An Intertemporal Computable General Equilibrium Model of Sustainable Toyohashi City with Green Energy and Smart Technology

Shamsunnahar KHANAM
Graduate School of Environmental and Life Sciences, Toyohashi University of Technology
and
Yuzuru MIYATA
Graduate School of Architecture and Civil Engineering, Toyohashi University of Technology

1. Introduction

Over the last few decades the negative impacts of transport depicting a growing concern for our environment (Van Wee[1)]). In Japan automobiles are still increasing. If this continuous, CO_2 emissions in this sector may increase through the first half of the 21st century. Consequently, a study of measures for reducing these CO_2 emissions is essential. In this paper, possible automotive technologies, introducing electric vehicle, improvements in fuel consumption and the introduction of electric vehicle society are discussed. The main objective of our study is to introduce Sustainable Toyohashi City with green energies and smart grid technology are to mitigate consequent fossil oil dependencies, thus reduction of GHG emissions in transportation sector, and making sure that the energy is used efficiently. In our previous study market penetration of introducing electric vehicle has evaluated already. However, this would require the simultaneous implication of fuel-consumption improvements and the introduction of electric vehicles in the society. Automobile consumers would be reluctant to accept these technologies, particularly electric vehicles, because of their high purchase-price and low benefits in terms of operating economy. Acceptance will require financial and institutional support from the public sector in introducing these automotive technologies into the Japanese transportation sector. The study reported here has three aims: simulating the amount of CO_2 emissions from Toyohashi's automotive sector for 20 years from 2005; evaluating the potential of electric vehicle if the price of goods falls (like the cost of EVs drop as a consequence of high production); and considering the individual dweller and stakeholders' responses of implementing the measures to introduce electric vehicle society; each household's response as a seller and buyer because in our study we assume that every household will have the electricity generation sources from solar.

2. The Model

2.1 Assumption of the Model

The main assumptions made in the model are as follows:

(1) There are thirty four markets including thirty two commodity markets, and two factor (labor and capital) markets. (2) Commodity, labor, and capital markets are perfectly competitive, and the real economic world is in equilibrium at each time under the endogenously determined capital stock and

(2) exogenously given labor endowment. (3) Each household has perfect foresight. (4) The simulation period is 20 years interval of 2005 to 2025.

2.2 Industries

Since the adjustment cost in industries' investment is not considered in the model, the industries' intertemporal optimization behavior is reduced to the static optimization behavior, i.e. profit maximization. Industries have *Leontief* technology with respect to intermediate composite and value added inputs, and *CobbDouglas* technology for both intermediate inputs, and labor and capital inputs. Constant returns to scale are assumed in the technology. Due to linear homogeneity in production technology, industries' behavior becomes cost minimization under the given commodity demands and prices, which can be written as;

$$\underset{(x_{ij}, L_j, K_j)}{Min} \quad \sum_{i=1}^{32} p_i x_{ij} + (1+tp_j)(w \cdot L_j + r \cdot K_j) \qquad (j = 1, \cdots, 31) \tag{1}$$

subject to

$$X_j = Min\{\frac{1}{a_{oj}} f_j(L_j, K_j), \frac{1}{A_{2j}} \prod_{i=1}^{31} x_{1j}^{a_{ij}}\} \tag{2}$$

$$f_j(L_j, K_j) \equiv A_{1j} L_j^{\alpha_j} K_j^{(1-\alpha_j)} \tag{3}$$

$$a_{oj}, A_{2j} > 0, \quad \sum_{i=1}^{31} a_{ij} = 1 \quad (a_{ij} \geq 0) \tag{4}$$

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} : share parameter on intermediate input x_{ij}, A_{ij} ,α_{ij}:technical parameters in industry

Cost minimization yields conditional demands for intermediate goods, labor, and capital in production process.

$$x_{ij} = A_{2j} \frac{a_{ij}}{p_i} \prod_{k=1}^{32} (\frac{p_k}{a_{kj}})^{a_{kj}} \tag{5}$$

$$LD_j = [\frac{(1-\alpha_j) r}{\alpha_j w}]^{\alpha_j} \frac{a_{oj} X_j}{A_{1j}} \tag{6}$$

$$KD_j = [\frac{\alpha_j w}{(1-\alpha_j) r}]^{(1-\alpha_j)} \frac{a_{oj} X_j}{A_{1j}} \tag{7}$$

where LD_j : conditional demand for labor in industry j, KD_j : conditional capital demand in industry j

Zero profit condition is realized in industries under perfect competition at each time.

$$profit = p_j X_j \sum_{i=1}^{31} p_i x_{ij} - (1+tp_j)(w \cdot LD_j + r \cdot KD_j) = 0 \tag{8}$$

2.3 Household

Households in Toyohashi city are assumed to be identical. The utility function is specified as a *CES* type of composite consumption and leisure. The representative household consumes composite goods and leisure time so as to maximize the integration of discounted utility function over time. Then the composite good is divided into thirty two types of commodities maximizing a sub-utility function.

