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Economy-wide Model of Rebound Effect for Environmental Efficiency

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1. Introduction

Rebound effects for environmental efficiency mean that improvements for the efficiency cause unintentional reactions and reduce the effects of those improvements. Many papers on rebound effects have been published in the research field of energy economics since 80's. Kazzoom(1980) stimulated researchers and generated many papers (e.g. Lovins 1988, Greeene 1992, 1999, Shipper 2000, Binswanger 2001, Jalas 2002, Hofstetter 2003). Empirical studies were also accumulated. The summary by Greening(2000) pointed out an interesting features that empirical works had been concentrated on the subjects for partial equilibrium, which means that they targeted one or a few goods or services. Greening(2000)'s summary picked up over 74 papers. However, only one paper (Kydes 1992) used economy-wide model for analysis of the rebound effects. Besides that, Although Saunders(1992) discussed about the rebound effects within the framework of the macroscopic neoclassical growth theory, there existed no prices and could not capture the economy-wide interrelations.

This paper presents the estimation of the rebound effects of Japanese economy with the applied general equilibrium model for the appraisal of environmental policies (hereinafter, we call it EPAM). EPAM disaggregate the economy into 33 industrial sectors inclusive of energy sectors (Coal products, Oil products, Electricity and Gas supply). EPAM can simulate the impact of the improvements of energy efficiencies on the total CO2 emission of Japanese economy. We will show the rebound effects depend upon the elasticity of substitution in industrial technology and in consumer's utility functions and the size of rebound effects are estimated 35% to 70%.

The structure of this paper is as follows. The second section describes the framework of EPAM. The third section includes the theoretical contents. The fourth section describes the simulations and the results. The sixth section is the conclusion.

2. Structure of EPAM

The features of EPAM are summarized as follows.

(1) EPAM is an applied general equilibrium model targeted Japanese economy.

(2) The dataset was created based upon the 1995 Input-Output Tables and will be updated to that of the year 2000 version after the publication (may be Spring, 2004).

(3) EPAM can simulate the influences of the improvement energy efficiency and the

imposition of tax on CO_2 emission.

(4) Industries are disaggregated into 33 sectors that include the sectors of energy production, (Coal products, Oil products, Electricity and Gas supply).

(5) Trade balance is adjusted by exchange rate, which is included in the equilibrium prices.

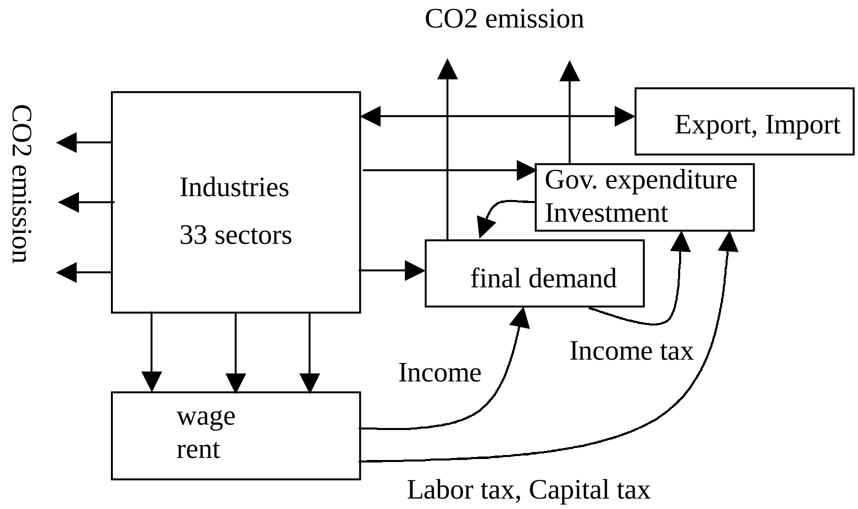
(6) Every substitutable production function and utility function is quasi-separable and a type of CES functions.

(7) Equilibrium prices are calculated by Merrill's fixed-point algorithm.

(8) Depend upon Hicks's equivalent variation calculated for each simulation, we can evaluate the welfare change due to the policy.

(9) CO_2 emission factors for products are calculated. Using them, gross CO_2 emissions are imputed to each category of final demands.

The Following figure shows the basic structure of EPAM.



