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Welfare Consequence of Internalizing Envirnmental Costs in an Open Economy

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Foreword

During the last three decades, the paramount concern of Korean government was an economic development through growth. And, having achieved its current economic status, Korea is faced with a new set of challenges involving public demand for clean air and safe water and the world's consciousness for global preservation. These factors have, in turn, advanced international environmental issue as a major international cooperative issue requiring active reciprocity. Followingly, Korea has reached a juncture at which its economic agenda needs to be adjusted to a long-term plan for sustainable developement.

We at the Korea Environmental Technology Research Institute have endeavored to devolope environmental policies that would effectively promote sustainable development. This research paper 「Welfare Consequences of Internalizing Environmental Costs in an Open Economy」 is written as a part of this purpose. This paper deals with the effect of environmental investment on macro-economic variables such as welfare, GNP, export, grouwth rate etc and suggest efficient environmental investment policy on the basis of the results obtained through two-country dynamic general equilibrium model. It is our hope that this research paper contributes to the development of appropriate environmental investment policies.

Dr. Hong-Kyun Kim(research fellow, KETRI), Drs. Jang-Ok Cho and Joon-Woo Nahm(professors of economics, Sogang University) headed the research and to them I express many thanks for their excellent work. Many people gave a very helpful comments in accomplishing this research. Especially, I thank two referees Drs. Myung-Hun Lee(Research Fellow, KETRI), Jong-Soo Lim(Research Fellow, KETRI) and seminar participants, Hoi-Seong Jung, Seung-Woo Kim, Kwang-Yim Kim, Hyun-Joo Moon and other KETRI research fellows for their helpful comments. Lastly I also thank Ms. Jeong-Sook Kim and Kyung-Sook Wang of KETRI, who contributed a great deal of their efforts in publishing this book.

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Welfare Consequences of Internalizing Environmental Costs in an Open Economy

Jang-OK Cho, Hong-Kyun Kim and Joon-Woo Nahm1) November, 1994

Abstract

We have constructed an international equilibrium model with two countries and two goods with pollution externalities in production and consumption. We have first estimated the model and then simulated it. We have found that the net effect of pollution on preference and production is close to zero and in addition that we cannot reject the hypothesis that the net effect is actually zero. Next the simulation has shown that the welfare costs of distortionary environmental tax in an endogenously growing economy are much higher than those obtained in the literature. The simulation has also shown that the benefits of improving environmental efficiency in the model economy are largest in the case of market production and smallest in the case of environmental government expenditures.

1. Introduction

Environmental interest is exploding these days. Global warming, acid rain, polluted water and air are some incidences often reported in daily journalism. Many people show some concerns about the deterioration in environmental quality in their private conversations. However, it is not believed that many of them understand the nature and scope of environmental problems. Economists consider that environmental problems are the consequences of externalities caused by production and consumption activities and associated market failure (see, for example, Cropper and Oates (1992)). They often suggest that introducing prices of environmental abuses in the form of unit tax or effluent fees may provide some signals to economize on the use of scarce environmental resources. They argue that these surrogate prices internalize the externalities.

As in the other externality problems, correcting distortions due to environmental externalities requires economic policies. However, before introducing any policy measures, we need to analyze the costs and benefits of those policies. Measuring both costs and benefits of policies regulating polluting activities may not be easy and we need theoretically and empirically elaborate economic models to do that. The costs of regulating polluting behavior can be calculated by adding up direct enforcement costs and productivity slowdown in the regulated industry or country as a whole (see, for example, Baltagi and Griffin (1988), Gray (1987) and Gollop and Roberts (1983)), but the benefits of a regulation cannot be measured easily. They have developed two methods of measuring the benefits of pollution control, namely indirect market methods and so-called contingent valuation approach.

The former methods2) include the adverting behavior approach (see Smith and Desvousges (1986), Dickie and Gerking (1991) and Gerking and Stanley (1986)), the weak complementarity approach (see Bockstael and McConnell (1983)), and the hedonic price methods (see Rosen (1974)). However, there are cases in which these methods cannot be used and many types of benefits cannot be measured indirectly. The contingent valuation method involves direct questioning about the benefits of pollution control. This method is more direct but involves some problems as in any other questioning. Especially, respondents may behave strategically (see Smith (1977)).

We think there can be a more direct macroeconomic approach of accessing the costs and benefits of environmental policies. As in the literature on equilibrium business cycle theory (see Prescott (1986)), an international dynamic general equilibrium model3)with environmental quality in preferences and production function is constructed in this paper. Advantages of following this approach are that nothing is hidden and that we can detect easily which part of the model should be improved. The preference depends on the amount of domestic and foreign goods, and leisure. It also depends on the quailty of water and air in two ways. Pollution has a direct negative effect on the preference and indirect positive effect through home production. The production in this paper depends on the amount of inputs and water and air pollution also in two ways; direct negative effect and indirect positive effect through productivity improvement. We also postulate laws of motion for water and air pollution which depend on the amount of consumption, production and cleaning up activiteis of the government.

We estimate the model using Korean data and simulate it. First, we estimate the preference parameters using the generalized method of moment (see Hansen (1982)). The estimates show that very strong negative effect on preference but it is off-setted by also a very strong positive effect on the productivity in home production. Second, we estimate the production function using log difference specification due to integration problem. We find that pollution has a strong direct negative effect on the production but it is once again offsetted by productivity effect that is almost the same. Finally, we estimate the laws of motion for water and air pollution. The estimates show that reducing pollution is very hard and time-consuming and that the rate of actual environmental budget increase is much lower than the rate required to keep the quality of water and air at some cleaner level. Using the estimates, we simulate the model and show how much costs in terms of growth rate and consumption have to be incurred to curb the increase in pollution.

The remainder of the paper proceeds as follows. In section 2, we describe the economic environment and the decision problem facing domestic and foreign agents. In section 3, the equilibrium of the model is defined and discussed, and the model is estimated in section 4. Section 5 suggests a direct method of obtaining Green GNP and discusses the required rate of environmental budget. Section 6 derives long run balanced growth path and section 7 simulates the model. Finally, section 8 concludes the paper.

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주석 2) See Cropper and Oates (1992) for details.

주석 3) See Cho, Cooley and Kim (1993) and Cho and Roche (1993) for international models used in the study of business cycles and inflation tax.

2. The Economic Environment

The international economy we study in this paper consists of two countries and two goods. Each country specializes in the production of one good. There is trade in goods between countries. A country can use the imported good for consumption but not investment purposes. Labor is assumed to be immobile across national boundaries. Each economy consists of a continuum of identical infinitely lived agents (or households). Each household in these countries is endowed with one unit of time per period, an initial capital stock k0 and the initial foreign debt (or asset) b0. Lowercase letters denote variables chosen by households and capital letters denote the aggregate per-capita counterparts. We first describe the problem faced by domestic consumers.1)

Each agent maximizes lifetime expected utility which is assumed to be time separable:

$$U^{d} = E\left\{\sum_{t=0}^{\infty}\beta^{t}\cdot v(\tilde{c}_t^{dd},\ \tilde{c}_t^{fd},\ l_t^{d},\ E_t^{d},\ A_t^{d}\ )\mid \Omega_0\right\}, \tag{1}$$

where β is a discount factor, and leisure in a period is denoted by ldt ·Edt and Adt are the amount of water and air pollution and Ω0 is the information set in period 0. Of course, the two types of pollution have adverse effect on utility and we will refer to this effect as the direct taste effect of pollution.

$\tilde{c}_t^{dd}$ and $\tilde{c}_t^{fd}$ are the final commodities produced using domestic and foreign goods2) respectively through home production3). Following Becker (1965, 1971), we assume that domestic and foreign goods cannot be consumed directly but with some manufacturing at home. This home production may be assumed to combine domestic and foreign goods with home capital like appliances and home labor. However, the key concern in this paper is the role of pollution in consumption and production activities and hence we will concentrate on the role of pollution in the home production process. Pollution is necessary in producing final commodities from domestic and foreign goods in the sense that the commodities cannot be produced without it. There can be many home production technologies in terms of combining pollution with other inputs. Given the amount of inputs, some home production technology may produce more final commodities than the other technologies. If the former is combined with less pollution, it will be surely adopted. However, if the former is combined with more pollution, there can be a conflict in adopting home production technology. We consider pollution to be the input in the home production process. We assume the following linear home production technology[4]

$$\tilde{c}_t^{dd} = \alpha_1 \cdot E_t^d \cdot A_t^d \cdot c_t^{dd} \tag{2}$$

$$\tilde{c}_t^{fd} = \alpha_2 \cdot E_t^d \cdot A_t^d \cdot c_t^{fd} \tag{3}$$

where c_t^{dd} and c_t^{fd} are the amount of domestic and foreign goods bought and used in the home production and α's are positive and measure the productivity of pollution in home production. According to the home production technology (2) and (3), given the amount of domestic and foreign goods, the amount of the commodities finally consumed by the agents (or households) are greater with more pollution. We will call this effect as the productivity effect of pollution in home production.

The specific parametric form for the utility function we use is:

$$u(\tilde{c}_t^{dd}, \tilde{c}_t^{fd}, l_t^d, E_t^d, A_t^d) = \frac{1}{1-\sigma} \cdot \left[(\tilde{c}_t^{dd})^{\phi_1} (\tilde{c}_t^{fd})^{\phi_2} (l_t^d)^{1-\phi_1-\phi_2} (E_t^d)^{\psi_1} (A_t^d)^{\psi_2} \right]^{1-\sigma} \tag{4}$$

We define ndt as 1-ldt. The parameters ø's and ѱ's indicate the household's preference for the commodities produced using domestic and foreign goods and for pollution. Note that Edt and Adt are not the choice for individual households and it can be controlled by the government by some environmental policies which will be specified later. If we use the home production technology (2) and (3) in (4), we may have a reduced form utility function as[5]:

$$u(c_t^{dd}, c_t^{fd}, l_t^{d}, E_t^{d}, A_t^{d}) = \frac{1}{1-\sigma} \cdot \left[(c_t^{dd})^{\phi_1} (c_t^{fd})^{\phi_2} (l_t^{d})^{1-\phi_1-\phi_2} (E_t^{d})^{\nu_1+\phi_1+\phi_2} \cdot (A_t^{d})^{\nu_2+\phi_1+\phi_2} \right]^{1-\sigma} \qquad (5)$$

Note in (5) that ν's are negative but ø's and α's are positive and hence that the power to the pollution terms may or may not be positive. If it is positive, it means that pollution has greater productivity effect in home production and if it is negative, pollution has greater direct taste effect. However, if the powers are close to zero, the productivity effect and the direct taste effect are offsetting.

The government may collect taxes on wages, capital income and consumption. We let τ_t^{dw}, τ_t^{dk}, τ_t^{dd} and τ_t^{fd} denote domestic tax rates on wage income, capital income, domestic goods consumption and foreign goods consumption respectively. Government buys goods and spends part of the revenue to get rid of water and air pollution. We assume that the government purchase of goods follows an AR(1) process:

$$\ln(G_t^{dw}) = r_1 \cdot t + \eta_{dw} \cdot \ln(G_{t-1}^{dw}) + \omega_t^{dw}, \qquad (6)$$

where γ1 measures the trend in the non-environmental government expenditure and ω_t^{dw} follows an i.i.d. random variable with mean 0 and variance $(\sigma_w^{dw})^2$. The environmental expenditure is also assumed to follow an AR(1) process:

$$\ln(G_t^{de}) = r_2 \cdot t + \eta_{de} \cdot \ln(G_{t-1}^{de}) + \omega_t^{de},$$

where γ2 measures the trend[6] in the environmental expenditure and ω_t^{de} follows an i.i.d. random variable with mean 0 and variance $(\sigma_w^{de})^2$.

For the moment we will simplify the problem by assuming that budget surplus (or deficit) is rebated to (taxed from) the private sector in a lump sum way.

