

Miyata, Yuzuru; Shibusawa, Hiroyuki; Fujii, Tomoaki

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Economic and Environmental Impacts of Electric Vehicle Society in Toyohashi City in Japan - A CGE Modeling Approach -

Yuzuru Miyata

Graduate School of Architecture and Civil Engineering, Toyohashi University of Technology

Hiroyuki Shibusawa

Graduate School of Architecture and Civil Engineering, Toyohashi University of Technology

Tomoaki Fujii

Graduate School of Architecture and Civil Engineering, Toyohashi University of Technology

Abstract:

In this paper, we explore the economic impact of promotion and realization of an electric vehicle society (EVS). 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, the possibility of price reductions, industrial structure change towards an EVS, and modal shift occurring towards an EVS.

Our simulation results demonstrate that after applying 5 ~ 25% up subsidies to five industries, such as 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 alone with non-ferrous metal industry. However, it is interesting that decreasing proportions are found in oil and coal product, mining, heat supply and gasoline vehicle (GV) transport industries.

Moreover, 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 decreased, conversely, the demand for EVs and renewable energy are increased that illustrates a different life style from the current one. However it does not mean that the total CO₂ emission is decreased. EV society makes some industrial outputs larger. Due to the fact that some industrial outputs are increased, CO₂ emissions of EV manufacturing and nonferrous metal are increased more than decreased industries.

Thus introducing 5 ~ 25% subsidies to EV manufacturing, EV transport, solar power, cogeneration and other transport can really represent a realistic alternative society to EVS if the total CO₂ emission can be reduced. Therefore we have to think what can make the total CO₂ emission reduced.

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

1. Introduction

Recently CO₂, 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 after electric power as the largest source of emissions, contributing about 20% of the total in recent trends and future projections [6].

In the case of Japan, similar to the world trend transportation, the country's transportation sector accounts for more than one-fifth of CO₂ emissions [7]. Especially, emissions generated from passenger and freight cars dominate 90% of the sector [8], while personal vehicles alone contribute 50% of transportation emissions in Japan [9]. In addition, it is expected that CO₂ 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 has become imperative to introduce a new society 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 demand to EVs and solar power to reduce CO₂ 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 how the economic impact of both production and policy implementation for promotion and realization of an EVS. From this point, previously we have 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 with new industries like EVs transport as small mileage is the main problem of EVs. It is expected that the spread of EVs would greatly reduce the CO₂ 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 to introduce an EVS. Moreover, cogeneration is also important to shift the 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, the possibility prices reduction, modal shift occurs towards an EVS, industrial structure change 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, CO₂ 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 are given, whereas Section 5 presents the results of the simulations. Finally, Section 6 summarizes the conclusion.

Table 1. Increase in the number of personal vehicles and CO₂ emissions in Toyohashi City, Japan

year	increase in number of personal vehicles	increase in total emissions mt/CO ₂
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 square kilometres and 9,900 persons [10]. At present the size of the city is 261.35 square kilometres with the population of 381,977 (density stands at 1462 persons per square kilometre) [11]. Attractive economic activity, especially heavy industries and a large scale sea-port, is attracting migration to the city and 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 is remaining 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.

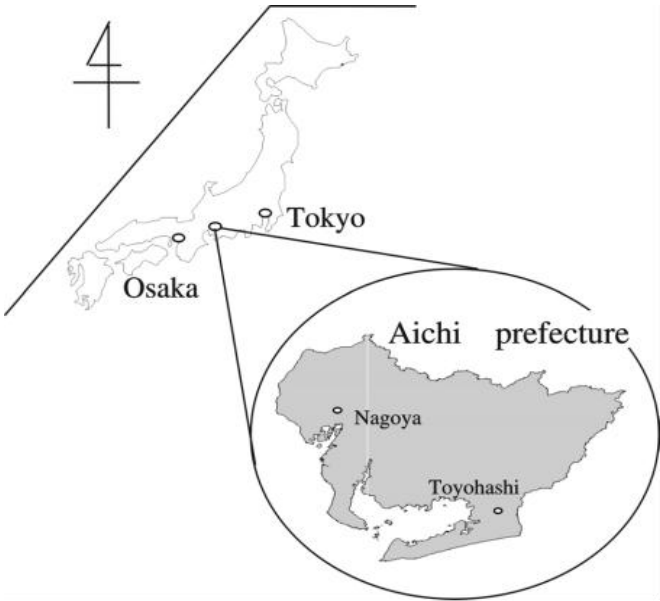


Figure 1. Location of Toyohashi City in Japan [12]

2.2 Methodology

The underlying approach of this study is a CGE model. In this study we have applied 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 referred 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) The 2005 Toyohashi City’s economy is examined. The economic agents are households, the firms in 38 industries, the government and the external sector.
- (2) In our model, the economic agents are households, the firms in 38 industries, the government and the external sector. The total of 40 markets is considered comprising 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.

In constructing the model discussed in this section, we referred to the literature of Miyata and Shibusawa [2], Shoven and Whally [3] and Shibusawa and Sugawara [4].