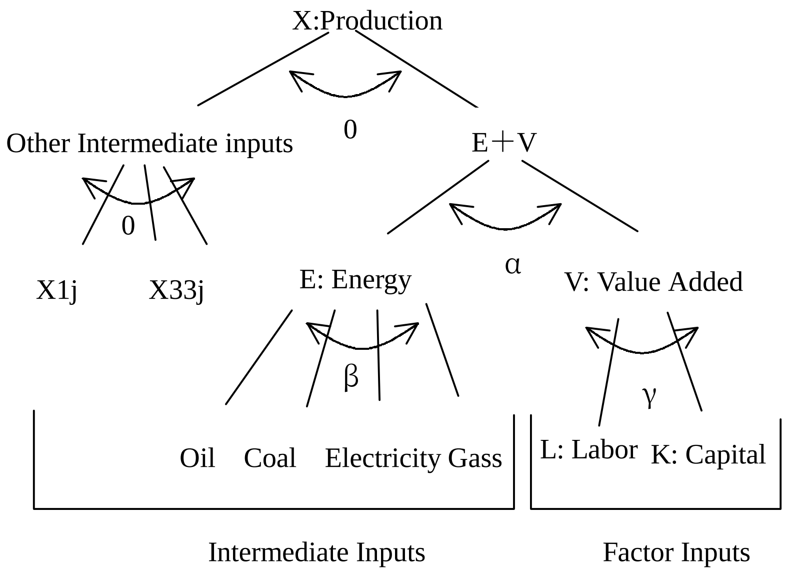
EPAM includes following sectors.

1.Agriculture and Fishery	12.Electric Machinery	23.Public Service
2.Mining	13.Transport Machinery	24.Education and Research
3.Food Products	14.Precision Instrument	25.Medicine, Health Care and Social Insurance
4.Apparel	15.Other Industrial Products	26.Other Public Services
5.Pulp, Paper, Wood Products	16.Construction	27.Services for Industries
6.Chemical Products	17.Water Supply and Wastes Material Processing	28.Services for Individual
7.Ceramics, Soil and Stone Products	18.Comerce	29.Unclassified
8.Steal	19.Finance and Insurance	30.Oil Products
9.Nonsteal Metal	20.Real Estate	31.Coal Products
	21.Transport	32.Electricity

3. Theoretical Framework

For understanding of EPAM, mathematical explanations are inevitable.

(1) Production functions and Coefficients



Structure of production functions is shown in the figure. Greek letters and number in arrows are the values of elasticity substitution. The elasticity of substitution between intermediate inputs and the compound factor of total value added and total energy input is zero. This relationship can be expressed as follows.

$$X_j = min\left\{\frac{V_j^e}{a_{0j}}, \frac{X_{1j}}{a_{1j}}, \cdots \frac{X_{29,j}}{a_{29,j}}\right\} \quad (j = 1,2,\cdots,33),$$

where $a_{0j}, a_{1j}, \cdots, a_{29,j}$ are constant. X_j's are real output for *j*th industry. If we assume the quasi separability, the compound factor V_j^e's are produced by the real net value added V_j^f and the compound energy input E_j^H. The relationship can be expressed by the following CES type of production function.

$$V_j^e = \Phi_j \left\{\alpha_j (V_j^f)^{\frac{\sigma_j - 1}{\sigma_j}} + (1-\alpha_j)(\varepsilon_j E_j^H)^{\frac{\sigma_j - 1}{\sigma_j}}\right\}^{\frac{\sigma_j}{\sigma_j - 1}} \quad (j = 1,2,\cdots,33),$$

where Φ_j is a scale parameter α_j is share a parameter, σ_j is an elasticity of substitution and ε_j efficiency parameter. V_j^f's are produced by Labor and Capital as follows.

$$V_j^f = \theta_j \left\{\beta_j K_j^{\frac{\rho_j - 1}{\rho_j}} + (1-\beta_j) L_j^{\frac{\rho_j - 1}{\rho_j}}\right\}^{\frac{\rho_j}{\rho_j - 1}} \quad (j = 1,2,\cdots,33),$$

where θ_j is a scale parameter, β_j is a share parameter and ρ_j is an elasticity of substitution. The production function for E_j^H is as follows.

$$E_j^H = \pi_j \left\{ \sum_{i=1}^{4} \gamma_{ij} E_{ij}^{\frac{\mu_j - 1}{\mu_j}} \right\}^{\frac{\mu_j}{\mu_j - 1}} \quad (j = 1,2,\cdots,33)$$

π_j is a scale parameter, γ_{ij} is a share parameter which makes $\sum_{i=1}^{4} \gamma_{ij} = 1$, μ_j is an elasticity of substitution. $E_{1j}, E_{2j}, E_{3j}, E_{4j}$ denote oil products, coal products, electricity and gasses respectively.

