A Computable General Equilibrium Analysis of Sustainable Toyohashi City with Green Energy and Smart Technology

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1. Introduction

Over the last few decades the negative impacts of transport depicting a growing concern for our environment (Van Wee[1]). Concomitant to this growing concern, industries are pushed to become more sustainable. With respect to the car industry, current dominant measures to reduce the demand for car usage have concerned assessments (Gärling and Loukopolos[2]), of how to reduce car use rather than reducing the environmental impact per car and consequently there exists no standard solution for sustainable car use (Morten Rask *et.al* [3]). Accordingly, as part of the growing awareness on sustainable development, changing the core technologies of cars as reflected in the emerging electric car appears to hold promises for more sustainable automobile usage. Such developments are in alignment with the general growing concern of the population as well as among policy makers. 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 though. In this study we apply a computable general equilibrium model which shows only the economic impact of spread of electric automobile.

2. The Model

2.1 Assumptions of the Model

Main assumptions made in our model are as follows:

(1) 2005 Toyohashi city's economy is examined. Economic agents are households, firms in 31 industries (agriculture, forestry, & fishery; mining; beverages and foods; textile; pulp, paper and wooden; chemical; petroleum and coal; plastics; ceramics; other ceramic, stone and clay; iron and steel; non-ferrous metals; metal products; general machinery; electrical machinery; information and communication electronics equipment; electronic components; automobile; aircraft; other transportation equipment; precision instruments; other manufactured; construction; electricity, gas and heat supply; water supply and waste disposal business; commerce; finance and insurance; real-estate; transport; information and communications; Services), the government and the external sector. (2) 33 markets are considered. They are 31 commodity markets, one labor market and one capital market. These are assumed to be perfectly competitive, and in equilibrium in 2005.

2.2 Industries

In industries intermediate input, labor and capital are invested to produce goods. Industries have *Leontief* technology with respect to intermediate input and value added inputs, and *Cobb-Douglas* technology for both intermediate inputs, and labor and capital inputs (see Figure 1). Due to homogeneity in production technology, industries' behavior becomes cost minimization under the given commodity demands and prices, which can be written as,

$$min \sum_{i=1}^{31} p_i x_{ij} + (1+tp_j)(wL_j + rK_j) \quad (j=1,\ldots,31) \tag{1}$$

with respect to X_{ij}, L_j and K_j

subject to

$$X_j = min\left[\frac{1}{a_{10j}} f_j(L_j, K_j), \frac{x_{1j}}{a_{1j}}, \ldots, \frac{x_{31j}}{a_{31j}}\right] \tag{2}$$

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

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 j

Cost minimization problem (1) to (3) yields conditional demands for intermediate goods, labor, and capital in production process.

$$X_{ij} = a_{ij} X_j \tag{4}$$

$$LD_j = \left[\frac{(1-\alpha_j)r}{\alpha_j w}\right]^{\alpha_j} \frac{a_{0j} X_j}{A_j} \tag{5}$$

$$KD_j = \left[\frac{a_j w}{(1-a_j)^r}\right]^{(1-a_j)} \frac{a_{0j} X_j}{A_j} \tag{6}$$

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.

$$profit = p_j X_j - \sum_{i=1}^{31} p_i x_{ij} - (1+tp_j)[w.LD_j + r.KD_j] = 0 \tag{7}$$

2.3 Households

Households in Toyohashi city are assumed to be homogeneous with the fixed number of households. 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, $p_I I = \sum_{i=1}^{31} p_i I_i$ is realized. Then the price of investment