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. real estate
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

3.2.1 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). Cost minimization problem can be written as follows:

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

with respect to x_{ij} , L_j and K_j

subject to

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

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

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

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

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

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

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}, α_{ij} : technological parameters in industry j

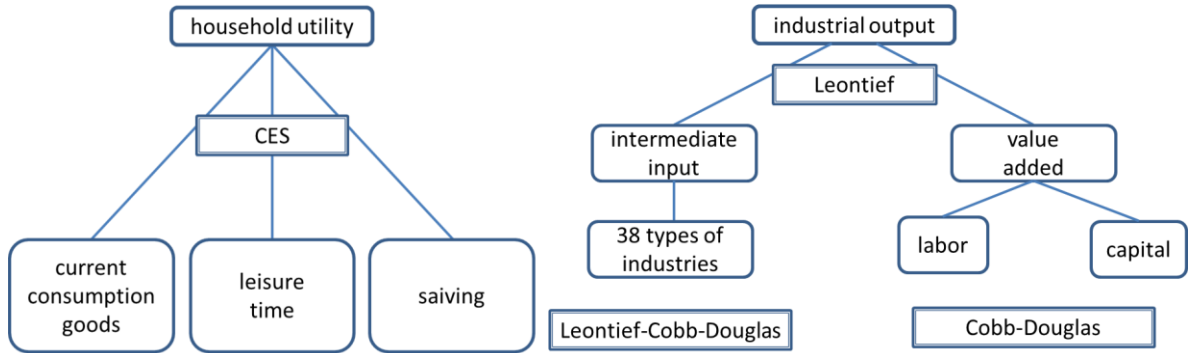


Figure 2. Hierarchical structure of the CGE model

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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.

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

3.2.2 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.

Households choose 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 income transfers. 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_I , $p_I I = \sum_{i=1}^{38} p_i I_i$ 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 $(1-ty)(1-k_o)(1-k_r)r\delta$, 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:

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

where

ty : direct tax rate imposed on households

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

k_r : capital depreciation rate

δ : 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 future good as the price of the current consumption good under the myopic expectation, and denoting the household real saving by S , the following equation holds.

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

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

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

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 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

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

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

where

α : 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

β : 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.

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

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:

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

3.2.3 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.

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

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

3.2.4 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 exports and transfer of Toyohashi, 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 (= $k_o \cdot r \cdot KS$)

3.2.5 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

3.2.6 Prices of Commodities

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 $ld_j = LD_j / X_j$ and $kd_j = KD_j / X_j$

3.2.7 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

Six cases are simulated in this study, and they are as follows:

(1) Base Case: This case assumes the existence of electronic vehicle (EV) production, solar power generation, cogeneration and EV transport in Toyohashi City. The penetration rates 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

(2) Case 1: This case assumes the introduction of government subsidies for industries mentioned above and other transport (mainly marine transport). The additional subsidies are calculated as 0.95 times the net indirect tax rates.

(3) Case 2: The additional subsidies are calculated as 0.90 times the net indirect tax rates.

(5) Case 3: The additional subsidies are calculated as 0.85 times the net indirect tax rates.

(5) Case 4: The additional subsidies are calculated as 0.80 times the net indirect tax rates.

(6) Case 5: The additional subsidies are calculated as 0.75 times the net indirect tax rates.

4.2 Simulation Results

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

4.2.1 Industrial Outputs

Changes in industrial outputs are shown in Figures 3 and 4. Industries with large output are found in service, commerce, GV manufacturing and construction sectors. It is seen that industries related to automobile are large in Toyohashi City because Toyota Motor Company (one of the world's largest automobile manufacturers by production) is located in this area. The new industries' shares are small. A large increase rates are found in industries including solar power (0.35% ~ 1.79% in Case1 ~ Case5), 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%). The balance of the growth between industrial changes depends on the subsidy policy. The reason behind large increase rate in non-ferrous metal corresponds to the demand for producing batteries used in EV. Because non-ferrous metal is necessary for producing batteries used in EV. Thus, the rise in non-ferrous metal production is indirectly influenced 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 this situation is considered as a positive factor of this study. The reason behind the large decrease of oil and coal product industry is according to an increase in share of EV, solar power and cogeneration. Moreover, falling trend in mining is related to reducing of oil and coal production. And a decline in the heat supply industry is found because of growing share of cogeneration. The total industrial output increases by 0.02%~0.09%.