The budget constraint imposed on the household is as follows. First, the household income is composed of full income, which is defined as income obtained if the household supplied its entire labor endowment, post depreciation capital income, current transfers from the government, labor income, property income, and current transfers from the external sector. A part of wage and capital incomes is transferred to the external sector. Direct taxes are subtracted from the household full income. Then the household allocate its disposable income on consumption and leisure. The balance of income and expenditures is saved financing capital investment. Thus household behavior may be expressed as follows:

$$\underset{G,H}{Max} \int_0^{\infty} \frac{\sigma}{\sigma - 1}[\{(1-\beta)^{1/v} C^{(v-1)/v} + \beta^{1/v} F^{(v-1)/v}\}^{v/(v-1)}]^{(\sigma-1)/\sigma} e^{-\eta(t)} dt \tag{9}$$

$$\dot{KS} = (1-ty)FI / p_I - (p / p_I)C - (1-ty)(1-l_o)(w / p_I)F - (\dot{E}/ E)KS \tag{10}$$

$$FI \equiv (1-l_o)w + (1-k_0)(r - p_I\delta)KS + LI + KI + TrGH + TrOH \tag{11}$$

$$\eta(t) \equiv \int_0^t \xi(s)ds \tag{12}$$

where

σ: intertemporal elasticity of substitution, β: share parameter, v: elasticity of substitution, C : composite consumption good, F : leisure, η(t) : subjective discount rate, KS : capital stock endowed per household, ty : direct tax rate

Gross investment per household, Ip, for capital accumulation is written as $Ip = \dot{KS} + \delta KS + (\dot{E}/E)KS$. Let us further specify Ip as a *Leontief* function of commodities produced by industries

$$Ip = Min\{Ip_1 / b_1, \cdots, Ip_{31} / b_{31}\} \tag{13}$$

where $b_i > 0$, $\sum_{i=1}^{31} b_i = 1$. It is assumed that the gross investment is made minimizing the investment costs $\sum_{i=1}^{31} p_i Ip_i$, thus it leads to $Ip_i = b_i Ip$ (i =1,…, 31). Denoting the price of capital good it is derived as $p_I = \sum_{i=1}^{31} b_i p_i$ since $p_I Ip = \sum_{i=1}^{31} p_i b_i Ip$. Let us now introduce the *current value Hamiltonian* in order to solve the intertemporal optimization problem defined in equations (9) to (12).

$$\begin{aligned} H(t) = {} & \frac{\sigma}{\sigma-1}[\{(1-\beta)^{1/v} C^{(v-1)/v} + \beta^{1/v} F^{(v-1)/v}\}^{v/(v-1)}]^{(\sigma-1)/\sigma} \\ & + \lambda[(1-ty)(1-l_o)(w/p_I)(1-F) + (1-ty)\{(1-k_0)(r/p_I - \delta)KS + \\ & (LI + KI + TrGH + TrOH)p_I\} - p \cdot C / p_I - (\dot{E}/E)KS] \end{aligned} \tag{14}$$

where, λ: costate variable associated with KS.

Necessary and sufficient conditions for maximizing the objective function (9) include;

・equation (10)・ $\dot{\lambda} = -\partial H / \partial KS + \xi\lambda$ ・C and F maximize the *Hamiltonian* at each time・the transversality condition. These conditions are expressed in mathematical form as follows:

$$\dot{KS} = (1-ty)FI / p_I - (p / p_I)C - (1-ty)(1-l_o)(w / p_I)F - (\dot{E}/ E \tag{15}$$

$$\dot{\lambda} = \lambda[\xi - (1-ty)(1-k_0)(r / p_I - \delta) + \dot{E}/ E] \tag{16}$$

$$C = (1 - \beta) p^{-v} \Omega [(\dot{E} / E) p_I / \lambda p]^{\sigma} \tag{17}$$

$$F = \beta[(1-ty)(1-l_o)w]^{-v} \Omega[(\dot{E}/ E) p_I / \lambda(1-ty)(1-l_o)w]^{\sigma} \tag{18}$$

$$LS = 1 - F \tag{19}$$

$$\lim_{t \to \infty} \lambda \cdot KS \cdot e^{-\eta(t)} = 0 \tag{20}$$

$$\Omega \equiv [(1-\beta)p^{1-\nu} + \beta((1-ty)(1-l_o)w)^{1-\nu}]^{(\sigma-\nu)/(\nu-1)} \tag{21}$$