The budget constraint facing the representative domestic household can be written as:

$$
\begin{aligned}
&(1+\tau_t^{dd})\cdot c_t^{dd}+i_t^{dd}+s_t\cdot\left[(1+\tau_t^{fd})\cdot c_t^{fd}+b_{t+1}^{d}\right] \\
&\leq(1-\tau_t^{dw})\cdot W_t^d\cdot n_t^d+(1-\tau_t^{dk})\cdot R_t^d\cdot k_t^d+\tau_t^{dk}\cdot\delta^d\cdot k_t^d \\
&\qquad +s_t\cdot(1+r_{t-1})b_t^d+TR_t^d, \qquad (8)
\end{aligned}
$$

where i_t^{dd} is domestic investment, b_{t+1}^d is the borrowing or lending in period t from the foreign country which will be measured in units of the foreign goods[7], W_t^d and R_t^d are the nominal wage rate and the nominal rental rate of capital respectively, δ^d is the capital depreciation rate in the domestic country, S_t is the exchange rate, r_{t-1} is the interest rate between periods t-1 and t, and TR_t^d is the lump sum transfer (or tax) from the government, which can be obtained as: [8]

$$
\begin{aligned}
TR_t^d=&\tau_t^{dw}\cdot W_t^d\cdot N_t^d+\tau_t^{dk}\cdot\left(R_t^d-\delta^d\right)\cdot K_t^d+\tau_t^{dd}\cdot C_t^{dd}+ \\
&\tau_t^{fd}\cdot C_t^{fd}+\tau_t^{de}\cdot Y_t^d-G_t^{dp}-G_t^{de}, \qquad (9)
\end{aligned}
$$

where the first and the second terms are the revenue from labor and capital income taxes. The terms in the left-hand side of (8) are the expenditures and those in the right-hand side are revenues. The third term in the right-hand side is the depreciation allowances written in the tax code and τ_t^{de} denotes the environmental tax per unit of output imposed on the firm in the domestic country, which will be used in cleaning up pollution.

There are many identical firms producing homogenous output specific to each country. Each firm produces output with an identical Cobb-Douglas production function. As in the case of home production, pollution plays two roles. First, it increases the productivity of inputs used in production process, i.e. a more pollutive technology produces more output than less pollutive ones, given the amount of other inputs[9]. We will refer this effect as the productivity effect of pollution in market production. Second, pollution may directly affect the production activity in an adverse way and we will call this effect as the direct production effect of pollution. We write the production function as follows.

$$Y_t^d = (1-\tau_t^{d*})\cdot(\lambda_t^d)^*\cdot(H_t^d\cdot N_t^d)^{1-\theta}\cdot(K_t^d)^{\theta}\cdot(E_t^d)^{\gamma_1}\cdot(A_t^d)^{\gamma_2}. \qquad (10)$$

where Ndt is aggregate hours worked, Kdt is the aggregate capital stock, Hdt is the aggregate per capita human capital accumulated through learning by doing and (λtd)* is the aggregate productivity which is affected by the level of pollution. The last two pollution terms measure the adverse effect of pollution on production and hence γ's are negative. We assume the following productivity function.

$$(\lambda_t^d)^* = \vartheta\,\lambda_t^d\cdot E_t^d\cdot A_t^d. \qquad (11)$$

where ϑ is a constant and λtd is the productivity shock to domestic production, which is assumed to follow AR(1) process.

$$\ln(\lambda_t^d) = \rho_d\cdot \ln(\lambda_{t-1}^d) + \varepsilon_t^d. \qquad (12)$$

where εtd follows i.i.d. process with mean 0 and variance (σdε)2. Note that ϑ measures the size of the productivity effect of pollution in market production and hence it is positive. Using (13) in (10), we can have the following reduced form production function.

$$Y_t^d = \vartheta\cdot(1-\tau_t^{d*})\cdot\lambda_t^d\cdot(H_t^d\cdot N_t^d)^{1-\theta}\cdot(K_t^d)^{\theta}\cdot(E_t^d)^{\gamma_1+1}\cdot(A_t^d)^{\gamma_2+1} \qquad (13)$$

Of course, the powers to the pollution terms may or may not be positive depending on which effect is dominating.

Production activities in the model have two types of externalities. First, human capital is accumulated through learning by doing and following Lucas(1988), we assume the following law of motion for the aggregate per capita human capital.

$$H_t^d = \varphi^d H_{t-1}^d \cdot N_{t-1}^d \qquad (14)$$

Here ϕd is the parameter determining the intensity of learning by doing in the domestic country.

Second, production activities produce pollution. We assume that the amount of accumulated water pollution follows the following law of motion.

$$\ln(E_t^d) = \ln(E_{t-1}^d) + \mu_0 + \mu_1 \cdot \ln(Y_t^d / Y_{t-1}^d)$$
$$+ \mu_2 \cdot \ln\left[\psi_t \cdot G_t^{de} / (\psi_{t-1} \cdot G_{t-1}^{de})\right] + \mu_3 \cdot \left[\ln(C_t^{dd}/C_{t-1}^{dd}) + \ln(C_t^{fd}/C_{t-1}^{fd})\right] \qquad (15)$$

where μ1 measures the rate of water pollution externality in output production, μ2 is the rate of water pollution reduction through environmental expenditures by the domestic government, μ3 measures the increase in water pollution due to domestic and foreign good consumption, and Ψt is the fraction of government expenditure which is devoted to the reduction of water pollution. This random walk specification of the law of motion for water pollution is assumed due to the fact that ln(Edt), ln(Ydt), ln(Ψt · Gdet), ln(Ctdd) and ln(Ctfd) are integrated. The law of motion for the water pollution is assumed to follow the following law of motion.

$$\ln(A_t^d) = \ln(A_{t-1}) + \xi_0 + \xi_1 \cdot \ln(Y_t^d / Y_{t-1}^d) + \xi_2 \cdot \ln\left[(1-\psi_t)\right.$$
$$\left. \cdot G_t^{de} / ((1-\psi_{t-1}) \cdot G_{t-1}^{de})\right] + \xi_3 \cdot \left[\ln(C_t^{dd}/C_{t-1}^{dd}) + \ln(C_t^{fd}/C_{t-1}^{fd})\right] \qquad (16)$$

This specification of the law of motion for air pollution is motivated by the fact that the variables in the right-hand side of the equation are integrated. In (15) and (16), we restrict the coefficients of the domestic and foreign goods consumption to be the same for the purpose of identification.10)

Finally, we have the law of motion for the domestic capital stock

which evolves according to:

Kdt+1 = (1 − δd) · Kdt + Itdd (17)

Of course, the individual capital stock follows an analogous law of motion.

The problem facing the firm is relatively simple as follows.

maximize Ydt – WdtNdt – RdtKdt (18)

Hence the profit maximizing conditions for the firm can be obtained as:

$$W_t^d=(1-\tau_t^{dw})\cdot(1-\theta)\cdot H_t^d\cdot(H_t^d\cdot N_t^d)^{-\theta}\cdot(K_t^d)^{\theta}\cdot(E_t^d)^{\gamma_1+\vartheta_1}\cdot(A_t^d)^{\gamma_2+\vartheta_2}, \qquad (19)$$

$$R_t^d=(1-\tau_t^{dk})\cdot\theta\cdot(H_t^d\cdot N_t^d)^{1-\theta}\cdot(K_t^d)^{\theta-1}\cdot(E_t^d)^{\gamma_1+\vartheta_1}\cdot(A_t^d)^{\gamma_2+\vartheta_2}, \qquad (20)$$

Aggregating equation (8) across the domestic agents using and (20), we have the aggregate resource constraint.

$$\begin{gathered} C_t^{dd}+I_t^{dd}+s_t\cdot C_t^{fd}+G_t^{dw}+G_t^{dk} \\ \leq \lambda_t^d\cdot(H_t^d\cdot N_t^d)^{1-\theta}\cdot(K_t^d)^{\theta}\cdot(E_t^d)^{\gamma_1+\vartheta_1}+(A_t^d)^{\gamma_2+\vartheta_2}+s_t\cdot\left[(1+r_{t-1})B_t^d-B_{t+1}^d\right]\cdot(21) \end{gathered}$$

The foreign debt (or asset) accumulation can be obtained as:

$$B_{t+1}^d=(1+r_{t-1})B_t^d-C_t^{fd}+C_t^{df}/s_t, \qquad (22)$$

where Ctdf is the amount of domestic goods consumed by foreigners.

The trade balance for the domestic country is defined as11):

TBdt = Ctdf- st · Ctfd (23)

If we use (22) in (21), we can have the resource constraint.

$$C_t^{dd}+C_t^{df}+I_t^{dd}+G_t^{dw}+G_t^{dk}\leq\lambda_t^d\cdot(H_t^d\cdot N_t^d)^{1-\theta}\cdot(K_t^d)^{\theta}\cdot(E_t^d)^{\gamma_1+\vartheta_1}\cdot(A_t^d)^{\gamma_2+\vartheta_2} \qquad (24)$$

Of course, the lefthand side of (24) shows how domestic product is used.

주석 1) Foreign consumers have an analogous problem.

주석 2) The first superscript refers to the country where the good is produced and the second superscript refers to the country where the good is used.

주석 3) See Gronau (1986) for a survey on home production literature and other references.

주석 4) We simplify the problem ignoring the role of home capital and home labor. Introducing these elements does not alter the result in the paper. See Benhabib, Rogerson and Wright (1992) for the role of home labor in home production and see Hercowitz and Greenwood (1992) for the role of home capital.

주석 5) We define u as follows :

$$u = v/\left[a_1^{\phi_1}\cdot a_2^{\phi_2}\right]^{1-\sigma}.$$

주석 6) The trend growth rate of G_t^{*} in a steady state is $\gamma 1/(1-\eta dg)$ and that of G_t^{*} is $\gamma_f/(1-\eta_{df})$. This growth rates have to be restricted to imply a balanced growth path. We will discuss this later.

주석 7) If bdt+1 is positive, it is a lending to foreigners and vice versa.

주석 8) An assumption is that domestic firms are owned by domestic agents and foreign firms are owned by foreign agents. An alternative would be to compute pooling equilibrium which allows foreign (domestic) agents to share a part of the domestic (foreign) firm's ownership.

주석 9) See Rosen (1986) for a discussion of this type of production function.

주석 10) In these equations, Ydt is included to measure the amount of pollution produced in the process of production, while Ctdd to measure the amount of pollution produced in the process of consumption. However, Ctdd is a part of Ydt and hence we have a difficulty in identifying the coefficient of these two variables. To overcome this difficulty, we use the fact that Ctfd is not a portion of Ydt and assume as in the text.

주석 11) Since foreign currency is required for the purchase of foreign goods, the trade balance does not play an important role in the following discussion.

3. Equilibrium

A decentralized equilibrium can be obtained by solving the problems facing the agents in both countries and then invoking the equilibrium conditions in the world commodity and loan market. If we define $V^d(\Omega_t)$ to be the equilibrium maximized value of the utility stream of the domestic representative agent as of period t when the state space is Ω_t, the problem facing the agent can be written as follows.

Bellman Equation for Domestic Household:

$$V^d(\Omega_t)=\max\left\{u(c_t^{dd},\ c_t^{fd},\ l_t^d,\ E_t^d,\ A_t^d)+\beta\cdot E\left[V^d(\Omega_{t+1})\mid\Omega_t\right]\right\} \quad (25)$$

$$S.t.\ (8),\ (19),\ (20),\ the\ laws\ of\ motion,$$

and non-negativity constraints.1) Domestic agents are assumed to solve the problem stated above taking all aggregate per capita variables and the price variables and the two price variables and the two price variables v_{t-1} and s_t as given.

If we let $V^f(\Omega_t)$ denote the equilibrium maximized value of the utility stream of the foreign representative household as of period t, the problem facing foreign agents is symmetric to the domestic agents' problem.

Bellman Equation for Foreign Household:

$$V^f(\Omega_t)=\max\left\{u(c_t^{df},\ c_t^{ff},\ l_t^f,\ E_t^f,\ A_t^f)+\beta\cdot E\left[V^f(\Omega_{t+1})\mid\Omega_t\right]\right\} \quad (26)$$

where the constraints for this maximization problem are analogous to those of the domestic household including the following budget constraint.

$$\begin{aligned}&(1+\tau_t^{df})\cdot c_t^{df}/s_t+i_t^{ff}+\left[(1+\tau_t^{ff})\cdot c_t^{ff}+b_{t+1}^f\right]\\ &\le(1-\tau_t^{hw})\cdot W_t^f\cdot n_t^f\cdot h_t^f+(1-\tau_t^{fk})\cdot R_t^f\cdot k_t^f+\tau_t^{fk}\cdot\delta^f\cdot k_t^f+(1+r_{t-1})b_t^f+TR_t^f \quad (27)\end{aligned}$$

Foreign agents are also assumed to solve the problem just stated taking all aggregate per capita variables and the interest rate and the real exchange rate as given.