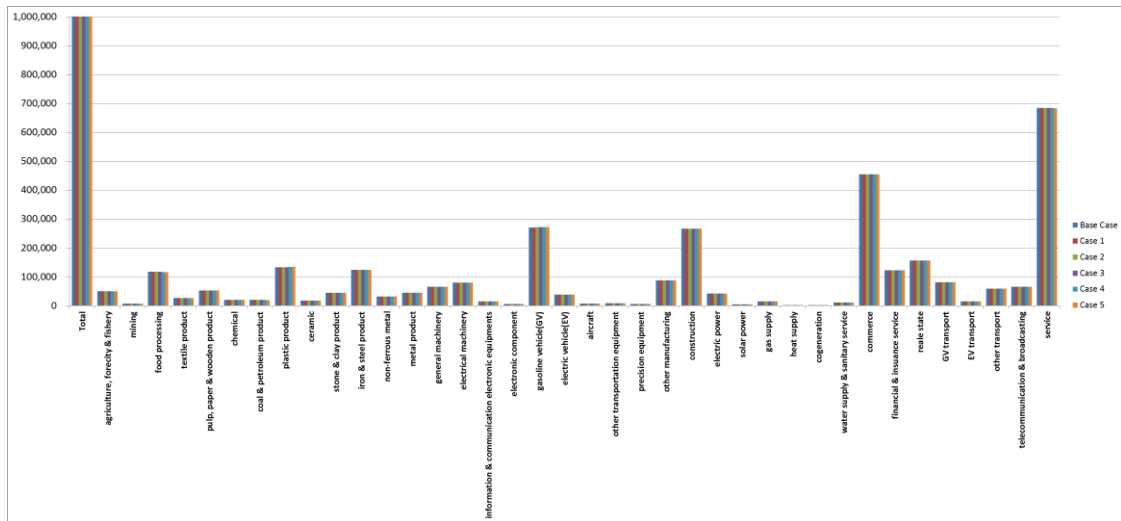


Figure 3. Industrial Output

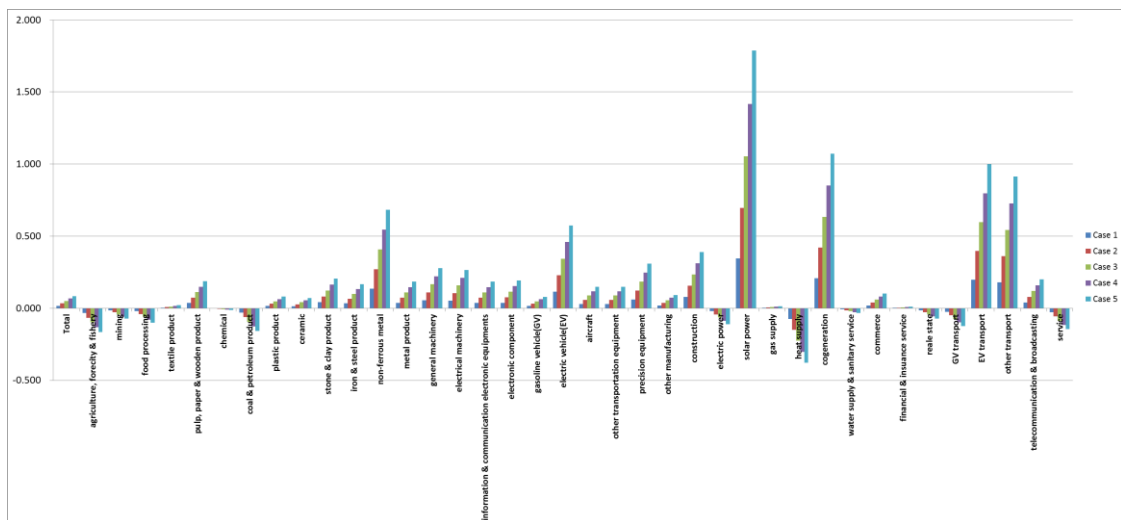


Figure 4. Change Rate in Industrial Output

4.2.2 City GDP

The city GDP is defined as the gross value added associated with the industrial output. The GDP depends on industrial output as shown in Figures 5 and 6. Net indirect taxes are reduced by the subsidy policy. Industries' GDP with high decrease rates are found in solar power (-0.43 ~ -2.24% in Case1 ~ Case5), EV manufacturing (-0.22 ~ -1.14%), cogeneration (-0.12 ~ -0.62%), EV transport (-0.25 ~ -1.10%), other transport (-0.25% ~ -1.27%) and heat supply (-0.07% ~ -0.38%) where subsidies are introduced. However, an increasing trend is found in industries including non-ferrous metal (0.14% ~ 0.68 %) and construction (0.08% ~ 0.39%) conversely.