Moreover, the composite good is divided into commodities produced by industries through maximizing *Cobb-Douglas* sub-utility function (20).

$$Max \quad \prod_{j=1}^{31} C_j^{\alpha_j} \qquad (\sum_{j=1}^{31} \alpha_j = 1) \tag{22}$$

subject to

$$\sum_{j=1}^{31} p_j \cdot C_j = p \cdot C$$

where ,C_j: consumption of commodity j, p_j: price of commodity j

Therefore we obtain the consumption demand for products of industries as;

$$C_j = \alpha_j p \cdot C / p_j \qquad (j = 1,\cdots,31) \tag{23}$$

where $p = \prod_{j=1}^{31} (\frac{p_j}{\alpha_j})^{\alpha_j}$

2.4 The Government

The government obtains its income from direct and net indirect taxes, and current transfers from the external sector, and then it expends the income on government consumption, current transfers to households, and current transfers to the external sector. The difference between income and expenditures are saved. Nominal consumption expenditures on commodities/services are assumed to be proportional to the government revenue with constant sectoral share. These are expressed as the following balance of payments.

$$ty \cdot Y + \sum_{i=1}^{31} tp_i (w \cdot LD_i + r \cdot KD_i) + TrOG = \tag{24}$$

$$\sum_{i=1}^{31} p_i CG_i + TrGH + WTC + TrGO + SG$$

where CG_i: government consumption expenditures on commodity *I*, *TrGH* : current transfers to households, *TrGO* : current transfers to the external sector, *SG* : government saving, *TrOG* : current transfers from the external sector

2.4 The External Sector

The external sector gains its income from Japan's imports, current transfers from the government, labor income transfers, and property income transfers. And then it expends the income on Japan's exports, current transfers to households and the government, labor and property income transfers to Japan. Quantity of exports of commodities are exogenously given, and that of imports is assumed to be proportional to the domestic commodity demand. These are also described as the following balance of payments.

$$\sum_{i=1}^{31} p_i EM_i + TrGO + KIO + LIO = \tag{25}$$

$$\sum_{i=1}^{31} p_i EX_i + TrOH + TrOG + KI + LI + SO$$

where EX_i: export of commodity *I*, EM_i: import of commodity *I*, *SO* : savings of the external sector (=-national current surplus), *LIO* : labor income transfers to the external sector (= $l_O \cdot w \cdot LS$), *KIO* : property income transfers to the external sector (= $k_0 \cdot r \cdot KS$)

2.5 Balance of Investment/Savings

In the model, private capital accumulation is internalized by maximizing the integration of the utility function.

In the real economy, however, there are other investments including public and housing investments etc. Here other investments are supposed to be financed by savings of the government and the external sector.

$$\sum_{i=1}^{31} p_i I_i = SG + SO \qquad (26)$$

where

I_i : demand for commodity i by other investments, SG : savings of the government, SO : savings of the external sector

Similar to the private investment, demand for commodities by other investments is derived in the following way. Let other investments, I , be a *Leontief* composite with technological parameters, b_i'. Then the price of I , q_I, is derived as;

$$q_I = \sum_{i=1}^{31} b_i p_i \quad (\sum_{i=1}^{31} b_i = 1, \ b_i \geq 0) \qquad (27)$$

Therefore other investments and their demand for commodities can be calculated as;

$$I = (SG + SO) / q_I \qquad (28)$$

$$I_i = b_i I \quad (i = 1, \cdots, 31) \qquad (29)$$

2.6 Prices

Wage and capital return rates, and commodity prices satisfy some price equation in temporal equilibrium because of the zero profit condition. The relationship between the commodity price and production costs in industry i in temporal equilibrium is denoted as follows:

$$p_j = [\sum_{i=1}^{31} p_i x_{ij} + (1 + tp_j)(w \cdot LD_j + r \cdot KD_j)] / X_j = \sum_{i=1}^{31} p_i a_{ij} + (1 + tp_j)(w \cdot ld_j + r \cdot kd_j) \qquad (j = 1, \cdots, 31) \qquad (30)$$

in which $a_{ij} \equiv x_{ij} / X_j$, $ld_j \equiv LD_j / X_j$, and $kd_j \equiv KD_j / X_j$.