Equilibrium in the world commodity markets requires that:

$$C_t^{dd}+C_t^{df}+I_t^{dd}+G_t^{da}+G_t^{de}\leq \vartheta\lambda_t^d\cdot(H_t^d\cdot N_t^d)^{1-\theta}\cdot(K_t^d)^{\theta}\cdot(E_t^d)^{\gamma_1+1}\cdot(A_t^d)^{\gamma_2+1} \quad (28)$$

$$C_t^{fd}+C_t^{ff}+I_t^{ff}+G_t^{fa}+G_t^{fe}\leq \vartheta\lambda_t^f\cdot(H_t^f\cdot N_t^f)^{1-\theta}\cdot(K_t^f)^{\theta}\cdot(E_t^f)^{\gamma_1+1}\cdot(A_t^f)^{\gamma_2+1} \quad (29)$$

Equilibrium in the loan market requires that:

Bdt+1 + Bft+1 = 0 (30)

Using the choices made by domestic and foreign households, two of three equilibrium conditions, (28) - (30), determine the real exchange rate st and the interest rate in the loan market.2)The distribution of wealth matters in a decentralized equilibrium and the state vector can be defined as:

$$\begin{aligned}\Omega_t=\Big\{&\lambda_t^d,\ \lambda_t^f,\ K_t^d,\ k_t^d,\ K_t^f,\ k_t^f,\ B_t^d,\ b_t^d,\ B_t^f,\ b_t^f,\ H_t^d,\ h_t^d,\ H_t^f,\ h_t^f,\\ &G_t^{da},\ G_t^{de},\ G_t^{fa},\ G_t^{fe},\ \tau_t^{dd},\ \tau_t^{fd},\ \tau_t^{df},\ \tau_t^{ff},\ \tau_t^{da},\ \tau_t^{fa},\ \tau_t^{dk},\ \tau_t^{fk},\ \tau_t^{de},\ \tau_t^{fe},\\ &Y_{t-1}^d,\ Y_{t-1}^f,\ \phi_t^d,\ \phi_{t-1}^d,\ \phi_t^f,\ \phi_{t-1}^f,\ C_{t-1}^{dd},\ C_{t-1}^{fd},\ C_{t-1}^{df},\ C_{t-1}^{ff},\\ &E_{t-1}^d,\ E_{t-1}^f,\ A_{t-1}^d,\ A_{t-1}^f\Big\} \end{aligned} \quad (31)$$

The price vector can be defined as:

Πt = {rt, st} (32)

With these preliminaries we can now define a decentralized equilibrium3) for this economy as follows.

Definition: A recursive competitive equilibrium for this economy consists of a set of decision rules {cdd(Ωt,Πt), cdf(Ωt,Πt), cfd(Ωt,Πt), cff(Ωt,Πt), idd(Ωt,Πt), iff(Ωt,Πt), nd(Ωt,Πt), nf(Ωt,Πt), bdt+1(Ωt,Πt), bft+1(Ωt,Πt)}, a set of aggregate decision rules {cdd(Ωt,Πt), cdf(Ωt,Πt), cfd(Ωt,Πt), cff(Ωt,Πt), Idd(Ωt,Πt), Iff(Ωt,Πt), Nd(Ωt,Πt), Nf(Ωt,Πt), Bdt+1(Ωt,Πt), Bft+1(Ωt,Πt)} the price vector Πt, and value functions Vd(Ωt) and Vf(Ωt) such that these functions satisfy:

(i) the foreign and domestic households problem (25) and (26);

(ii) the foreign and domestic firms problems [(18) and its foreign counterpart];

(iii) the consistency of individual and aggregate decisions;

(iv) the equilibrium conditions in world commodity and currency market, (28)-(30).

In fact, (iv) in the above definition can be solved for the price vector as a function of Ω_t and hence the individual and aggregate decision can be solved for Ω_t too.

주석 1) The domestic firm's problem is completely characterized by (20) and (21) and since we use those conditions in (25), we do not need to consider the domestic firm's problem separately.

주석 2) One among the three equilibrium conditions is redundant according to Walras' Law.

주석 3) See Prescott and Mehra(1980) for a definition of recursive competitive equilibrium.

4. Estimation of the Model

Using Korean data, we estimate the model first to see the role of pollution at home and in the market. We use the Generalized Method of Moment (GMM) to estimate the preference parameters.1)We also estimate the market production function and the laws of motion of the water and air pollution.

(i) Data

In the estimation, all the variables are quarterly and real. They are seasonally adjusted by X-11. All series except water and air pollution are obtained from the Korea Developement Institute (KDI) database. Domestic goods consumption (ctdd) is constructed by subtracting the amount of imported consumption goods from total private consumption, and foreign goods consumption (ctfd) is the amount of imported consumption goods. Total hours of work (Ntd) in a period are the product of the average weekly hours of employed persons and the number of weeks in a quarter, and the leisure time (ltd) is calculated by subtracting the quarterly hours of work from time endowment in a quarter. As the measure of interest rate(γt), we use average rate of return on corporate bonds. Real wage rate (Wtd) is the average monthly compensation for all employees. The pollution series are obtained from the Korea Environmental Yearbook. As the measure of water pollution (Etd), we use the average amount of Biological Oxygen Demand(BOD) in a liter of water from four major rivers which are the important sources of drinking water in Korea. As the measure of air pollution (Atd), we use the average amount of sulfu dioxide(SO_2) in the air for the largest five cities in Korea. In estimating the production function, we use Gross Domestic Product as the measure of output. To estimate the laws of motion of water and air pollution, we use annual expenditures on cleaning up water and air pollution and assume that they have been spent equally over a year. The time period covered in the estimation is between the fourth quarter of 1982 and the fourth quarter of 1992.

(ii) Estimation of the Preference Parameters}

GMM method is well known in labor supply and asset pricing literature. The method directly estimates the Euler equations implied by the consumer's problem. The consumer's problem in our model implies the following Euler equations.

$E[M_t \mid \Omega_t] = 0$, (33)

where $M_t = \{M_{1t}, M_{2t}, M_{3t}\}$ and ′´′ denotes the transpose of the matrix. Here M_{it} can be defined as:

$$M_{1t} = \beta \cdot \left\{ \left(\frac{C^{dd}_{t+1}}{C^{dd}_t}\right)^{\phi_1} \cdot \left(\frac{C^{fd}_{t+1}}{C^{fd}_t}\right)^{\phi_2} \cdot \left(\frac{\ell^{d}_{t+1}}{\ell^{d}_t}\right)^{1-\phi_1-\phi_2} \cdot \left(\frac{E^{d}_{t+1}}{E^{d}_t}\right)^{\Delta_1} \cdot \left(\frac{A^{d}_{t+1}}{A^{d}_t}\right)^{\Delta_2} \right\}^{1-\sigma} \cdot \left(\frac{C^{dd}_{t+1}}{C^{dd}_t}\right)^{-1} \cdot (1+r_t) - 1 \qquad (34)$$

$$M_{2t} = \beta \cdot \left\{ \left(\frac{C^{dd}_{t+1}}{C^{dd}_t}\right)^{\phi_1} \cdot \left(\frac{C^{fd}_{t+1}}{C^{fd}_t}\right)^{\phi_2} \cdot \left(\frac{\ell^{d}_{t+1}}{\ell^{d}_t}\right)^{1-\phi_1-\phi_2} \cdot \left(\frac{E^{d}_{t+1}}{E^{d}_t}\right)^{\Delta_1} \cdot \left(\frac{A^{d}_{t+1}}{A^{d}_t}\right)^{\Delta_2} \right\}^{1-\sigma} \cdot \left(\frac{C^{fd}_{t+1}}{C^{fd}_t}\right)^{-1} \cdot (1+r_t) - 1 \qquad (35)$$

$$M_{3t} = \beta \cdot \left\{ \left(\frac{C^{dd}_{t+1}}{C^{dd}_t}\right)^{\phi_1} \cdot \left(\frac{C^{fd}_{t+1}}{C^{fd}_t}\right)^{\phi_2} \cdot \left(\frac{\ell^{d}_{t+1}}{\ell^{d}_t}\right)^{1-\phi_1-\phi_2} \cdot \left(\frac{E^{d}_{t+1}}{E^{d}_t}\right)^{\Delta_1} \cdot \left(\frac{A^{d}_{t+1}}{A^{d}_t}\right)^{\Delta_2} \right\}^{1-\sigma} \cdot \left(\frac{\ell^{d}_{t+1}}{\ell^{d}_t}\right)^{-1} \cdot \left(\frac{W^{d}_t(1+r_t)(1+\tau^{dw}_t)}{W^{d}_{t+1}(1+\tau^{dw}_{t+1})}\right) - 1, \qquad (36)$$

where $\Delta_1 = \nu_1 + \phi_1 + \phi_2$ and $\Delta_2 = \nu_2 + \phi_1 + \phi_2$. Now the method involves choosing instrumental variables belonging to the information set and invoking the orthogonality conditions embodied in the Euler equations (33). If we let Z_t denote a vector of the instrumental variables, we can have the following.

$$E(M_t \otimes Z_t) = E\left[E(M_t \mid \Omega_t) \otimes Z_t\right] = 0 \qquad (37)$$

If M_t is stationary, we use this moment restrictions to estimate the parameters involved in the Euler equations.

Now the sample moment corresponding to the expected value in (37) can be obtained as:

$$M = \frac{1}{T} \cdot \sum_{t=0}^{T} M_t \otimes Z_t \tag{38}$$

If (37) is true, we can expect that M is close to zero and hence if the number of parameters is the same as the number of equations in (38), we can solve for the parameters from:

M=0 (39)

However, the number of equations is larger in most of cases that we face than the number of parameters and thus they estimate the parameter values by solving the following minimization problem.

$$\min S = (T \cdot M)' \cdot \hat{V} \cdot (T \cdot M), \tag{40}$$

where $\hat{V}$ is a consistent estimate of the covariance matrix of T · M. Hansen (1982) shows that the minimized value of S, which we will denote as J, has a χ 2-distribution with WW1-W2 degrees of freedom, where W,W1 and W2 are the number of instruments, the number of equations in M and the number of parameters respectively. Of course, if the model is true, J is close to zero.

Now define the following:

$$X_t = \left(\frac{c^{dd}_{t+1}}{c^{dd}_t}, \frac{c^{fd}_{t+1}}{c^{fd}_t}, \frac{l^{d}_{t+1}}{l^{d}_t}, \frac{E^{d}_{t+1}}{E^{d}_t}, \frac{A^{d}_{t+1}}{A^{d}_t}, \frac{W^{d}_t(1-\tau^{dw}_t)(1+r_t)}{W^{d}_{t+1}(1-\tau^{dw}_{t+1})} \right).$$

Then the vector of instrument Zt is assumed to contain one-period and two-period lagged values of Xt. Many of the series used in the estimation are integrated but {(Xt, Zt), t=1, 2, ⋯} $ does not have any trends. Although Mt and Zt are serially correlated, we know that Zt∈Ωt and hence they are orthogonal.

In estimating the Euler equations, we put a restriction on the parameter β. Since β is related to the long run interest rate as:

$$r=\frac{1}{\beta}-1,\ i.\ e.\ \beta=\frac{1}{1+r}\quad, \tag{41}$$

where γ is the long run interest rate. Since it is about 0.028 percent in Korea, we assume that β=0.97310. In fact, the estimates are not sensitive to the value of β (as far as β is close to one). Now the estimates are as follows (the numbers in parentheses are t-ratio).

$$\hat{\phi}_1=0.41031(3.38633),\ \hat{\phi}_2=0.29912(4.51283),\ \hat{\sigma}=6.10524(5.27722)$$
$$\hat{\triangle}_1=-0.05472(-1.7822),\ \hat{\triangle}_2=0.01080(0.63443),$$

The estimates of ø's and σ are well in the range of those obtained in the literature2). From the definition of △'s, we can identify the parameters characterizing the tastes toward pollution as follows.

$$\hat{\nu}_1=\hat{\triangle}_1-\hat{\phi}_1-\hat{\phi}_2=-0.76415,\quad \hat{\nu}_2=\hat{\triangle}_2-\hat{\phi}_1-\hat{\phi}_2==-0.69863$$

The estimates show that Korean people dislike water pollution more than air pollution by a slight margin. In addition, we can conclude that they have strong preference against those pollutions themselves. However, the overall impact of pollution on the preferences is not that great. In other words, △'s measure the sum of productivity effect of pollution in home production and its taste effect, and we can see that these estimates are not far away from zero (t-ratios are also small and hence we cannot reject the hypothesis that △'s are zero). This means that if we take into account the productivity effect and taste effect together, we cannot say that pollution has had serious impact on the preference so far. One unfortunate fact about the estimation is that the data on pollution in Korea are not good enough to measure the structural break in the taste against pollution. In other words, they argue that the preferences against pollution change over time with growing real income and hence we expect that they had less strong preferences against pollution in the 1960's than in the 1990's. However, since we do not have enough data, we cannot detect the timing and the size of the structural break in the taste.