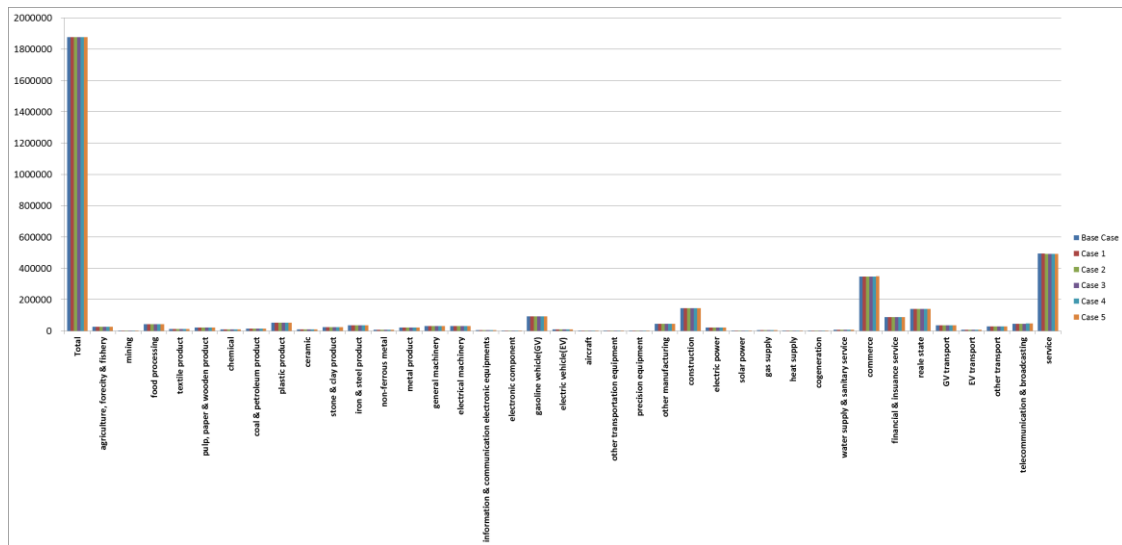


Figure 5. City GDP

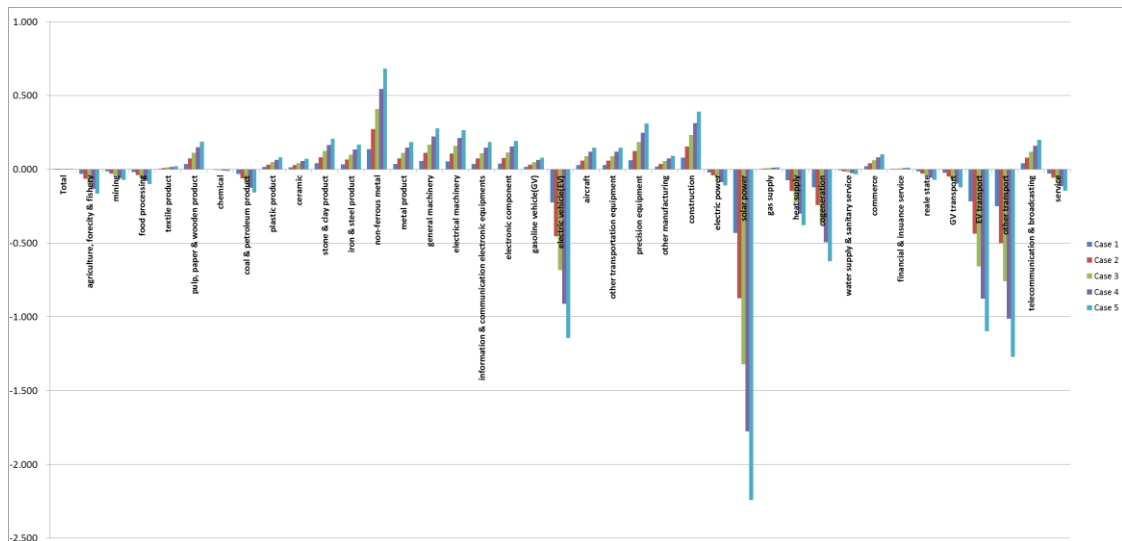


Figure 6. Change Rate in City GDP

4.2.3 Labor Demand

Looking at the changes in labor demand by sector in Figures 7 and 8, it can be seen that the changes in labor demand in industry correspond to the expense of the subsidy policy. That is, labor demands rise in industries where additional subsidies are spent. Large increasing changes in labor demand are found in solar power (1.45% ~ 7.31% in Case1 ~ Case5), cogeneration (1.12% ~ 5.63%), other transport (0.61% ~ 3.05%), EV manufacturing (0.44% ~ 2.18%) and EV transport (0.27% ~ 1.35%). The total labor demand increases (0.02% ~ 0.11%). Taking into account the current serious situation of job opportunity in Toyohashi City, an increase in labor demand may be interpreted as a positive fact. However, this reduces leisure time implying that the household utility will show a decrease in some cases.

