illustrates the result of expansion in outputs in electric vehicle manufacturing, solar power generation, cogeneration, electric vehicle transport and other transport. The outputs in mining and coal and petroleum industries shrink by substitution effect. Moreover, electric vehicle purchase increases in household sector. However, the total CO<sub>2</sub> emission slightly increases due to the fact of increases in outputs in industries generating much CO<sub>2</sub>. This is interpreted as a rebound effect by spread of electric vehicles that are characterized by energy and parts saving type.

On the other hand, in the cases with a carbon tax, outputs in industries generating much CO<sub>2</sub> including iron & steel, electricity, other clay & stones decrease while outputs in industries with additional subsidies grow resulting in a reduction in the total output and CO<sub>2</sub> emission. It can be said that this result comes from the price incentive effect which implies decreases in outputs in industries generating much CO<sub>2</sub> emissions due to rises in prices of products of such industries.

When the subsidy rate is raised, then the total industrial output increases leading to an increase in the total CO<sub>2</sub> emission. When the carbon tax is imposed on industrial outputs, outputs in industries generating much CO<sub>2</sub> emissions decrease resulting in a reduction in the total output and CO<sub>2</sub> emission. In this study, the additional subsidies are assumed to increase by 5% leading to a proportional increase in the industrial outputs. Among others the expansions in industrial outputs with the additional subsidies are larger as compared with other outputs.

When the additional subsidies are introduced, the equivalent variation shows a negative value implying Toyohashi City's welfare loss. Although there is an income effect resulting from a fall in consumer price index, de-

creases in household income and leisure time are over the income effect. However if the carbon tax is introduced, current transfers from the government to households expand resulting in increases in household income and leisure time showing a positive equivalent variation.

This study has shown a solution for the problem of the rebound effect in CO<sub>2</sub> emissions raised in the authors' previous literature by introducing the carbon tax. This study has also illustrated a path to an environmental-friendly society in Toyohashi City with more spread of electric vehicles, CO<sub>2</sub> reduction and an increase in household utility due to introduction of appropriate subsidies and carbon tax. In the near future Aichi Prefecture IO table will be published, hence areas worth examining include improvement of estimation accuracy of the model.

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