The estimated value of the J-statistic is 16.0548 and the right-tail probability value is 0.813158. \ Hence the over-identifying restrictions are not rejected and thus it can be said that the orthogonality conditions characterizing the Euler equations hold true.

(iii) Estimation of the Technology Parameters

We estimate the aggregate production function(10). If we assume that τtde = 0 and take logarithm of both sides of (10), we can have the following.

$$\ln(Y_t^d) = \ln(\vartheta) + \ln(\lambda_t^d) + \theta \cdot \ln(K_t^d) + (1-\theta) \cdot \ln(N_t^d) + \Lambda_1 \cdot \ln(E_t^d) + \Lambda_2 \cdot \ln(A_t^d), \tag{42}$$

where Λ1=ν1+1 and Λ2=ν2+1. However, we have a problem in estimating this Cobb-Douglas production function, namely because there has been a huge increase in the labor share in Korea since 1988, i.e. a large decrease in θ. As we can see in Figure 2, labor share in total output3) has been increasing from 0.525 to 0.61 during the period between 1988 and 1992. To capture the structural break in the labor and capital share, we use a dummy variable as follows.

$$\begin{aligned} \ln(Y_t^d) &= \ln(\vartheta) + \ln(\lambda_t^d) + \left[\theta + \theta_1 \cdot D_t \cdot (t - 86.1)\right] \cdot \ln(K_t^d) \\ &+ \left[1 - \theta - \theta_1 \cdot D_t \cdot (t - 86.1)\right] \cdot \ln(N_t^d) + \Lambda_1 \cdot \ln(E_t^d) \\ &+ \Lambda_2 \cdot \ln(A_t^d), \end{aligned} \tag{43}$$

where Dt=0 if t<86.1 and Dt=0 if t ≥ 86.1. Since Ydt, Kdt and Ndt are integrated, we calculate the difference (43) and estimated the differenced version. Now the estimates are obtained as follows.

$$\hat{\vartheta} = 1.00816(1.36593), \ \hat{\theta} = 0.51188(1.82731),$$

$$\hat{\theta}_1 = -0.03619(-0.15746)$$

$$\hat{\Lambda}_1 = 0.02734(0.118484), \ \hat{\Lambda}_2 = 0.00646(0.31012)$$

and $R^2 = 0.223$. Using the definition of Λ's, we can identify γ's as :

$$\hat{\gamma}_1 = -0.97266 \text{ and } \hat{\gamma}_2 = -0.99354.$$

These estimates show that pollution has a substantially large (adverse) direct production effect. However, as in the case of preference estimates, the overall effect as the sum of the productivity effect of pollution in market production and the direct production effect of pollution is small and we cannot reject the hypothesis that the overall effect is zero.

(iv) Estimation of the Laws of Motion for Water and Air Pollution

We estimate the laws of motion for water and air pollution to see how the two types of pollution respond to changes in the sources of pollution. The estimates are obtained as follows.

$$\begin{aligned}
\ln(E_t^d) = \ln(E_{t-1}^d) - \underset{(-1.14267)}{0.04173} + \underset{(0.96424)}{1.18783} \\
\cdot \ln(Y_t^d / Y_{t-1}^d) - \underset{(-0.41620)}{0.02846} \cdot \ln\left[\psi_t \cdot G_t^{de} / (\psi_{t-1} \cdot G_{t-1}^{de})\right] \\
+ \underset{(0.52081)}{0.22831} \cdot \left[\ln(C_t^{dd} / C_{t-1}^{dd}) + \ln(C_t^{fd} / C_{t-1}^{fd})\right] \qquad (44)
\end{aligned}$$

The numbers in the parentheses are t-ratio and R2=0.046.

$$\ln(A_t^d) = \ln(A_{t-1}) - \underset{(-1.31244)}{0.05081} + \underset{(0.56521)}{0.73428}$$

$$\cdot \ln(Y_t^d / Y_{t-1}^d) - \underset{(-0.88709)}{0.08232}$$

$$\cdot \ln\left[(1-\phi_t) \cdot G_t^{de} / ((1-\phi_{t-1}) \cdot G_{t-1}^{de})\right] + \underset{(1.52745)}{0.70881}$$

$$\cdot \left[\ln(C_t^{dd} / C_{t-1}^{dd}) + \ln(C_t^{fd} / C_{t-1}^{fd})\right] \qquad (45)$$

and R2=0.084. The constant terms in (44) and (45) show the rate of pollution reduction when there is no growth in output, environmental budget and consumption. The estimates show that air pollution can be cleaned up more rapidly than water pollution. Since we are using log-linear specification, the coefficients are elasticities. If there is one percent increase in the domestic production, water pollution increases by 1.19 percent and air pollution by 0.73 percent, i.e. output production has more impact on water pollution than on air pollution. The elasticity of pollution growth with respect to environmental expenditure is -0.028 in the case of water pollution and -0.082 in the case of air pollution. This low elasticities tell us that pollution reduction should be a task carried out for a long period of time. The elasticity with respect to consumption is 0.228 in the case of water pollution and 0.709 in the case of air pollution and hence air pollution is more sensitive to consumption increase than water pollution.

주석 1) See Hansen (1982) and Hansen and Singleton (1983).

주석 2) See Eichenbaum, Hansen and Singleton (1987).

주석 3) See Bils and Cho (1994) for U.S. case.

5. Discussions on Green GNP and Environmental Budget

The estimates obtained in the previous section have non-trivial implications on the various aspects of environmental problems. As a few examples, we will consider some issues on the so-called Green GNP and environmental budget.

(i) Green GNP

They have argued that pollution is one of the factors which make GNP an inappropriate measure of economic welfare. Recently they have tried to construct a measure of gross national product net of environmental costs. That is, they collect data on how much damage has been done to the environment due to production and consumption activities and try to transform the damages into money value. By subtracting the costs from GNP, they are trying to construct the so-called Green GNP. However, although the analysis is restricted by the pollution data we have used, we can illustrate that Green GNP may be calculated more easily and directly from the estimates we have got in the previous section.

Removing the pollution produced during the production and consumption process is equivalent to removing the direct taste effect of pollution and hence we may ask how much has to be compensated to the household if the household is to feel as if there were no pollution. To calculate the amount of compensation, let x_t denote the amount of compensation as the proportion of consumption (domestic and foreign).

Then we can calculate x_t from the following equation.

$$\frac{1}{1-\sigma}\cdot\Big[\{c_t^{dd}(1+x_t)\}^{\phi_1}\{c_t^{fd}(1+x_t)\}^{\phi_2}(\ell_t^{d})^{1-\phi_1-\phi_2}(E_t^{d})^{\nu_1+\phi_1+\phi_2}$$

$$(A_t^{d})^{\nu_2+\phi_1+\phi_2}\Big]^{1-\sigma} = \frac{1}{1-\sigma}\cdot\Big[(c_t^{dd})^{\phi_1}(c_t^{fd})^{\phi_2}(\ell_t^{d})^{1-\phi_1-\phi_2}$$

$$(E_t^{d})^{\phi_1+\phi_2}(A_t^{d})^{\phi_1+\phi_2}\Big]^{1-\sigma} \tag{46}$$

Simplifying(46) gives us the following expression for xt

$$\phi_1 \cdot \ln(1+x_t) + \phi_2 \cdot \ln(1+x_t) = -\nu_1 \cdot \ln(E_t^d) - \nu_2 \cdot \ln(A_t^d) \qquad (47)$$

If xt is not large, we can have the following approximation for xt

$$x_t = \left[-\nu_1 \cdot \ln(E_t^d) - \nu_2 \cdot \ln(A_t^d) \right] / (\phi_1 + \phi_2) \qquad (48)$$

Now the green GNP can be calculated by the following formula.
YtG = Yt - (Ctdd + Ctfd) · xt(49)

We use this formula and the estimates obtained in the previous section to calculate the green GNP for Korea.

Figure 3 contains Green GNP when we consider only water pollution measured by BOD and air pollution measured by SO2. We assume that the pollution level in the third quarter of 1983 is the base1).Then we calculate water and air pollution indices and use them in (48). Figure 3 tells us that if we consider only BOD and SO2, Green GNP was overall lower than GNP during the years before 1990.

However, Green GNP is higher than GNP during the years after 1990 and up to 1992. This improvement in pollution during those years is mainly due to the reduction in SO2 and this can be seen in figure 3a. The figure shows that there has been substantial improvement in SO2 pollution since 1990, while there has not been noticeable improvement in water pollution.

Note here that since we are using only BOD and SO2 in the estimation, we cannot argue that Green GNP in Figure 3 is the GNP net of environmental damages. However, if sufficient environmental data are accumulated in the future, we believe that this method can be used without major costs.

(ii) A Discussion on the Environmental Budget

From the laws of motion for water and air pollution, we can calculate the relationship between environmental expenditure (or budget) and the rate of increase in water and air pollution in the long run. Suppose gtY, gtdd, gtfd denote the rate of output, domestic and foreign goods consumption growth between t-1 and t respectively. In addition, let gtdE, gtdA, gtgE, gtgA denote the rate of increase in water and air pollution and the environmental expenditures on water and air pollution. Then we can have the following from the laws of motion for water and air pollution.

$$\ln(1+g_t^{dE}) = \mu_0 + \mu_1 \cdot \ln(1+g_t^{Y}) + \mu_2 \cdot \ln(1+g_t^{gE}) + \mu_3 \cdot [\ln(1+g_t^{dd}) + \ln(1+g_t^{fd})] \qquad (50)$$

$$\ln(1+g_t^{dA}) = \zeta_0 + \zeta_1 \cdot \ln(1+g_t^{Y}) + \zeta_2 \cdot \ln(1+g_t^{gE}) + \zeta_3 \cdot [\ln(1+g_t^{dd}) + \ln(1+g_t^{fd})] \qquad (51)$$

Given the rate of growth in output and consumption, the rate of environmental budget increase which keeps the environmental quality the same, i.e. gtdE = gtdA = 0, can be obtained as:

$$g_t^{gE}(g_t^{dE}=0) = \exp\{-[\mu_0 + \mu_1 \cdot \ln(1+g_t^{Y}) + \mu_3 \cdot (\ln(1+g_t^{dd}) + \ln(1+g_t^{fd}))]/\mu_2\} - 1 \qquad (52)$$

$$g_t^{gA}(g_t^{dA}=0) = \exp\{-[\zeta_0 + \zeta_1 \cdot \ln(1+g_t^{Y}) + \zeta_3 \cdot (\ln(1+g_t^{dd}) + \ln(1+g_t^{fd}))]/\zeta_2\} - 1 \qquad (53)$$

Now, given the rate of output and consumption growth, we can calculate the growth rate of environmental budget which keeps the pollution level constant. (Note that these rates are not the same.)

Figure 4 shows the growth rate of environmental budget which keeps the rate of pollution increase at zero. The average growth rate of the environmental budget which keeps the growth rate of water pollution at zero during the period between 1983 and 1992 was 36.06 percent, whereas the average actual growth rate was 2.68 percent. The required rate of budget growth in the case of air pollution was 5.68 percent, while the average actual rate was 3.86. We can see clearly that the rate of budget increase keeping the growth rate of pollution at zero is much larger than the actual rate. Figure 5 shows the required rate of budget increase to keep the growth rate of pollution at -1, -2 and -3 percent. We can see in the figure that the rate of environmental budget growth increase geometrically with the decrease in the rate of pollution growth. This means that reducing pollution in a short period of time involves geometrically higher costs than in a long period of time.