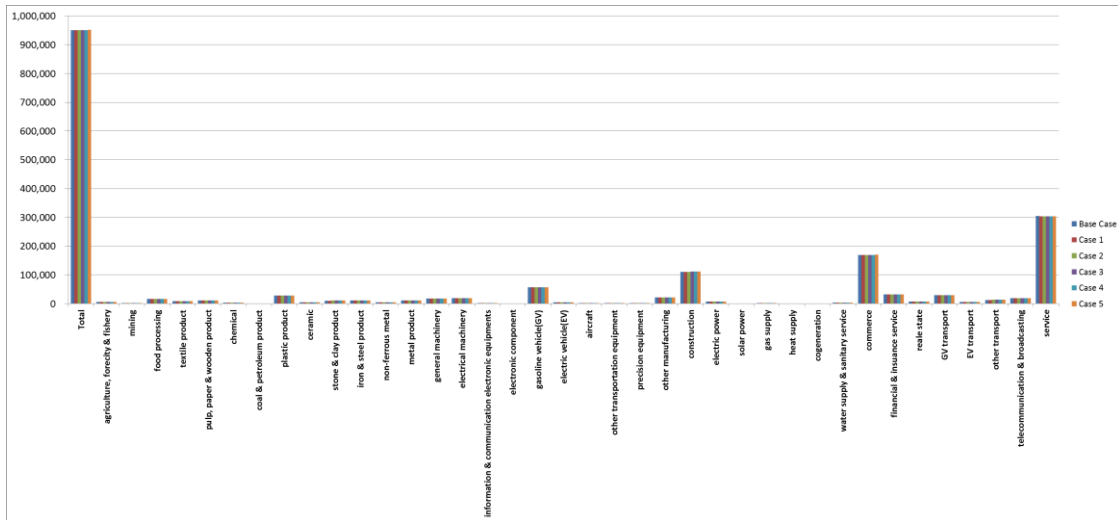


Figure 7. Labor Demand

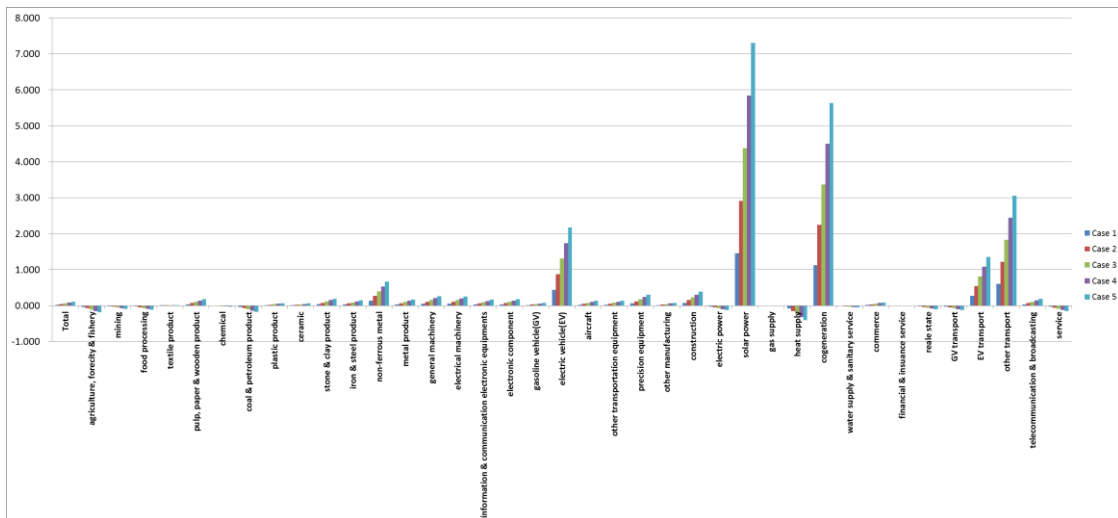


Figure 8. Change Rate in Labor Demand

4.2.4 Capital Demand

Since the total capital endowment by households is fixed in this model, therefore the total demand for capital does not change as well. Looking at the changes in capital demand by industry as shown in Figures 9 and 10, the manner of changes is considerably different from the labor demand in industries. As a result a decreasing trend of capital demand is found in all industries to which additional subsidies are spent, such as other transport (-0.25 ~ -1.27% in Case1 ~ Case5), EV manufacturing (-0.23 ~ -1.14 %), EV transport (-0.21% ~ -1.08%), cogeneration (-0.12% ~ -0.64%) and heat supply (-0.07% ~ -0.37%). However, a large decreasing rate in capital demand is seen in solar power (-0.44% ~ -2.23%). Therefore, the substitution in production factors from capital to labor occurs in these industries. On the other hand, an increase in capital demand is seen in non-ferrous metal industry (0.14% ~ 0.70%) and construction (0.08% ~ 0.41 %) which correspond to increases in the outputs.

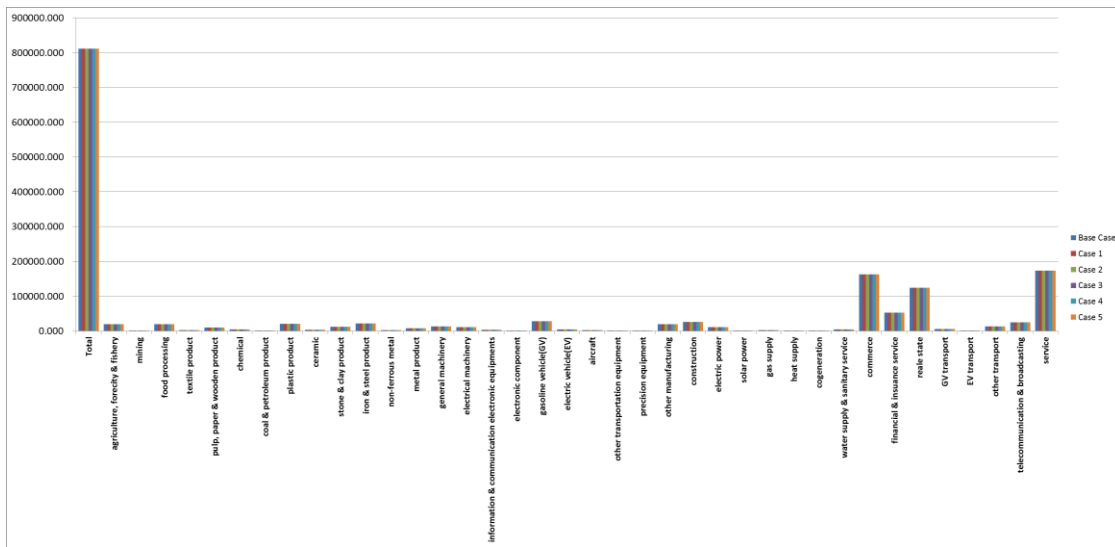


Figure 9. Capital Demand

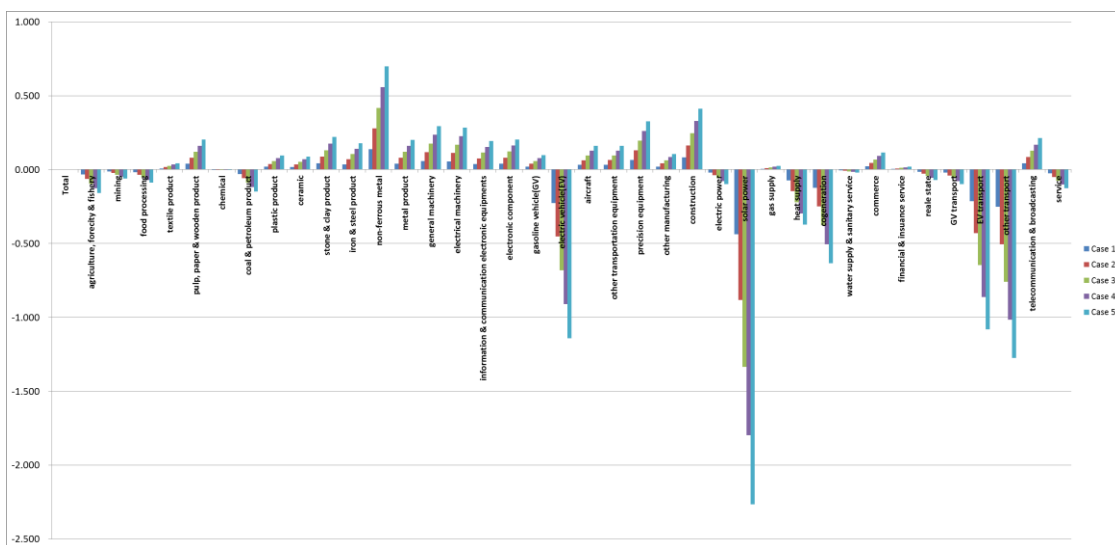


Figure 10. Change Rate in Capital Demand

4.2.5 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 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. Prices of commodities decrease with additional subsidies. Observing Figure 11 and Figure 12, the prices of solar power (-0.38 ~ -1.92%), other transport (-0.27 ~ -1.25%), EV manufacturing (-0.11 ~ -0.54%), EV transport (-0.25 ~ -1.25%) and cogeneration (-0.23 ~ -1.15%) largely decrease. The price of GV transport decreases by -0.03 ~ -0.15% due to a fall in the price of other transport. The decreasing trends of all the commodity prices are found due to introduction of subsidies in some industries, leading to a fall in the consumer price index.