Since all those functions are homogeneous of degree one, the optimal behavior of the firm is to minimize the total production cost subject to those production functions. Then we have the production coefficients as the function of relative prices.

$$\frac{E_{ij}}{E_j^H} = e_{ij}(P_1^e, P_2^e, P_3^e, P_4^e) \quad (i = 1,\cdots,4;\ j = 1,2,\cdots,33)$$

$$\frac{L_j}{V_j^f} = v_{fj}^l(r,w) \quad (j = 1,2,\cdots,33)$$

$$\frac{K_j}{V_j^f} = v_{fj}^k(r,w) \quad (j = 1,2,\cdots,33)$$

$$\frac{V_j^f}{V_j^e} = v_{ej}^f(P_j^{eH}, P_{vj}^f) \quad (j = 1,2,\cdots,33)$$

$$\frac{E_j^H}{V_j^e} = v_{ej}^e(P_j^{eH}, P_{vj}^f) \quad (j = 1,2,\cdots,33)$$

where $P_1^e, P_2^e, P_3^e, P_4^e$ are energy prices, r, w are capital rent and wage rate respectively, and the compound price P_j^{eH}, P_{vj}^f are defined as follows.

$$P_j^{eH} = (P_1^e + \tau^e h_j^m)e_{1j} + P_2^e e_{2j} + P_3^e e_{3j} + P_4^e e_{4j} \quad (j = 1,2,\cdots,33)$$

$$P_{vj}^f = (1 + \tau_j^o)\left\{(1 + \tau_j^l) w v_{fj}^l + (1 + \tau^k) r v_{fj}^k\right\} \quad (j = 1,2,\cdots,33)$$

where h_j^m is the coefficient of CO2 emission caused by the usage of import energy materials in jth industry. $\tau^e, \tau^k, \tau_j^o, \tau_j^l$ are the tax rate for CO2 emission, capital, products and labor respectively.

(2) Behavior of Household

We assume that there exists one representative consumer who takes charge of the final consumption demand. The income I of the consumer is expressed as follows.

$$I = \left\{(w\overline{L} + r\overline{K})(1 - \tau^y - \tau^t)\right\}(1 - s) + B - \tau^e H_C^R$$

where $\overline{L}$ and $\overline{K}$ denote the amount of labor and capital supplied by the household. τ^y and τ^t are the income tax and the payment for social insurance respectively. s is the rate of saving, and is assumed to be constant. B is the transfer from Government.

Let assume the quasi separability of utility function and specify the following layered utility functions.

$$U=\left\{\varphi_m C^{\frac{\zeta_m-1}{\zeta_m}}+(1-\varphi_m)(\varepsilon_c E_c)^{\frac{\zeta_m-1}{\zeta_m}}\right\}^{\frac{\zeta_m}{\zeta_m-1}}$$

$$E_c=\left(\sum_{i=1}^{4}\varphi_{ei}E_{ic}^{\frac{\zeta_e-1}{\zeta_e}}\right)^{\frac{\zeta_e}{\zeta_e-1}}$$

$$C=\left(\sum_{i=1}^{29}\varphi_{ci}C_i^{\frac{\zeta_c-1}{\zeta_c}}\right)^{\frac{\zeta_c}{\zeta_c-1}}$$

where E_c and C are compound energy goods and compound ordinary consumer goods. The household maximizes the utility subject to the budget constraint. Then the demand functions for those goods are given by relative prices.

For compound goods E_c and C, under the budget constraint $I=P_c^e E_c+P_c C$ demand functions are given as follows (Prices for compound goods are given later).

$$E_c=E_c(P_c,P_c^e)$$
$$C=C(P_c,P_c^e)$$

For each commodity, the budget constraint is,

$$P_c C=\sum_{i=1}^{29}P_i C_i$$

$$P_c^e E_c=(P_1^e+\tau^e h_c^m)E_{1c}+\sum_{i=2}^{4}P_i^e E_{ic},$$

where h_c^m is the coefficient for the CO2 emission by using imported goods. Then we have the demand functions.

$$C_j=C_j(P_1,P_2,\cdots,P_{29},P_c C)\quad (j=1,2,\cdots,29)$$
$$E_{jc}=E_{jc}(P_1^e,P_2^e,P_3^e,P_4^e,P_c^e E_c)\qquad (j=1,2,3,4)$$

P_c^e and P_c are given by the following equations.

$$P_c^e=\left(\varphi_{c1}^{\zeta_c}(P_1^e+\tau^e h_c^m)^{1-\zeta_e}+\sum_{i=2}^{4}\varphi_{ei}^{\zeta_e}(P_i^e)^{1-\zeta_e}\right)^{\frac{1}{1-\zeta_c}}$$

$$P_c=\left(\sum_{i=1}^{29}\varphi_{ci}^{\zeta_c}P_i^{1-\zeta_c}\right)^{\frac{1}{1-\zeta_c}}$$

Since it may difficult to understand how the actual consumption demand is given, some explanations have to be useful. First, given the prices of ordinary goods and energy goods, then the above two equation give the priced for compound goods. Second, given the income for this household, the consumption demand for compound goods is determined. Finally, the demand for each commodity is given.