On the other hand, the laws of motion also show us the consequences of not appropriating the environmental budget properly. If the rate of growth of environmental budget is smaller than the growth that we calculated in (52) and (53), environmental quality will be deteriorating over time geometrically.

주석 1) Of course, the measured Green GNP is sensitive to the base quarter.

6. Long Run Equilibrium: Balanced Growth Path

(i) Stationarity Inducing Transformation

To facilitate the characterization of the balanced growth path, we will accept the hypothesis that Δ1=Δ2=Λ1=Λ2=0 according to the estimates in the previous section. In addition, we also assume that ϑ = 1 If we accept the hypothesis, the growth rate of the economy can be obtained as:

1 + gdH = ϕd · Nd, (54)

where gdH is the rate of growth of human capital and the variables without subscript denote the value along the balanced growth path of the counterpart with subscript. Now all domestic variables except hours of work and the rental price of capital grows at this rate. To get the balanced growth path, we need to apply changes of variables as follows. Let Xtd and Xtf denote a domestic and foreign variable growing at the rate of gdH and gfH respectively and define the following.

$$\overline{X}_t^d = X_t^d \cdot (1+g_H^d)^{-t} \text{ and } \overline{X}_t^f = X_t^f \cdot (1+g_H^f)^{-t} \tag{55}$$

Using these definitions1), we have to perform stationarity inducing transformation. First, we can transform the preference as follows.

$$U^d = E\left\{ \sum_{t=0}^{\infty} \overline{\beta}^t \cdot \frac{1}{1-\sigma} \left[(\overline{c}_t^{dd})^{\phi_1} (\overline{c}_t^{fd})^{\phi_2} (l_t^d)^{1-\phi_1-\phi_2} \right]^{1-\sigma} \mid \Omega_0 \right\} \tag{56}$$

where the discount factor can be obtained as:

$$\overline{\beta} = \beta \cdot (1+g_H^d)^{\phi_1(1-\sigma)} \cdot (1+g_H^f)^{\phi_2(1-\sigma)} \tag{57}$$

The budget constraint can be transformed as:

$$(1+\tau^{dd})\cdot \bar{c}_t^{dd}+\bar{i}_t^{dd}+\bar{s}_t\cdot[(1+\tau^{fd})\cdot \bar{c}_t^{fd}+(1+g_H^f)\cdot \bar{b}_{t+1}^d]$$

$$\leq(1-\tau^{dw})\cdot \overline{W}_t^d\cdot n_t^d+(1-\tau^{dk})\cdot R_t^d\cdot \bar{k}_t^d+\tau^{dk}\cdot \delta^d\cdot \bar{k}_t^d+\bar{s}_t\cdot(1+r_{t-1})$$

$$\cdot \bar{b}_t^d+\overline{TR}_t^d \qquad (58)$$

where the transfer from the government can be obtained as:

$$\overline{TR}_t^d=\tau^{dw}\cdot \overline{W}_t^d\cdot N_t^d+\tau^{dk}\cdot(R_t^d-\delta^d)\cdot \overline{K}_t^d+\tau^{dd}\cdot \overline{C}_t^{dd}+\tau^{fd}\cdot \overline{C}_t^{fd}+$$

$$\tau^{dr}\cdot \overline{Y}_t^d-\overline{G}_t^{dc}-\overline{G}_t^{di}. \qquad (59)$$

and the real exchange rate is defined as2)

$$\bar{s}_t=\frac{(1+g_H^f)^t}{(1+g_H^d)^t}\cdot s_t$$

Here we assume that tax rates are fixed according to the tax code.

The laws of motions are transformed as follows. To transform the laws of motion for the government expenditures, we assume the following.

$$\frac{\gamma_1}{1-\eta_{dc}} = g_H^d \text{ and } \frac{\gamma_2}{1-\eta_{di}} = g_H^d \qquad (61)$$

That is, we assume that both types of governement expenditure grow at the rate of gHd . Using these assumptions, we can have the following laws of motion for government expenditures.

$$\ln(\overline{G}_t^{dr}) = -\eta_{dr} \cdot \ln(1+g_H^d) + \eta_{dr} \cdot \ln(\overline{G}_{t-1}^{dr}) + w_t^{dr} \qquad (62)$$

$$\ln(\overline{G}_t^{de}) = -\eta_{de} \cdot \ln(1+g_H^d) + \eta_{de} \cdot \ln(\overline{G}_t^{de}) + w_t^{de} \qquad (63)$$

The laws of motion for domestic capital and foreign debt can be obtained as follows.

$$(1+g_H^d) \cdot \overline{K}_{t+1}^d = (1-\delta^d) \cdot \overline{K}_t^d + \overline{I}_t^{dd} \qquad (64)$$

$$(1+g_H^f) \cdot \overline{B}_{t+1}^d = (1+r_{t-1}) \cdot \overline{B}_t^d - \overline{C}_t^{fd} + \overline{C}_t^{df} / s_t \qquad (65)$$

The law of motion for human capital can be obtained as:

$$\overline{H}_{t+1}^d = \left(\frac{N_t^d}{N^d}\right) \cdot \overline{H}_t^d, \qquad (66)$$

where Nd is the hours of work along the balanced growth path. Finally, the resource constraint is transformed as:

$$\overline{C}_t^{dd} + \overline{C}_t^{df} + \overline{I}_t^{dd} + \overline{G}_t^{dr} + \overline{G}_t^{de} = \lambda_t^d \cdot (\overline{H}_t^d \cdot N_t^d)^{1-\theta} \cdot (\overline{K}_t^d)^\theta. \qquad (67)$$

Of course, foreign equations can be transformed in the same way.

(ii) Balanced Growth Path

From the transformed domestic household's problem, we can have the first order conditions for the equilibrium consumption and leisure as follows3)

$$\phi_1(\bar{c}_t^{dd})^{\phi_1(1-\sigma)-1}(\bar{c}_t^{fd})^{\phi_2(1-\sigma)}(l_t^d)^{(1-\phi_1-\phi_2)(1-\sigma)} = (1+\tau^{dd})\Gamma_t^d \tag{68}$$

$$\phi_2(\bar{c}_t^{dd})^{\phi_1(1-\sigma)}(\bar{c}_t^{fd})^{\phi_2(1-\sigma)-1}(l_t^d)^{(1-\phi_1-\phi_2)(1-\sigma)} = (1+\tau^{fd})\Gamma_t^d\,\bar{s}_t + \Psi_t^d \tag{69}$$

$$(1-\phi_1-\phi_2)(\bar{c}_t^{dd})^{\phi_1(1-\sigma)}(\bar{c}_t^{fd})^{\phi_2(1-\sigma)}(l_t^d)^{(1-\phi_1-\phi_2)(1-\sigma)-1}$$

$$= (1-\tau^{dw})\bar{W}_t^d\,\Gamma_t^d \tag{70}$$

$$\Gamma_t^d = q_t^d \tag{71}$$

$$(1+g_H^d)\cdot q_t^d = \bar{\beta}\cdot$$

$$E_t\Big[(1-\delta^d)q_{t+1}^d + \{(1-\tau^{dk})R_{t+1}^d + \tau^{dk}\delta^d\}\Gamma_{t+1}^d\Big] \tag{72}$$

$$(1+g_H^d)\cdot(\bar{s}_t\Gamma_t^d + \Psi_t^d) = \bar{\beta}\cdot E_t\Big[(\bar{s}_{t+1}\Gamma_{t+1}^d + \Psi_{t+1}^d)\cdot(1+r_t)\Big] \tag{73}$$

and the resource constraint for domestic goods. Here Γ_t^d and q_t^d and Ψ_t^d are the Lagrange multiplier attached to the budget constraint, the law of motion for the domestic capital stock and that of the law of motion for the foreign capital debt. The meaning of the first order conditions are standard. (68) says that the multiplier attached to the budget constraint is the marginal utility of income. (69) equates the marginal utility of foreign goods consumption to its cost and (70) balances the marginal utility of leisure (left-hand side) and its marginal opportunity costs (right-hand side). The left-hand side of (72) is the marginal cost of capital accumulation and the right-hand side of the equation is the marginal benefit of it. (73) also equates the marginal cost (left-hand side) and the marginal benefit of foreign asset (or debt) accumulation.

The analogous conditions for the foreign household can be obtained as follows[4]

$$\phi_1(\bar{c}_t^{ff})^{\phi_1(1-\sigma)-1}(\bar{c}_t^{df})^{\phi_2(1-\sigma)}(l_t^f)^{(1-\phi_1-\phi_2)(1-\sigma)}=(1+\tau^{ff})\Gamma_t^f \qquad (74)$$

$$\phi_2(\bar{c}_t^{ff})^{\phi_1(1-\sigma)}(\bar{c}_t^{df})^{\phi_2(1-\sigma)-1}(l_t^f)^{(1-\phi_1-\phi_2)(1-\sigma)}=(1+\tau^{df})\Gamma_t^f/\bar{s}_t+\Psi_t^f \qquad (75)$$

$$(1-\phi_1-\phi_2)(\bar{c}_t^{ff})^{\phi_1(1-\sigma)}(\bar{c}_t^{df})^{\phi_2(1-\sigma)}(l_t^f)^{(1-\phi_1-\phi_2)(1-\sigma)-1}$$

$$=(1-\tau^{fw})\bar{W}_t^f\Gamma_t^f \qquad (76)$$

$$\Gamma_t^f = q_t^f \qquad (77)$$

$$(1+g_H^f)\cdot q_t^f = \bar{\beta}\cdot$$

$$E_t\left[(1-\delta^f)q_{t+1}^f+\{(1-\tau^{fk})R_{t+1}^f+\tau^{fk}\delta^f\}\Gamma_{t+1}^f\right] \qquad (78)$$

$$(1+g_H^f)\cdot(\Gamma_t^f/\bar{s}_t+\Psi_t^f)=\bar{\beta}\cdot E_t$$

$$\left[(\Gamma_{t+1}^f/\bar{s}_t+\Psi_{t+1}^f).(1+\gamma_t)\right] \qquad (79)$$

and the resource constraint for the foreign goods. Once again Γtf qtf and Ψtf are the Lagrange multipliers for the foreign budget constraint, the law of motion for the foreign capital stock and that of domestic asset (or debt) owned by foreigners.

From these conditions, the definition of $\bar{s}_t$ and the first order conditions for the domestic and foreign firms' profit maximization, we can obtain the balanced growth path. To derive the path, we need to specify the steady state requirements. First, since foreign asset (or debt) should not be accumulated in a balanced growth path, the marginal value of foreign asset (or debt) has to be zero.

Ψd= Ψf = 0 (80)

where variables without time subscript denote the value in the balanced growth path. Second, transformed capital stock should not be accumulated and hence we have the following condition between transformed investment capital stock from the law of motion for capital stock.

$$\bar{i}^{dd} = (g_H^d + \delta^d)\cdot \bar{k}^d \qquad (81)$$

$$\bar{i}^{ff} = (g_H^f + \delta^f)\cdot \bar{k}^f \qquad (82)$$

Third, all transformed variables are stationary along the balanced growth path and hence they are constant. With these restrictions, the path is derived in an appendix.

주석 1) Note that $\bar{X}_t^d$ and $\bar{X}_t^f$ do not have trends in them.

주석 2) This is the only exception of the barred variables.

주석 3) We use the individual version of (65) in (58) in deriving the first order conditions.

주석 4) We assume that the preference and technology parameter values are symmetric between domestic and foreign agents.

7. Calibration and Long Run Simulation

(i) Calibration

The values of parameters in preference, technology and laws of motion of water and air pollution are taken from the estimation in section 4. The remaining parameters are tax rates, the share of government expenditures, the rate of capital depreciation and the growth parameter. From the Korean experience, we obtain the following values for the tax rates.

$\tau dd=0.05$, $\tau df=0.0851$, $\tau dw=0.08$, $\tau dk=0.164$

Since there is no available rate for the capital income tax, we use the tax rate on returns on financial assets as τdk. The depreciation rate for buildings is between 5.8 and 6.2.percent, and that for machinery is between 22.2 percent and 30.13 percent. We use an intermediate value, namely $\delta d=0.15$. We vary the value of τde and see what happen to the balanced growth path and welfare.