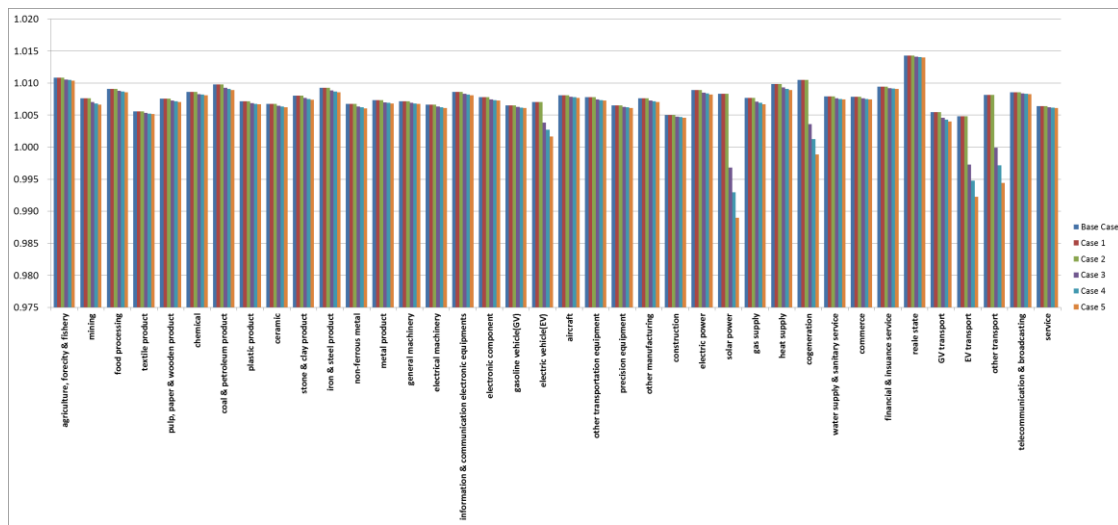


Figure 11. Commodity Prices.

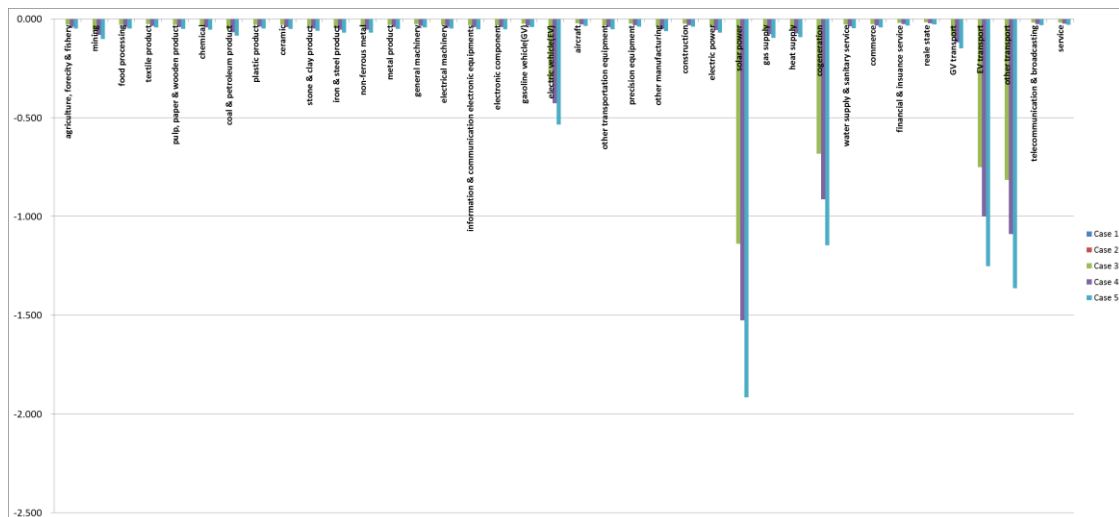


Figure 12. Change Rate in Commodity Price

4.2.6 CO₂ emissions

Looking at the changes in CO₂ emissions by sector in Figures 13 and 14, it can be seen that changes in CO₂ emissions in industry correspond to the expense of the public subsidies. As a result decreasing trends of CO₂ emissions are found in heat supply (-0.07% ~ -0.38% in Case1 ~ Case5), coal and petroleum product (-0.03% ~ -0.16 %) and GV transport (-0.02% ~ -0.12%). Decreases in CO₂ emissions in these industries are attributed to increases in industrial outputs including cogeneration, solar power and EV transport. However a large increasing rate of CO₂ emissions is seen in other transport (0.18% ~ 0.91%), non-ferrous metal (0.03% ~ 0.68%), EV manufacturing (0.11% ~ 0.58%) and construction (0.08% ~ 0.39%). These industries correspond to the industries where industrial output increased. The total of CO₂ emissions is eventually increased by 3,191 t-CO₂ (0.14%) in Case 5. By popularisation of EV, CO₂ emissions of heat supply and coal and petroleum product were reduced, but the industrial productions which emit more CO₂ such as other transport and non-ferrous metal are increased. Thus the total of CO₂ emissions is increased.