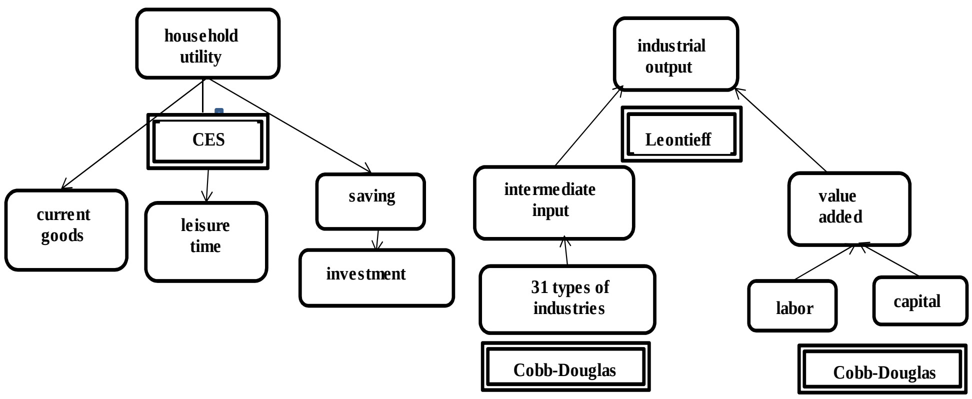

Figure 1. Hierarchical Structure of the Model

good is expressed as $p_I = \sum_{i=1}^{31} b_i p_i$. 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 $(1\text{-}ty)(1\text{-}k_O)(1\text{-}k_r)r\delta$, 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:

$$r_s = (1 - ty)(1 - k_r)r\delta / p_s \tag{8}$$

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 present consumption good under the myopic expectation, and denoting the household real saving by S, the following equation holds.

$$p \cdot H = (1 - ty)(1 - k_o)(1 - k_r)r\delta \cdot S \tag{9}$$

This yields $[p_S p/(1\text{-}ty)(1\text{-}k_O)(1\text{-}k_r)r\delta]H = p_S S$, and setting the price of future good p_H associated with the real saving S as;

$$p_H = p_s p /(1 - ty)(1 - k_o)(1 - k_r)r\delta \tag{10}$$

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.

$$\max_{G,H} \quad u(G,H) \equiv \{\alpha^{1/v_1} G^{(v_1-1)/v_1} + (1-\alpha)^{1/v_1} H^{(v_1-1)/v_1}\}^{v_1/(v_1-1)} \tag{11}$$

$$\text{subject to} \quad p_G \cdot G + p_H \cdot H = (1 - ty)FI - TrHO \tag{12}$$

$$FI \equiv (1 - l_o)w \cdot E + LI + (1 - k_o)(1 - k_r)r \cdot KS + KI + TrGH + TrOH \tag{13}$$

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 present and future goods are obtained yielding a household saving function.

$$G = \frac{\alpha[(1 - ty)FI - TrHO]}{p_G^{v_1} \cdot \Delta} \tag{14}$$

$$H = \frac{(1 - \alpha)[(1 - ty)FI - TrHO]}{p_H^{v_1} \cdot \Delta} \tag{15}$$

$$S = p_H H / p_s \tag{16}$$

$$\Delta \equiv \alpha p_G^{1-v_1} + (1-\alpha)p_H^{1-v_1} \tag{17}$$

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.

$$\max_{C,F} \ G \equiv \{\beta^{1/v_2} C^{(v_2-1)/v_2} + (1-\beta)^{1/v_2} F^{(v_2-1)/v_2}\}^{v_2/(v_2-1)} \tag{18}$$

$$\begin{aligned} & subject \ to \\ & p \cdot C + (1-ty)(1-l_o) w \cdot F = (1-ty)FI - TrHO - SH \end{aligned} \tag{19}$$

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.

$$C = \frac{\beta[(1-ty)FI - TrHO - SH]}{p^{v_2} \cdot \Omega} \tag{20}$$

$$F = \frac{(1-\beta)[(1-ty)FI - TrHO - SH]}{[(1-ty)(1-l_o)w]^{v_2} \cdot \Omega} \tag{21}$$

$$LS = E - F \tag{22}$$

$$\Omega = \beta p^{(1-v_2)} + (1-\beta)[(1-ty)(1-l_o)w]^{(1-v_2)} \tag{23}$$

where LS : household labor supply

Substituting composite consumption (20) and leisure time (21) into (18), the price index of the present good is derived as follows:

$$p_G = \{\beta \ p^{1-v_2} + (1-\beta)[(1-ty)(1-l_o)w]^{1-v_2}\}^{1/(v_2-1)} \tag{24}$$