The values for the share parameters of government expenditures are obtained as follows.

ad=0.1849,ed=0.0002

Here we can see that the proportion of environmental expenditures is strikingly small. For reference, we calculate the share of water and air pollution expenditures in total environmental expenditures as $\Psi=0.904$, i.e. about 90 percent of the environmental budget is devoted to cleaning up water pollution and the remaining 10 percent to cleaning up air pollution.

The parameter in human capital accumulation is determined in the following way. Since the growth in our model is endogenous, determining the value of Ψd is equivalent to determining the growth rate of the economy along a balanced growth path. One important fact we have to note is that the growth rates of those growing variables are the same along a balanced growth path. However, we know that the growth rates of aggregate variables in an economy, especially in an economy growing vigorously like Korean economy, are not the same and hence we cannot determine the growth rate of the economy simply by looking at the growth rate of

GDP (or GNP). We calculate the mean growth rates of GDP, domestic and foreign goods consumption and government expenditures, and then obtain a rate by averaging those rates with weights. The number from this exercise is 0.03478 (3.478 percent) and we determine the value of Ψd to have the same growth rate in the model. The implied value is: $\Psi d=1.60248$. On the other hand, since the average growth rate of foreign countries, especially that of trading partners of Korea, is smaller than the Korean rate, we use $\Psi f=1.58328$, which implies 1.5 percent growth for foreign countries.

(ii) Findings

We use the values of parameters in the balanced growth path solution obtained in the appendix and try to get answers to various questions we have had in mind.

We ask first what happens to the growth rate of the economy if we increase the environmental tax rate. In Figure 6, we plot the response of the growth rate of the economy to an increase in the rate of environmental tax. We can see in the figure that the rate of growth decreases monotonically with the tax rate and the slope of the curve is about 0.435. That is, the growth rate of the economy will decrease by about 0.435 percent as the environmental tax rate increases from zero to one percent of GDP. In our model the environmental tax affects the level of pollution in two ways. First, increasing environmental tax rate means more resources that can be used to reduce pollution level and second, higher tax rate implies slower growth, which means fewer sources of pollution due to less production and consumption. The model implies that appropriating proper amount of environmental budget is important but that far more important thing in terms of reducing pollution is to reduce the sources of pollution, namely production and consumption in our model1)

Next we ask how large the size of the welfare costs of environmental tax is. We calculate the welfare costs in the following way. Let $(utd)^*$ and $(utd)^\tau$ denote the period transformed utilities in t when $\tau de=0$ and $\tau de=\tau$ respectively [see(56)] and let χt be the amount of compensation in terms of some percentage of consumption which makes the period utilities before the transformation the same. Then we can have the following.

$$\left[(1+\bar{g}_H^d)^{\phi_1(1-\sigma)}(1+\bar{g}_H^f)^{\phi_2(1-\sigma)}\right]^t \cdot (u_t^d)^{\tau} \cdot (1+x_t)_t^{(\phi_1+\phi_2)(1-\sigma)}$$

$$=\left[(1+\hat{g}_H^d)^{\phi_1(1-\sigma)}(1+\hat{g}_H^f)^{\phi_2(1-\sigma)}\right]^t \cdot (u_t^d)^{*} \qquad (83)$$

where gH-d and gH^d are the growth rate of the economy when τde=τ and τ de = 0 respectively. Hence the rate of compensation xt can be obtained as:

$$x_t = \left(\frac{(u_t^d)^*}{(u_t^d)^{\tau}}\right)^{\frac{1}{(\phi_1+\phi_2)(1-\sigma)}} \cdot \left(\frac{1+\bar{g}_H^d}{1+\hat{g}_H^d}\right)^{\frac{\phi_1}{\phi_1+\phi_2}t} \cdot \left(\frac{1+\bar{g}_H^f}{1+\tilde{g}_H^f}\right)^{\frac{\phi_2}{\phi_1+\phi_2}t}, \qquad (84)$$

where we know that (udt)* and (udt)τ are constant along the balanced growth path and gH-d < gH^d. In other words, the rate of compensation is increasing along the balanced growth path and this is due to the fact that an increase in the environmental tax rate reduces the growth rate of the economy. We may calculate the fixed rate of compensation from the time varying compensation. Let x denote the fixed rate of compensation in terms of consumption. Then we have:

$$\sum_{t=0}^{\infty} \beta^t \cdot x_t = \sum \beta^t \cdot x, \ \ i.e.\ x=(1-\beta)\cdot \sum_{t=0}^{\infty} \beta^t \cdot x_t. \qquad (85)$$

Here we have to note that if the environmental tax rate is too high xt may grow faster than 1/β and hence x becomes infinite. However, our result shows that we do not need the tax rate which is that high.

Figure 7 shows how x responds to an increase in the environmental tax rate. Once again we can see that the welfare costs of an increase in the environmental tax rate are increasing monotonically. The slope of the cost curve is about 5.15, which means that if we increase the environmental tax rate from zero to one percent, the welfare costs will increase from zero percent to 5.5 percent of total consumption. We think this is a substantial amount compared to the results in the literature (see, for example, Cooley and Hansen (1992a, 1992b)).

However, note that we have an endogenous growth in the model, while there has not been an endogeneity in growth in any model studying the costs of distortionary taxes. One interesting fact in Figure 7 is that foreign welfare is also decreasing substantially as the domestic country (Korea) increases the rate of environmental tax. As Korea increases the rate by one percent, foreign welfare costs will be about 3.5 percent of total consumption. In sum, Figure 7 tells us that environmental policies across countries have to be coordinated.

We also simulated the effects of the tax on output, domestic goods consumption, export and total hours of work. These effects are depicted in Figures 8, 9, 10 and 11. We can easily detect the similarity among Figures 8,9 and 10 and the similarity comes from the characteristics of a balanced growth path. The figures show that if the tax rate increases by one percent, output, consumption and export decrease by about 0.91 percent. However, the welfare costs will increase in the long run due to a fall in the growth rate. Of course, the welfare costs will increase more with the tax rate. Figure 11 shows quite a different response of total hours of work to an increase in the rate of environmental tax rate. In the case of hours of work, the initial period response will not change over time. This result is from the construct of CES utility function. The figure shows that hours of work will decrease about 0.41 percent with one percent increase in the tax rate.

Finally, we ask how the rate of changes in environmental quaity vary with environmental tax and expenditures. Figure 12 depicts the rate of changes. If we keep the current environmetal policies, the quality of water (BOD in our case) will deteriorate by about 0.6 percent per quarter and the quality of air (SO_2 in our case) will improve by about 0.4 percent per quarter. However, we know that water pollution is the more serious problem in Korea than air pollution and hence we calculate the required increase in the tax rate (or environmental expenditures) which keeps the quality of water constant at the current level. Figure 12 shows that it is about one percent of GDP. This number is much larger than the mean of environmental budget for the period between 1983 and 1992, which was 0.02 percent of GDP. The Korean Government announced recently that it will increase substantially environmental enpenditures in the budget of the fiscal year 1995. Although this is a desirable change in the environmental policy, we believe that the environmental budget is not large enough to reduce the water pollution.

주석 1) Of course, we acknowledge that technological progress in environmental industry may have significant implications in this respect.

8. Increases in Environmental Efficiency, Growth and Welfare Costs

The coefficient estimates in the laws of motion of water and air pollution in (44) and (45) reflect the efficiency of environmental expenditures, market and home production. That is, if the absolute value of the coefficient of Gtde is large, environmental government expenditure is efficient in reducing pollution and vice versa. On the other hand, if the coefficients of Ytd and Ctdd are large, the market and home production are inefficient in the sense that the amount of pollution is large, given an amount of output in home and market production. However, the coefficients of these variables cannot be considered to be constant in the long run. As they invest in environmental protection technologies and develop more efficient ones, these coefficients will change. If we are to examine the effectiveness of environmental investment, we need to calculate the costs and benefits of the investment. However, the data on environmental investment are scarce and hence we cannot obtain the costs and benefits directly from the data. Although we cannot calculate in our model the costs of improving environmental technologies, we are fortunate enough to calculate the benefits of environmental investment and thus we can obtain the upper limit of environmental investment indirectly.

In this section, we simply ask how much effect changes in the coefficients have on growth and welfare of the economy. These analyses, we think, can shed light on how much environmental investment is needed. If there is an increase in the efficiency in environmental government expenditures, we need lower environmental tax rate to keep the growth rate of pollution constant at some level. This means that the curves in Figure 12 shift to the left. We depict these shifts in Figures 13 and 14 where the efficiency of environmental expenditures increases by 100, 200 and 300 percent respectively. Those figures show that increasing the efficiency of environmental expenditures by 100 percent will reduce the tax rate by about 0.15 percent (of GNP) in the case of BOD and by about 0.31 percent in the case of S2. Reducing tax rate will have growth and welfare effects which we have discussed so far, i.e. growth rate increases and the welfare costs decrease.

We measure the effects first by changing the efficiency of environmental government expenditures1) Figure 16 shows how much growth rate increases with improvement in the expenditure technology.2) According to the figure, if the efficiency increases by 10 percent, the growth rate will increase by about 0.032 percent and if the efficiency increase 100 percent (i.e. two times), it will increase by about 0.32 percent. The resulting welfare increase is shown in Figure 16. If the expenditure efficiency increases by 10 percent, welfare costs will be saved by about 0.095 percent and if the efficiency increases by 100 percent (two times), the costs will be saved by about 0.95 percent (of consumption). These numbers look small but recall that they are costs in each period. If we calculate the discounted sum over the life-time of the stand-in consumer, we can see in Figure 17 that savings in the costs cannot be ignored. If the efficiency increases by 10 percent, the lifetime costs saving will be about 3.56 percent of current consumption. If we reinterpret the results, we can say that if the costs of improving the efficiency of environmental government expenditures3) by 10 percent are less than 3.56 percent of current consumption, then it is worthwhile to improve the efficiency of environmental expenditure4) We believe that a lot of improvement can be made in this area.

The same kind of exercises is done in the cases of market and home production. The case of market production is depicted in Figures 18 and 19. Figure 18 shows the growth effect of increases in the environmental efficiency in market production. As we can see in the figure, the effect is much larger in the case of market production than in the case of environmental expenditures. If the efficiency in the market production increases by 10 percent, the growth rate will increase by about 1.071 percent. This is really a hugh number. However, we believe that improving the environmental efficiency of market production is much harder than improving that of environmental government expenditures and hence much more investment is required. Figure 19 shows the welfare gains of improving environmental efficiency in market production. If there is 10 percent improvement in the environmental efficiency, welfare costs will be saved by about 3.186 percent of current consumption. The discounted sum of the lifetime welfare gains is about 118.44 percent of current consumption and thus we can say that if the discounted total costs of increasing environmental efficiency of market production by 10 percent are less than 118.44 percent of current consumption, it is better to improve it.

Figures 20 and 21 show the growth and welfare effects in the case of home production. The numbers are smaller in this case than in the case of market production and larger than in the case of environmental government expenditures. Now, 10 percent improvement in environmental efficiency in home production will increase the growth rate by 0.261 percent and the costs will be reduced in each period by 0.777 percent of current consumption.

In sum, improving the environmental efficiency in market and home production involves much larger growth and welfare effect than improving that in environmental government expenditures. We think that it is much more difficult to improve the efficiency in market and home production. However, the costs of improving the efficiency, we believe, are well justified by the numbers we have obtained form the model.

주석 1) We add up the the effects on BOD and SO2 using the expenditure weights discussed in the previous section.

주석 2) We calculate the reduction in the tax rate arbitrarily assuming that the growth rate of BOD is 0.265 percent and that of So2 is −0.726. We think that changing these rates will not affect the result drastically.

주석 3) Of course, this is the environmental cleanup technology.

주석 4) Here we have the problem of intergenerational income redistribution. Although the improved technology will be in effect forever and hence future generations will benefit from it, the costs of improvement are incurred by the current generation.

9. Summary and Conclusion

We have constructed an international general equilibrium model with two countries and two goods with pollution externalities in production and consumption. The model has been built up with an urgent purpose of analyzing the impact of so-called Green Round and of introducing an environmental tax on the economy. We first estimated the model and then simulated the model. The utility parameters were estimated using GMM estimation method. The most important finding in the estimation is that the productivity effect of pollution in home production is almost the same as the direct negative taste effect. The production parameters were estimated using dummy variables and differencing due to the fact that output, capital stock and total hours of work are integrated. We found from the estimation that the productivity effect of pollution in market production is also almost the same as the direct negative effect of pollution on production. In sum, we found that the net effect of pollution on preferences and production is close to zero and in addition we cannot reject the hypothesis that the net effect is actually zero.