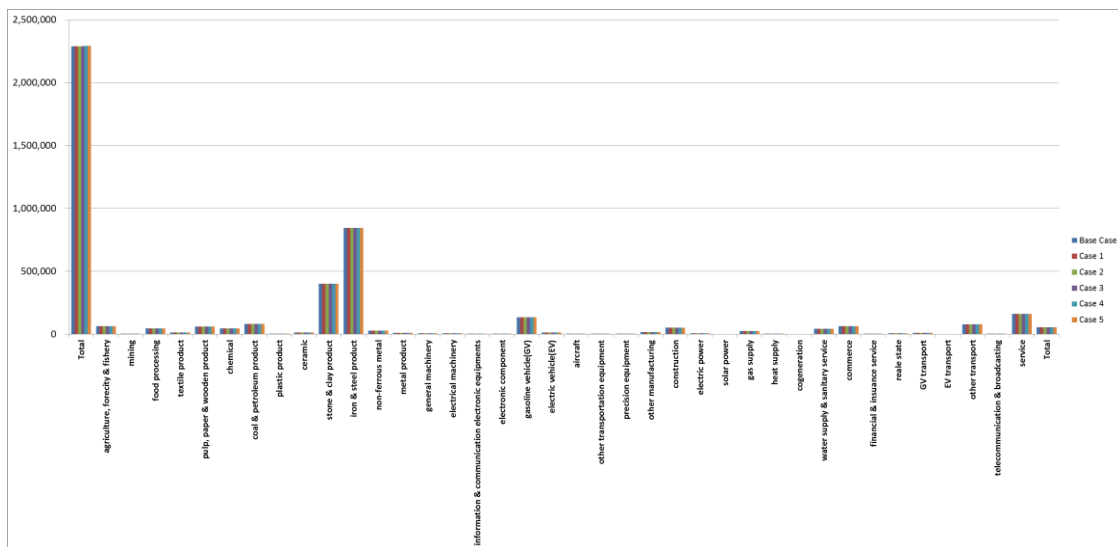


Figure 13. CO₂ emission

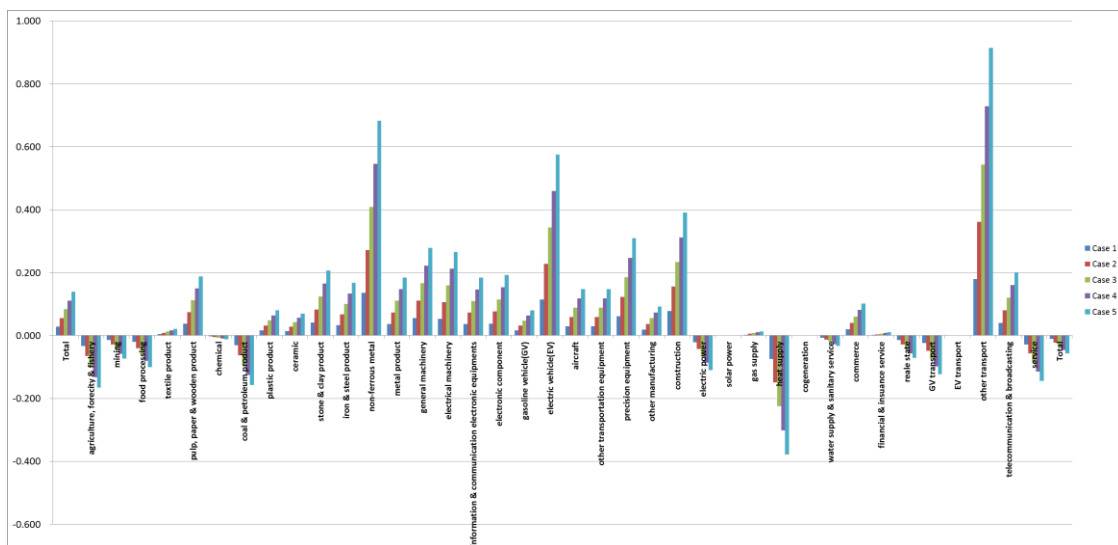


Figure 14. Change Rate in CO₂ emission

4.2.7 Other Variables

Let us look at Figures 15 and 16 to see the changes in other variables. Large increase rates are found in the total investment (0.37% in Case5), EV purchase (0.42%) and labor supply (0.11%). The increase in the labor supply corresponds to a growth on the labor demand associated with the increase in the gross value added. Besides, decreasing trends are found in some variables, especially in household income. A decrease in household income relates to the reduction in the capital return rate. This is due to the fact that a less material economy leads to less demand for production factors. Moreover, a decreasing trend is also found in net indirect tax, and in all variables relating to the government including government revenue and government savings. The consumer price decreases but the household consumption decreases despite the fact of income effect. Toyohashi City's economy shows a direction where the primary consumption is surely decreased. It is a key issue how Toyohashi City gets the welfare gain.