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.

$$\max \quad C \equiv \prod_{i=1}^{31} C_i^{\gamma_i} \qquad (\sum_{i=1}^{8} \gamma_i = 1) \tag{25}$$

subject to

$$\sum_{i=1}^{31} p_i \cdot C_i = (1-ty)Y - TrHO - SH \tag{26}$$

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.

$$C_i = \frac{\gamma_i}{p_i}[(1-ty)Y - TrHO - SH] \qquad (i = 1,\cdots,31) \tag{27}$$

The price of composite consumption is calculated as follows:

$$p = \prod_{i=1}^{31} \left[\frac{p_i}{\gamma_i}\right]^{\gamma_i} \tag{28}$$

2.4 The Government

The government obtains its income from the following balance of payments.

$$\sum_{i=1}^{31} p_i \cdot CG_i + TrGH + TrGO + SG = ty \cdot Y + \sum_{i=1}^{31} tp_i(w \cdot LD_i + r \cdot KD_i) + TrOG \tag{29}$$

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

2.5 The External Sector

The external sector gains its income from the following balance of payments.

$$\sum_{i=1}^{31} p_i \cdot EX_i + TrOH + TrOG + KI + LI + SO = \sum_{i=1}^{31} p_i \cdot EM_i + TrHO + TrGO + KIO + LIO \qquad (30)$$

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 (= $k_0 \cdot r \cdot KS$)

2.6 Balance of Investment and Saving

Household, government, area department`s savings, the total consumption of fixed capital, which determines the total investment.

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

where

I_i : demand for commodity i by other investments, DR_i: consumption of fixed capital amount of industry i

2.7 Prices

Cost consists of the following is derived from the Zero profit condition of the industry.

$$p_j X_j = \sum_{i=1}^{31} p_i x_{ij} + (1 + tp_j)[w \cdot LD_j + r \cdot KD_j] \quad (j = 1,\ldots, 31) \qquad (32)$$

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

$$P = (I - A')^{-1}[(1 + tp_j)(w.ld_j + r \cdot kd_j)] \qquad (33)$$

where

P : vector of commodity prices, A': transposed matrix of industries' input coefficients, [・]：column vector whose elements are in parentheses $ld_j \equiv LD_j / X_j$ and $kd_j \equiv KD_j / X_j$

2.8 Derivation of Equilibrium

In this model there are 31 industries, and 33 markets including labor and capital markets. The equilibrium condition in the model can be summarized as follows

Commodity market

$$\begin{bmatrix} X_1 \\ \vdots \\ X_{31} \end{bmatrix} = \begin{bmatrix} a_{11} & \cdots & a_{131} \\ \vdots & \ddots & \vdots \\ a_{311} & \cdots & a_{3131} \end{bmatrix} \begin{bmatrix} X_1 \\ \vdots \\ X_{31} \end{bmatrix} + \begin{bmatrix} C_1 \\ \vdots \\ C_{31} \end{bmatrix} + \begin{bmatrix} CG_1 \\ \vdots \\ CG_{31} \end{bmatrix} + \begin{bmatrix} I_1 \\ \vdots \\ I_{31} \end{bmatrix} + \begin{bmatrix} EX_I \\ \vdots \\ EX_{31} \end{bmatrix} - \begin{bmatrix} EM_I \\ \vdots \\ EM_{31} \end{bmatrix} \qquad (34)$$

Labor market

$$LS = \sum_{j=1}^{31} LD_j \qquad (35)$$

Capital rental market

$$KS = \sum_{j=1}^{31} KD_j \qquad (36)$$

To solve all the endogenous variables of the study, it requires a model of all formulas, expression alone is insufficient to balance. Walras law in this study is, Total value of excess demand for labor - Total value of the excess demand of capital = *0*. In numerical computation, iteration for the equilibrium prices is made on the capital return rate letting labor be the numeraire (*w=1*).