Next we calibrated and simulated the model along the balanced growth path and hence the simulation is on the long run properties of the model economy. In determining the parameter values which we did not estimate, we used Korean data. The simulation results shows that introducing environmental tax to clean up water and air pollution may have significant growth effects. According to our calculation, one percent environmental tax implies 0.435 percent decrease in the GDP growth rate. Due to the growth effect, environmental tax may have substantial welfare effect. The simulation shows that the welfare costs associated with one percent environmental tax is about 5.15 percent of total consumption. This is much larger than any estimate of the welfare costs of distortionary taxes and this is due to the introduction of endogenous taxes. Finally, the simulation shows the rate of environmental tax which is required to keep the water pollution constant at the present level. It is about one percent of GDP, which is a lot higher than the current environmental budget.

The costs of improving environmental efficiency in government expenditures on environment, market and home production are difficult to obtain. However, the benefits of it can be calculated easily in our model. The benefits of improving environmental efficiency are largest in the case of market production and smallest in the case of environmental government expenditures. This means that given the costs of improving given level efficiency, improving the environmental efficiency of market production is most urgent.

Although we believe that many of the results obtained in the paper are robust in many respects, we also acknowledge many limitations of the study. First, our analyses are limited by the data used in the project. We have used only BOD as the measure of water pollution and only SO2 as the measure of air pollution. However, it is well known that there are many other factors polluting water and air. The only reason that we have used only BOD and SO2 is that we do not have enough observations in the case of other polluting factors. If an opportunity is given to us in the future when enough data points are available, we have every willingness to introduce many other polluting factors in our analyses. Second, we have constructed an international model, estimated only the domestic country, namely Korea, and then assumed the estimates are the same across countries. However, this may not be true and especially the parameters affecting the effects of pollution may be substantially different depending on the cultural and econo-sociological factors specific to a country. We cannot estimate foreign country's parameters basically due to two facts. First, it is not easy in a two country international model to specify the foreign countries. Second, we cannot have enough international data set.

Some other limitations of the paper can be improved easily in the future. First, we have looked at only the tax on output and hence we have implicitly assumed that pollution expenditures are financed by taxing producers. However, consumers are also polluting water, air and the nature and hence we have to consider financing environmental expenditure by taxing consumers. One interesting question here is which tax is more efficient and what combination of taxes is optimal. In addition, we need to derive the optimal tax rate, given a type of tax. Second, we have not analyzed the short run behavior of the model with uncertainty and shocks. We believe this can be done easily and we plan to look into it soon. Third, the model can be used to analyze the size of costs and the time periods of cleaning up pollution to meet some international standard.

Finally, we do not think we have arrived at a definite result in the paper. We believe we have opened up the possibility of applying open economy general equilibrium models in analyzing many environmental issues. If this line of research is worthwhile to pursue, the next step, we believe, is to develop more elaborate ones.

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Appendix : Balanced Growth Patd

The balanced growth path discussed in the text can be obtained as follows. First, define the following.

$$F_1 = \frac{(1+\tau^{dd})\phi_2}{(1+\tau^{fd})\phi_1}$$

$$F_2 = \left[\frac{(1+g_H^d)/\bar{\beta} - 1 + \delta^d(1-\tau^{dk})}{(1-\tau^{dk})(1-\tau^{dw})\theta\lambda^d(H^d)^{1-\theta}}\right]^{\frac{1}{\theta-1}}$$

$$F_3 = \frac{(1+\tau^{dd})(1-\phi_1-\phi_2)}{\phi_1(1-\tau^{dw})(1-\tau^{dk})(1-\theta)\lambda^d F_2^{\theta}(\bar{H}^d)^{1-\theta}}$$

$$F_4 = \frac{(1+\tau^{fd})\phi_1}{(1+\tau^{ff})\phi_2}$$

$$F_5 = \left[\frac{(1+g_H^f)/\bar{\beta} - 1 + \delta^f(1-\tau^{fk})}{(1-\tau^{fk})(1-\tau^{fw})\theta\lambda^f(\bar{H}^f)^{1-\theta}}\right]^{\frac{1}{\theta-1}}$$

$$F_6 = \frac{(1+\tau^{ff})(1-\phi_1-\phi_2)}{\phi_1(1-\tau^{fw})(1-\tau^{fk})(1-\theta)\lambda^f F_5^{\theta}(\bar{H}^f)^{1-\theta}}$$

$$F_7 = (1-a^d-e^d)\lambda^d(\bar{H}^d)^{1-\theta}(F_2)^{\theta-1}$$

$$F_8 = (1-a^f-e^f)\lambda^f(\bar{H}^f)^{1-\theta}(F_5)^{\theta-1}$$

$$F_9 = \frac{F_7 - (\delta^d + g_H^d)}{1+F_1}$$

$$F_{10} = \frac{F_8 - (\delta^f + g_H^f)}{1+1/F_4}$$

where a's are non-environmental government purchases as a fraction of total output and e's are environmental government expenditures as a fraction of output. We assume that these are given. Using these definitions, we can derive the balanced growth path as follows

$$N^d = \frac{1}{1+F_2F_3F_9}$$

$$\overline{K}^d = F_2 \cdot N^d$$

$$\overline{C}^{dd} = F_9 \cdot \overline{K}^d$$

$$\overline{C}^{df} = F_1 \cdot \overline{C}^{dd}$$

$$N^f = \frac{1}{1+F_5F_6F_{10}}$$

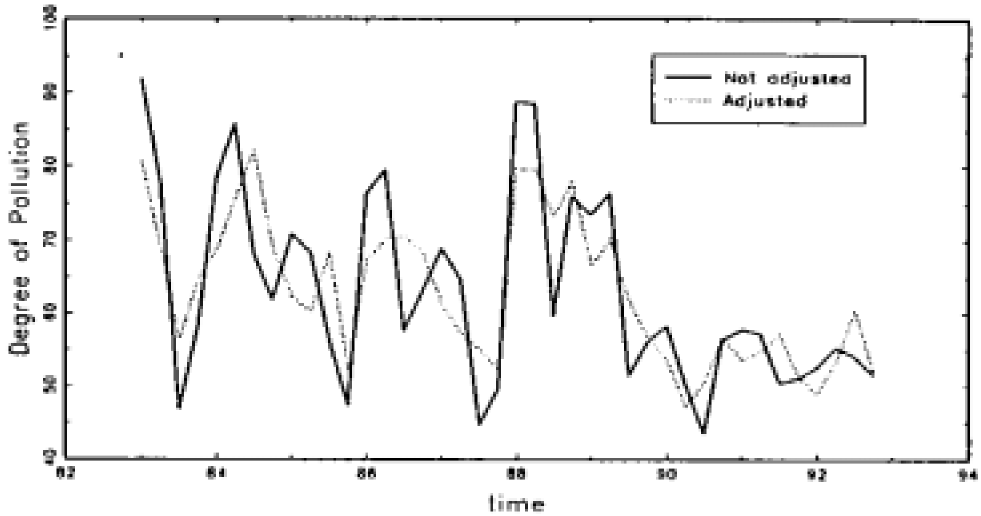
$$\overline{K}^f = F_5 \cdot N^f$$

$$\overline{C}^{ff} = F_{10} \cdot \overline{K}^f$$

$$\overline{C}^{fd} = \frac{1}{F_4} \cdot \overline{C}^{ff}$$

Figure 1 : Data Description

(A) Water Pollution - BOD



(B) Air Pollution - SO_2

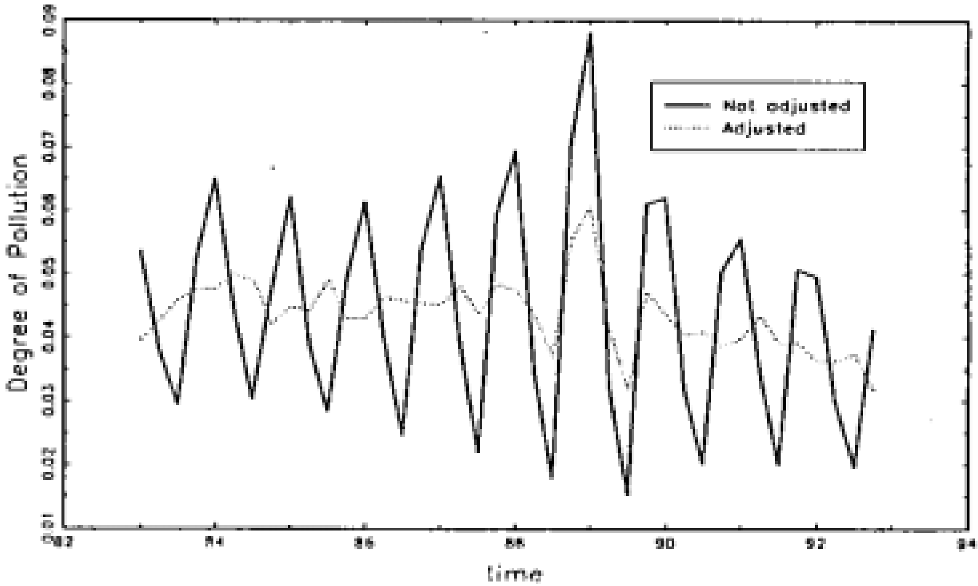
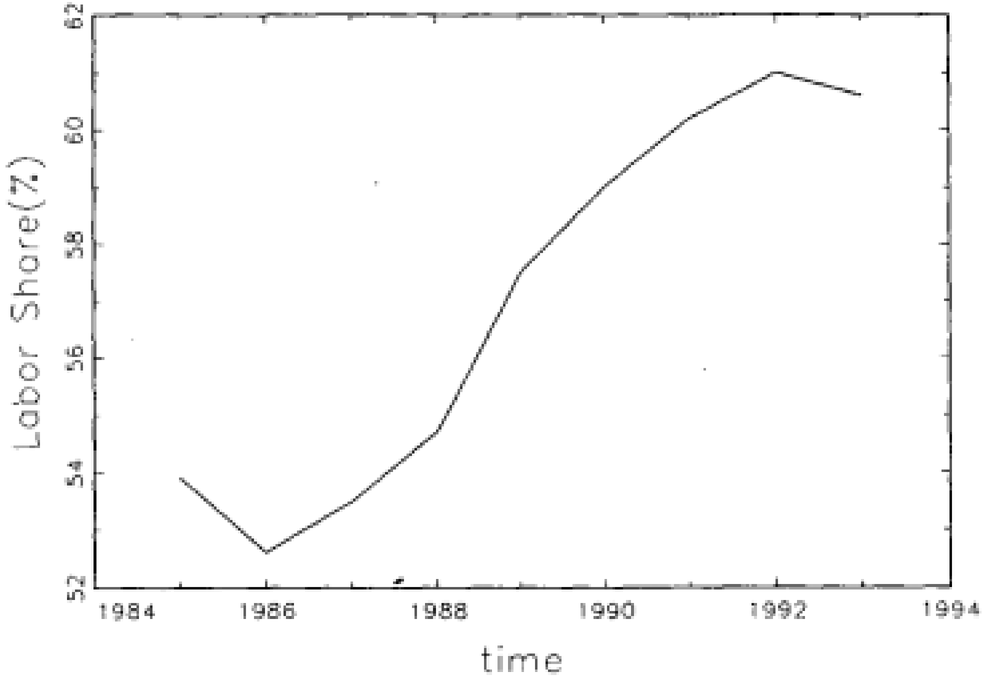


Figure 2 : Labor Share



Data source: Bank of Korea

Figure 3 : Green GNP of Korea(1983.3=1)

