ESTIMATING MARGINAL ABATEMENT COSTS BY SECTOR BY A MULTI-SECTORAL CGE MODEL: THE PRELIMINARY STUDY FOR INTRODUCING SECTORAL EMISSION REDUCTION TARGET TO TRANSPORT SECTOR

by Atit TIPPICHAI**, Atsushi FUKUDA*** and Hisayoshi MORISUGI****

1. Introduction

This paper aims to describe estimation of marginal abatement cost (MAC) by sector in a computable general equilibrium (CGE) context through a simple multi-sectoral CGE model as a case study. The model structure and algebra of equilibrium with the constraint of carbon tax which is introduced into the model in order to estimate associated emission reductions by sector are illustrated. Moreover, we discuss utilization of MAC curves by sector to analyze impacts of introducing sectotal emission reduction target in transport sector in this paper as well.

2. Model Description

(1) Model structure

In this model, there are four sectors that produce four single goods; two energy (x_1 and x_2) and two non-energy (x_3 and x_4) goods. Production factors include capital (K) and labor (L) endowed by household. Technology of productions and preference of household consumption are illustrated with elasticity of substitution parameters as shown in Figure 1.

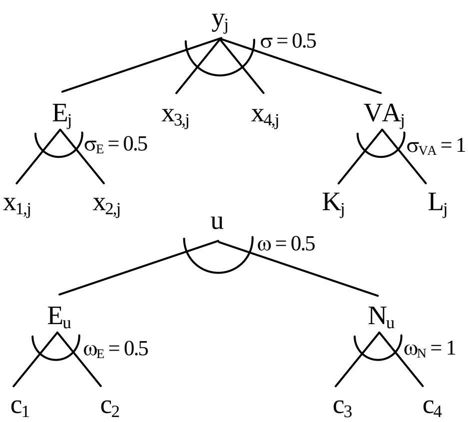

Figure 1: The structure of production and consumption

Industry sectors produce goods by inputting intermediate goods and factors under the production cost minimization. Industries determine input volume of composite of energy goods (E_j), each non-energy goods, and composite of value-added (VA_j) at the first level. Then, at the second level, they decide on input volume of each energy goods and each factor. On the other hand, household chooses produced goods under the income constraint. First, household decides consumption level of composite energy goods (E_u) and composite non-energy goods (N_u), and then decide consumption level of each goods.

(2) Equilibrium conditions with carbon tax constraint

In equilibrium, there are three conditions[1)]; (a) zero profit, i.e. price of goods equals to unit cost, (b) market clearance, i.e. supply of each sector equals to total demand by sectors and household, and (c) income balance, i.e. income equals to endowment of factors and carbon tax revenue. Carbon emissions by sector can be calculated through intermediate inputs of energy goods.

a) Zero profit

$$p_j = \left\{ \alpha_{E,j}\left[\sum_e \alpha_{e,j}\left(p_e + \tau^{CO_2}\phi_e\right)^{1-\sigma_E}\right]^{\frac{1-\sigma}{1-\sigma_E}} + \sum_n \alpha_{n,j} p_n^{1-\sigma} + a_{VA,j}\left[\frac{1}{\beta_{VA,j}}\left(\frac{p_K}{\alpha_{K,j}}\right)^{\alpha_{K,j}}\left(\frac{p_L}{\alpha_{L,j}}\right)^{\alpha_{L,j}}\right]^{1-\sigma}\right\}^{\frac{1}{1-\sigma}} \quad (1)$$

$$\theta = \left\{ \delta_E\left[\sum_e \delta_e\left(p_e + \tau^{CO_2}\phi_e\right)^{1-\omega_E}\right]^{\frac{1-\omega}{1-\omega_E}} + \delta_N\left[\frac{1}{\gamma_N}\prod_n\left(\frac{p_n}{\delta_n}\right)^{\delta_n}\right]^{1-\omega}\right\}^{\frac{1}{1-\omega}} \quad (2)$$

b) Market clearance

$$y_e = \sum_{j=1}^{4}\frac{\alpha_{e,j}\alpha_{E,j}p_j^{\sigma}}{p_e^{\sigma_E}}\left[\sum_e \alpha_{e,j}\left(p_e + \tau^{CO_2}\phi_e\right)^{1-\sigma_E}\right]^{\frac{\sigma_E-\sigma}{1-\sigma_E}} y_j + \frac{\delta_e\delta_E\theta^{\omega}}{p_e^{\omega_E}}\left[\sum_e \delta_e\left(p_e + \tau^{CO_2}\phi_e\right)^{1-\omega_E}\right]^{\frac{\omega_E-\omega}{1-\omega_E}} u \quad (3)$$

$$y_n = \sum_{j=1}^{4}\frac{\alpha_{n,j}p_j^{\sigma}}{p_n^{\sigma}} y_j + \frac{\delta_n\delta_N\theta^{\omega}}{p_n}\left[\frac{1}{\gamma_N}\prod_n\left(\frac{p_n}{\delta_n}\right)^{\delta_n}\right]^{1-\omega} u \quad (4)$$