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

$$P = (I - A')^{-1} [(1 + tp_j)(w \cdot ld_j + r \cdot kd_j)] \qquad (31)$$

Where, P : vector of commodity prices, A': transposed matrix of industries' input coefficients

2.7 Intertemporal Equilibrium Condition

commodity market

$$X_i + EM_i = \sum_{i=1}^{31} x_{ij} + C_i + CG_i + Ip_i + I_i + EX_i \qquad (i = 1, \cdots, 31) \qquad (32)$$

labor market

$$LS = \sum_{i=1}^{31} LD_j \qquad (33)$$

capital rental market

$$KS = \sum_{i=1}^{31} KD_j \qquad (34)$$

In numerical computation, iteration for the equilibrium prices is made on the capital return rate letting labor be the numeraire (w=1).

3. Concluding Remarks

In Toyohashi city, GHG emissions are growing in transportation sector because of an increase in the number of vehicles. Not only the growing concern on emission reduction, recently have we seen how growing demand rapidly pushes prices on oil up. Normally, demand and supply finds a balance but with declining supply and increasing demand the world could face an uncontrollable situation unless alternative energy sources are developed fast.

Thus, the main objective is to introduce a sustainable Toyohashi city with green energy and smart technology to mitigate consequent fossil oil dependencies by developing alternative energy supplies and making sure that the energy is used efficiently. In our study electric vehicles are the main subject. Some might ask how the use of EVs will influence our climate if the electricity should come from burning gasoline and diesel. Actually, EVs will be the more environmentally friendly and alternative even if not charged with renewable energy such as wind or solar power. Another important aspect is that all the power plants are strongly regulated by the government of Japan. However, energy generation from the renewable sources will truly be significant for reducing emissions and resource circulation in the society. Toyohashi city is considered one of the most potential for generating the renewable sources of energies, especially wind and solar energies because of its location and weather. To the south of Toyohashi city is the Pacific Ocean, and the city opens onto Mikawa Bay in the west. Thus, there is always a strong tendency of the wind. Moreover, the climate of this area is relatively warm and sunny days are more frequent (see Figure 1) round the year.

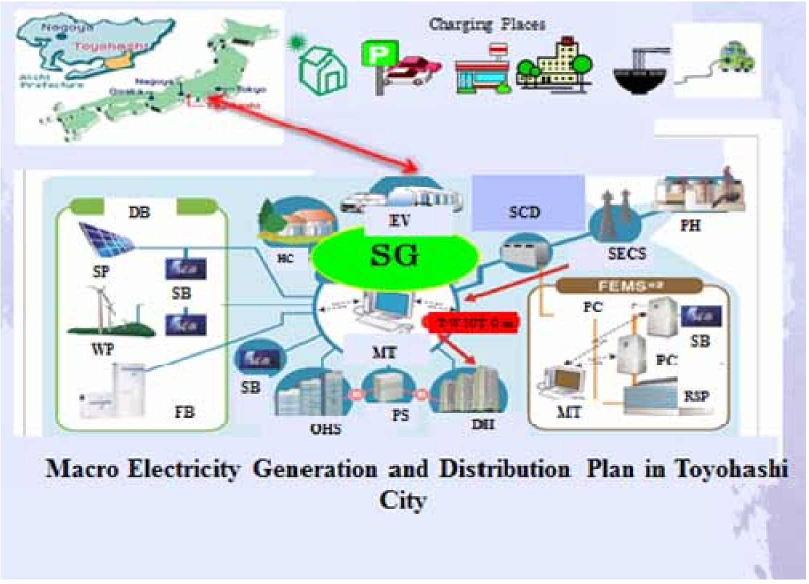

Figure 1. Sustainable Toyohashi City with Green Energy, and Smart Grid Technology

Note:

DB : Dispersion Battery, SP : Solar Power, WP : Wind Power, SB : Storage Battery, FB : Fuel Battery, HS : Home School, EV : Electric Vehicle, SG : Smart Grid, MT : Monitor, PS : Power Supply, SCD : System Cooperation Device, OHS : Office, Hospital, Shop, DH : Demand foe Heat, PC : Power Conditioner, RSP : Rooftop Sunlight Panel, SECS : System of Electricity in Commercial Sector, PH : Power House, PS : Power Supply.

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