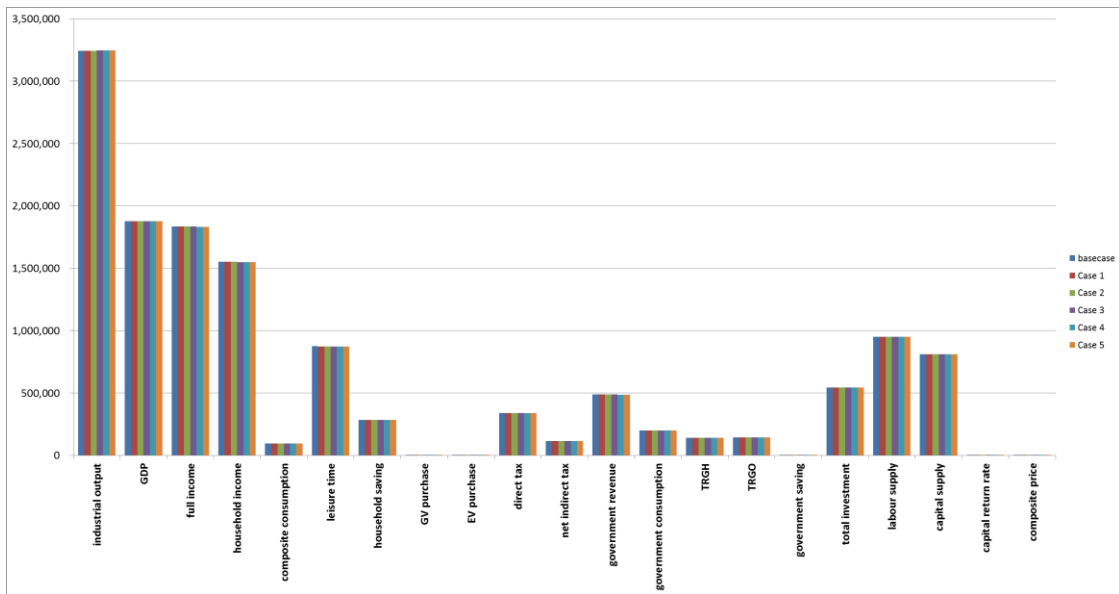


Figure 15. Other Variables

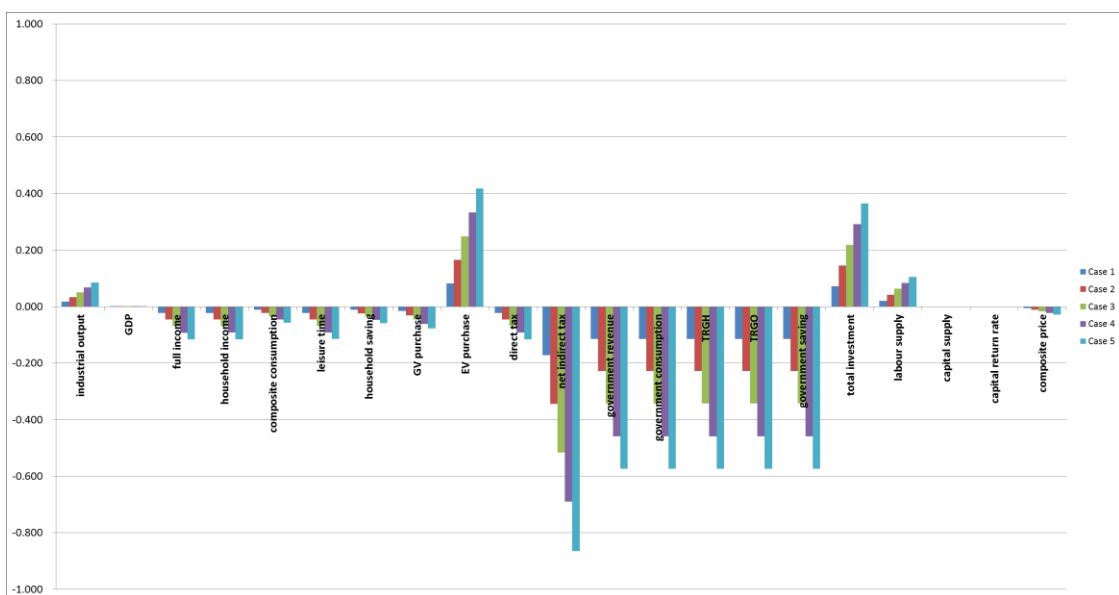


Figure 16. Change Rates in Other Variables

5. Concluding Remarks

In this article we have applied a CGE model to evaluate the possibility and economic impacts of an EVS taking Toyohashi City in Japan as a study region.

By employing the CGE model, the six numerical simulations have been implemented. From the simulation results, some interesting conclusions have been obtained.

The results demonstrate that after applying 5 ~ 25% subsidies to five industries including EV manufacturing, EV transport, solar power, cogeneration and other transport, the total industrial output and city GDP increase slightly. However a large growth rates are found in industries where subsidies are introduced except non-ferrous metal industry. It is also interesting that decreasing trends are found in oil and coal product, mining, heat supply and GV transport industries.

On the other hand, the total of CO₂ emission is increased after applying 5 ~ 25 % subsidies to five industries. This is due to the reason that by the spread of EV, CO₂ emissions of heat supply and coal and petroleum product can be reduced. But the industrial productions which exhaust more CO₂ such as other transport and non-ferrous metal are increased.

Moreover, all the commodity prices decrease because of subsidies. Hence, Toyohashi City's economy shows a direction where the demand for conventional vehicles and energy are decreased, but conversely the demand for EVs and renewable energies are increased illustrating a different lifestyle from the current one.

In this study therefore it is clear that a society change occurs towards EVS. For all these reasons, as a conclusion of the study, giving 5 ~ 25% subsidies to EV manufacturing, EV transport, solar power, cogeneration and other transshipment can really represent a realistic alternative society for EVS both in terms of economic development and less resource exhaustion. Thus we can suggest a promotion of new industrial structure to introduce EVS in Toyohashi City in Japan. The proposed model can even be applied to the other cities in Japan and other countries in the world which are similar to this area.

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