3. Simulation Results and Concluding Remarks

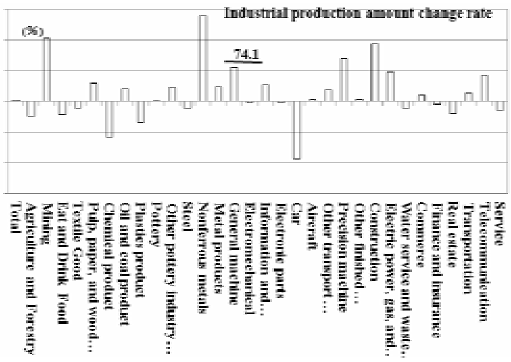

Figure 2. Change rate of industrial Production

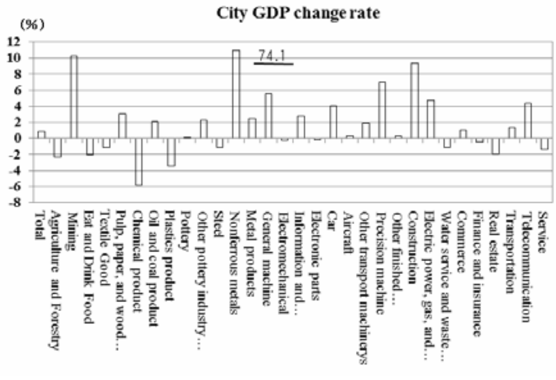

Figure 3. Change rate of city GDP

In this study, we have developed a computable general equilibrium (CGE) model to investigate the economic repercussions of electric vehicle production in Toyohashi city in Japan. The simulation are conducted for two cases: (1) business as usual (base case) and (2) 100 % production of electric vehicles in the automobile industry (case 1). The results have demonstrated that after launching electric vehicles, the total industrial output only slightly grows but GDP of the automobile sector increases by 4.1%. The reason is attributed to the fact that the number of parts is reduced in electric vehicle manufacturing resulting in a higher value added rate. This should be highlighted in this study. Moreover the labor demand goes up as well implying a contribution to the current imbalance in Japan's labor market. However there is no concept of unemployment in this CGE modeling, so an increase in labor demand reduces the household leisure time leading to welfare loss. For Toyohashi city, it should focus on a new industrial structure to cope with a change of production system. Particularly it is necessary to promote industries such as non-ferrous metal manufacturing where a large economic impact appears and to attempt to incorporate such impact into Toyohashi city's economy.

This research has just started from a starting line, thus there will be many points worth investigating in the future. Particularly the estimation of city's data is prior to other points. Usually a CGE model heavily depends on an input-output (IO) table. This study estimated Toyohashi city's IO table, but the estimated IO table shows an inconsistency a little. Therefore more precise estimation might be necessary. Finally this paper is focusing on the production process of electric vehicles, however, socio-economic impacts of spread of electric vehicles seems to be more important than production. Spread of electric vehicles with green energy and smart grid would greatly reduce the carbon dioxide emissions, demand of fossil fuel, and finally, will bring a sustainable Toyohashi City with resources circulation in our society.

References

(1) Van Wee, Bert (2007), *Environmental Effects of urban Traffic*. In: Threats from car traffic to the quality of urban life problems, causes, and solutions. Gärling & Steg ed. 11-32. Elsevier.

(2) Gärling & Loukopolos (2007), *Effectiveness, Public Acceptance, and political Feasibility of Coercive Measures for Reducing car Traffic*. In: Threats from car traffic to the quality of urban life problems, causes, and solutions. Gärling & Steg ed., 313-324. Elsevier.

(3) Morten Rask, Poul Houman Andersen, Mai Skjøtt Linneberg & Poul Rind Christensen Local Design & Global Dreams – Emerging Business Models creating the Emergent Electric Vehicle Industry, Aarhus School of Business, Aarhus University, Denmark