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** Student Member of JSCE, M. Sc., Graduate School of Science and Technology, Nihon University
(739C 7-24-1 Narashinodai, Funabashi, Chiba, Japan, TEL/FAX 047-469-5355, E-mail: csat07002@g.nihon-u.ac.jp)
*** Member of JSCE, Dr. Eng., Department of Transportation Engineering and Socio-Technology, College of Science and Technology, Nihon University
(7-24-1 Narashinodai, Funabashi, Chiba, Japan, TEL/FAX 047-469-5355, E-mail: fukuda@trpt.cst.nihon-u.ac.jp)
**** Member of JSCE, Dr. Eng., Advanced Research Institute for the Sciences and Humanities, Nihon University
(7-24-1 Narashinodai, Funabashi, Chiba, Japan, TEL/FAX 047-469-5355, E-mail: morisugi.hisayoshi@nihon-u.ac.jp)

$$K = \sum_{j=1}^{4} \frac{\alpha_{VA,j}}{\beta_{VA,j}} \left(\frac{\alpha_{K,j} p_L}{\alpha_{L,j} p_K} \right)^{\alpha_{L,j}} y_j \tag{5}$$

$$L = \sum_{j=1}^{4} \frac{\alpha_{VA,j}}{\beta_{VA,j}} \left(\frac{\alpha_{L,j} p_K}{\alpha_{K,j} p_L} \right)^{\alpha_{K,j}} y_j \tag{6}$$

$$u = \frac{M}{\theta} \tag{7}$$

c) Income balance

$$M = p_K K + p_L L + \tau^{CO_2} Q^{CO_2} \tag{8}$$

d) Total and sectoral emissions

$$Q^{CO_2} = \sum_e \phi_e y_e \tag{9}$$

$$Q_j^{CO_2} = \sum_e \phi_e x_{e,j} \tag{10}$$

$$Q_c^{CO_2} = \sum_e \phi_e c_e \tag{11}$$

3. Data and Results

To validate the model, we employed the assumed benchmark data of the National Institute for Environmental Studies, Japan[2] as shown in Table 1. Based on the data, all parameters of the model equations can be calculated. Coefficients of carbon emission are also assumed as 0.5 for goods x1 and 0.2 for goods x2. To generate the MAC curves, we introduce carbon tax and vary the relative prices of carbon from 0 (base case) up to 2 by the interval of 0.5. Then, we can get the coordinates of the carbon taxes and associated emission reductions which can be plotted as the MAC curve by sector as shown in Figure 2.

Table 1: Benchmark accounting data

Goods \ Sectors		Energy (e)		Non-energy (n)		u	Total
		1	2	3	4		
Energy (e)	1	10	20	30	10	50	120
	2	30	30	10	20	40	130
Non-energy (n)	3	20	10	10	40	60	140
	4	30	30	20	20	50	150
K		10	20	30	30		90
L		20	20	40	30		110
Total		120	130	140	150	200	

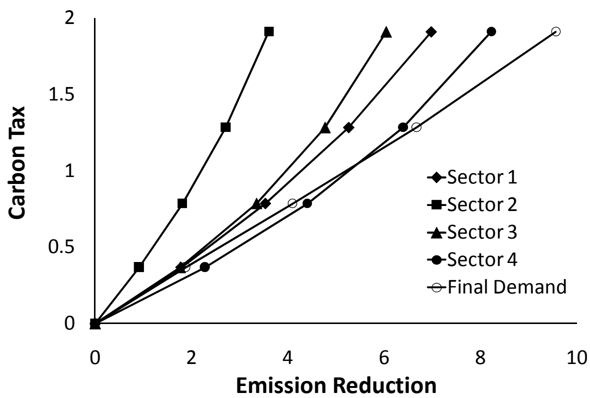

Figure 2: Sectoral MAC curves

4. Conceptual Idea to Analyze Impacts of Sectoral Emission Reduction Target by Using Sectoral MAC Curves

A sectoral approach by imposing the sectoral emission reduction target for transport sector to Annex-I countries additionally to the national targets of the Kyoto Protocol is introduced. Therefore, the sectoral MAC curves by country can be utilized in order to determine optimal emission reduction in each country that minimizes total abatement cost as shown in Figure 3. Then, we can know the optimal emission amounts which countries should reduce in their own countries and how much they should purchase emission permit from other countries.

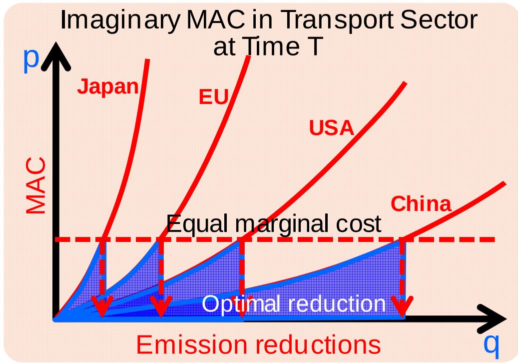

Figure 3: Imaginary Sectoral MAC curves by country

5. Conclusion and Further Works

This paper describes the estimation of marginal abatement costs by sector and theoretically shows how to generate sectoral MAC curves by using a simple CGE model. Cost of emission reduction depends on volume of energy goods inputs and ability of substituting to other non-energy goods. Further research will apply the mentioned concept to the real world and analyze the impacts of sectoral emission reduction targets in transport sector by using the sectoral MAC curves.

Appendix: List of variables and parameters

y_j	output of sector *j*	α, β	parameter of production
$x_{i,j}$	input of goods *i* by sector *j*	u	utility of consumption
K_j	input of capital by sector *j*	c_i	consumption of goods *i*
L_j	input of labor by sector *j*	δ, γ	parameter of consumption
σ, ω	elasticity of substitution	M	income level
φ	emission coefficient	θ	unit expenditure index

References

1) Sue Wing, I.: Computable General Equilibrium Models for the Analysis of Energy and Climate Policies, International Handbook of Energy Economics (forthcoming).

2) Masui, T.: Introduction of AIM/CGE Training Workshop, National Institution for Environmental Studies, Tsukuba, Japan, 20-24 October 2008.