(3) Government Expenditure and Investment Demand

It is not appropriate to describe those expenditures in detail. Therefore, it is one of rational choices to treat them at a fixed proportion. However, if we assume it, we would have only one subject to react to priced. The multi-dimensional response should play an important role from the viewpoint of total performance of the mode. Thus we have introduced the quasi consumer who act and decide this part of expenditure subject to the sum of Government expenditure and Investment expenditure. The revenue comes from savings and taxation. Let denote the total revenue G. A part of it is transferred as social insurance for the household. This part is denoted as B. The ratio for G is fixed as b, i.e. $bG = B$. The rest of it is used for the expenditure. Since the specifications are mostly equivalent to that of genuine consumer, we do not give them hear.

(4) Export and Import

Goods for export and import are assumed to have same quality and to be substitutable perfectly. Export and import functions specified in Boadway and Treddennicck (1978) is adopted as follows.

$$F_j = \psi_j^f \left(\frac{P_j}{\chi} \right)^{\xi^f} \qquad (j = 1, 2, \cdots, 33)$$

$$M_j = \psi_j^m \left(\frac{P_j}{\chi} \right)^{\xi^m} \qquad (j = 1, 2, \cdots, 33)$$

where F_j and M_j are real export and real import of jth goods, ψ_j^f and ψ_j^m are scale parameters, ξ^f and ξ^m are elasticity for export and import., and χ is a exchange rate. For simplicity, we denote prices as $P_{i+29} = P_i^e \quad (i = 1, 2, 3, 4)$. We do not introduce any import tax.

4. Simulation and Results

Let us show four simulations where energy efficiencies for production and consumption are improved 1%. In the following table, ε, ε_c and ε_g show the efficiency factors for

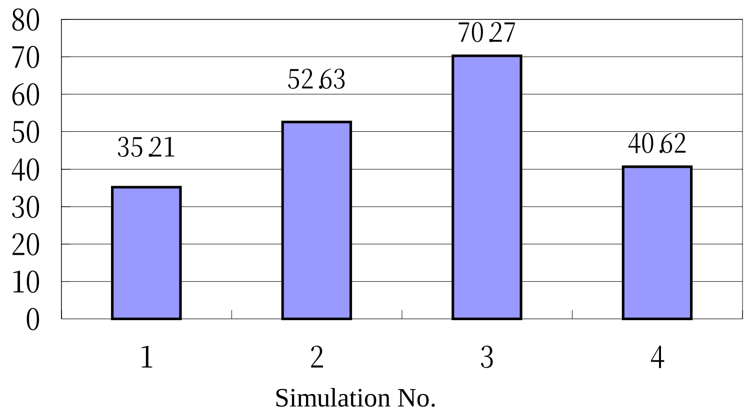
No.	ε	ε_c	ε_g	σ	ρ	μ	ζ_m	ζ_c	ζ_e	CO2Reduction (%)	Rebound Effect (%)
1	1.01	1.01	1.01	0.3	0.3	0.3	0.7	0.5	0.7	0.6479	35.21
2	1.01	1.01	1.01	0.5	0.5	0.5	0.7	0.5	0.7	0.4737	52.63
3	1.01	1.01	1.01	0.7	0.7	0.5	0.7	0.5	0.7	0.2973	70.27
4	1.01	1.01	1.01	0.5	0.5	0.5	0.3	0.3	0.3	0.5938	40.62

production, consumption, and Government Expenditure and Investment respectively. The number 1.01 means that 1% improvement. σ, ρ, and μ are the elasticity parameters for production that have been shown in the production functions. ζ_m, ζ_c, and ζ_e are the elasticity parameters for consumption. The parameters in the area Embraced by double line are changed. CO2 reductions caused by the improvement of efficiency vary over the change of elasticity. The rate of rebound is defined as follows.

Rate of rebound = Improvement rate of efficiency – Reduction rate of CO2

The result is shown in the last column of the table and is graphically shown in the following figure.

Rate of Rebound Effect(%)



The result tells us two important facts. First, the rebound effect measured by the economy-wide model has significant sizes. It shows that the size is 35$ to 70%. If we compare this result with the summary of Greening (200), this feature is confirmed clearer.

Economic actor	End use	Potential size of rebound	Number of Studies
Consumer	Space heating	10-30%	26
	Space cooling	0-50%	9
	Water heating	<10-40%	5
	Residential lighting	5-12%	4
	Automotive transport	10-30%	22
Firm	Process use	0-20%	1
	Lighting	0-2%	4

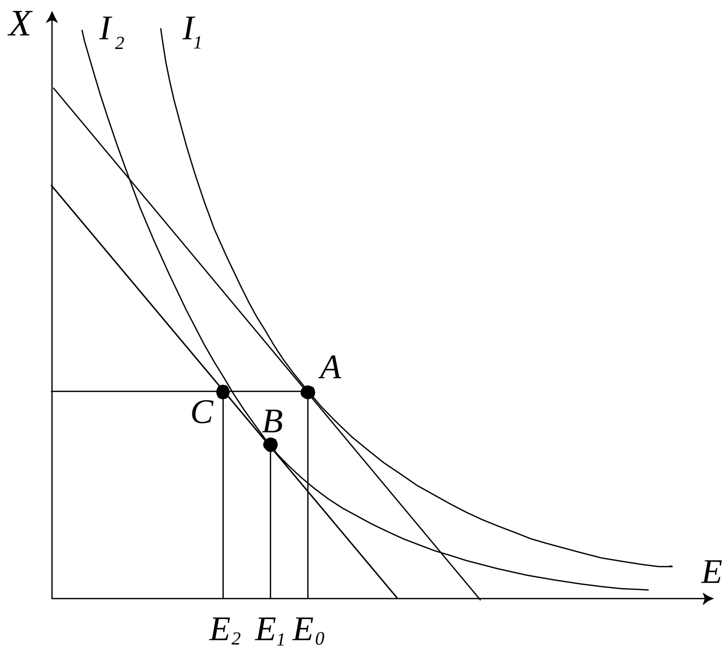
	Long run aggregate impact	<100-0%	
Economy Wide	Change in total output growth	0.48%(?)	1

The average is thought to be around 30%.

Second, the result also shows that it depends heavily upon the elasticity of substitution. The size of rebound effect increases with the increase of elasticity in production. Furthermore this tendency can be confirmed in the consumption as shown in the result of simulation 4.

As Shoven and Whalley (1992) pointed out, estimated values of elasticity are unstable and quite sensitive on data or methods. Although we have to consider this insight, it is worthwhile to examine some examples. The average of the elasticity estimated by Piggott and Whalley (1995) for ENgland, which is summarized in Shoven and Whalley (1992), is 0.821. If we employ this estimation, the size of rebound effect has to be over 70%. On the other hand, the estimation by Tokutsu (1992) for Japanese is 0.35 to 0.43. Then the size of the rebound effect may be about 35% to 40%.

The reason why the rebound effect depends upon the elasticity is described as follows. Let us see the following figure.



The horizontal axis shows the input of energy, and the vertical axis shows the input of the other goods or factors. The improvement of energy efficiency shifts the isoquant to the left. In the case of fixed coefficient production technology, i.e. Leontief types of technology, the elasticity of substitution is zero, and the improvement fully caused the reduction of energy input. This means in that figure, the point of the cost minimization shifts to the left paralleled with the horizontal axis. However, if the rate of elasticity is large, as the improvement of efficiency and the shift of isoquant, the point of cost minimization is to be B in the figure. The reduction of energy input is substituted by the reduction of the other goods or factors.

5. Concluding Remarks

We constructed a compact model of applied general equilibrium analysis for Japanese economy. The simulation results show the size of rebound effect is significant. This means that if we neglect the rebound effect, environmental policies are distorted.

For example, Japanese government pledged the 6% reduction of global warming gasses (e.g. CO2) compared with the emission level of 1990 in the Kyoto convention for global warming. However, the emission increased in 8% compared with the level of 1990. Therefore, the introduction of the emission tax for CO2 is a controversial issue in Japan. People who opposed introduction of the tax insist that the most important way to reduction of CO2 emission is not those types of regulations, but the voluntary actions. However, they do not pay attention to the rebound effect caused by those actions. On the other hand, people who insist the introduction the tax depend upon a special model that heavily depends upon the improvement of technology and say that the low level of taxation is sufficient for reduction of CO2 emission.

Hereafter, inducing voluntary actions and economic methods for environmental policies compared with traditional regulations become increasingly important. Then, the consideration for rebound effect also become increasingly important. However, researches and attentions for economy-wide rebound effect is quite insufficient. We are required to develop a variety of models to estimate the size of this type of rebound effects.

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