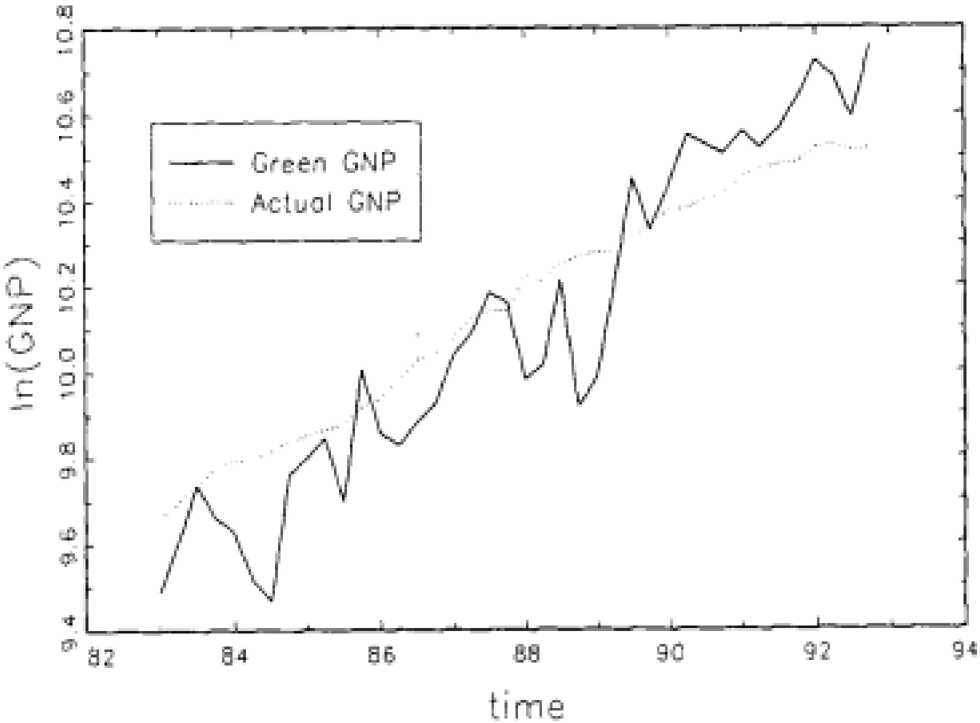
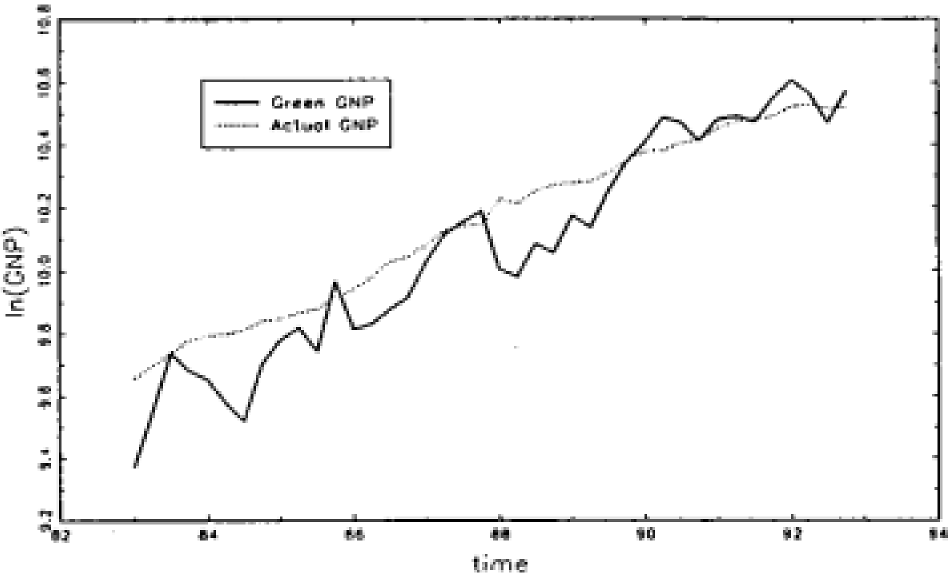


Figure 3a (A) Green GNP for Korea(BOD 1983.3=1)



(B) Green GNP for Korea (SO_2 1983. 3=1)

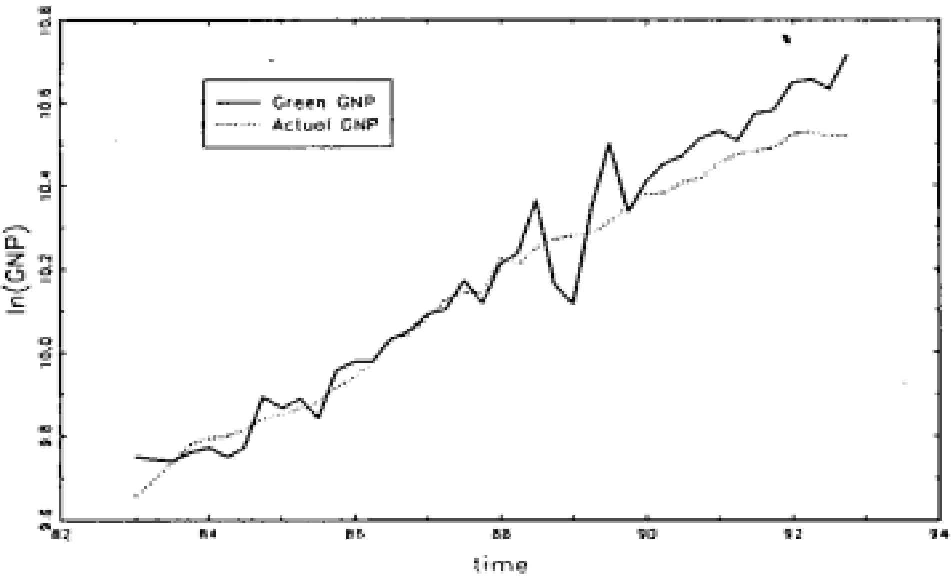
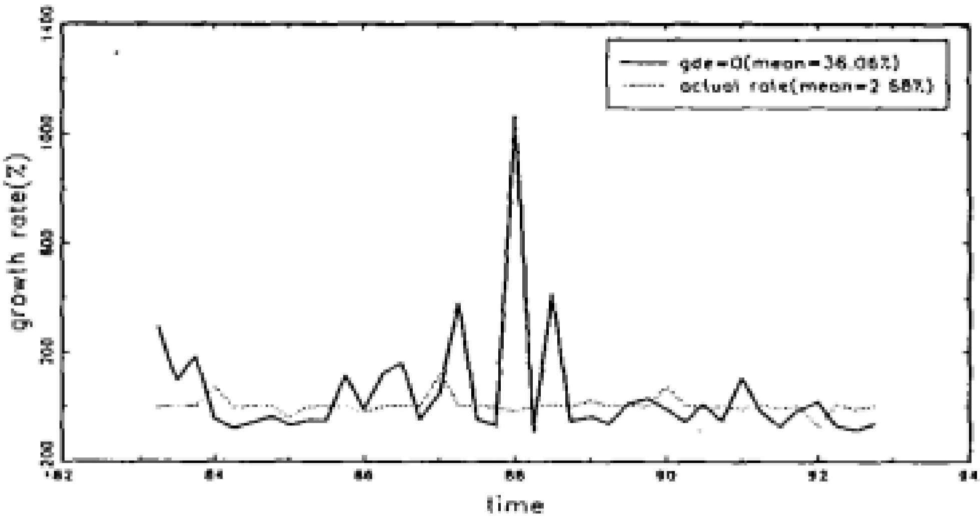


Figure 4 : The Rate Budget Increase : Pollution Increase=0%

(A) Required Growth Rate of Expenditure : Water (Gde=0)



(B) Required Growth Rate of Expenditure : Air (Gda=0)

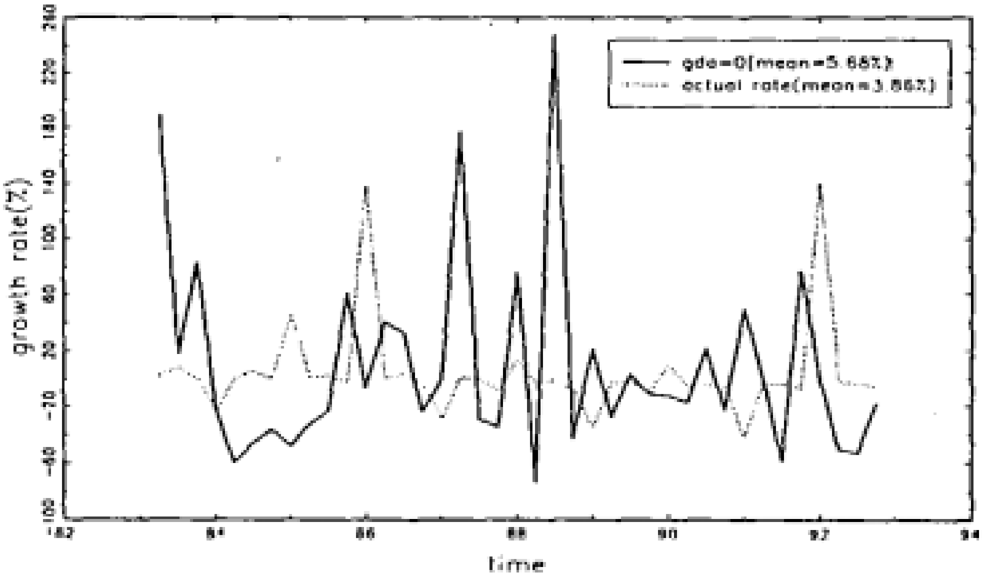
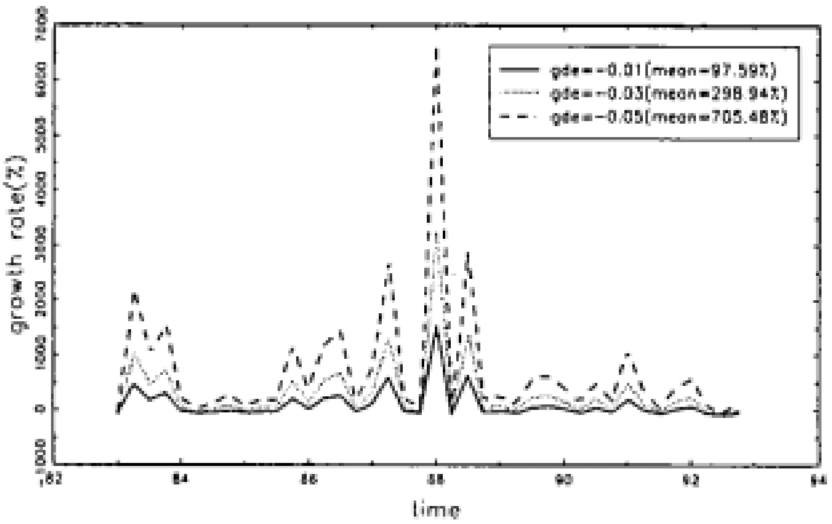


Figure 5 : The Rate of Budget Increase : Pollution Increase=-1, -3, -5%

(A) Req'd Growth Rate of Expenditure : Water(Gde= -0.01, -0.03, -0.05)



(B) Req'd Growth Rate of Expenditure : Air(Gda= -0.01, -0.03, -0.05)

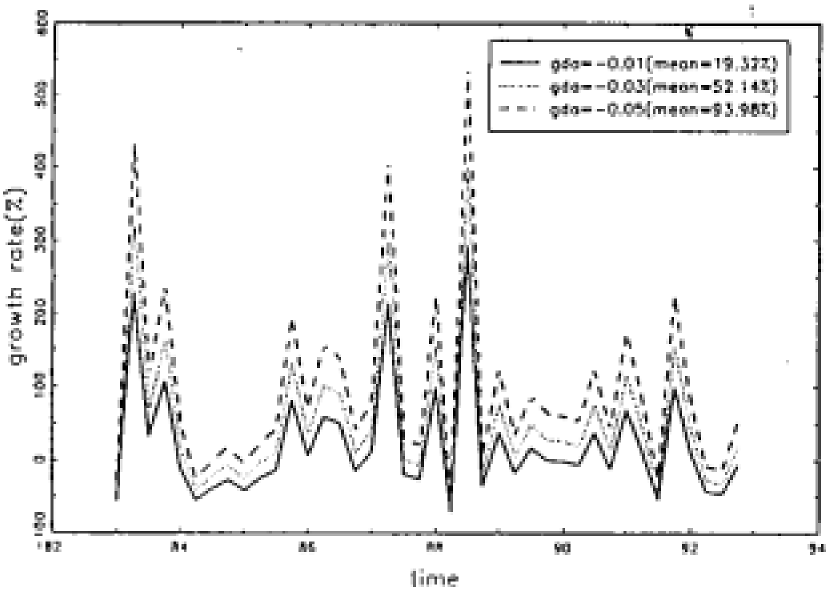


Figure 6 : Effects on the Growth Rate

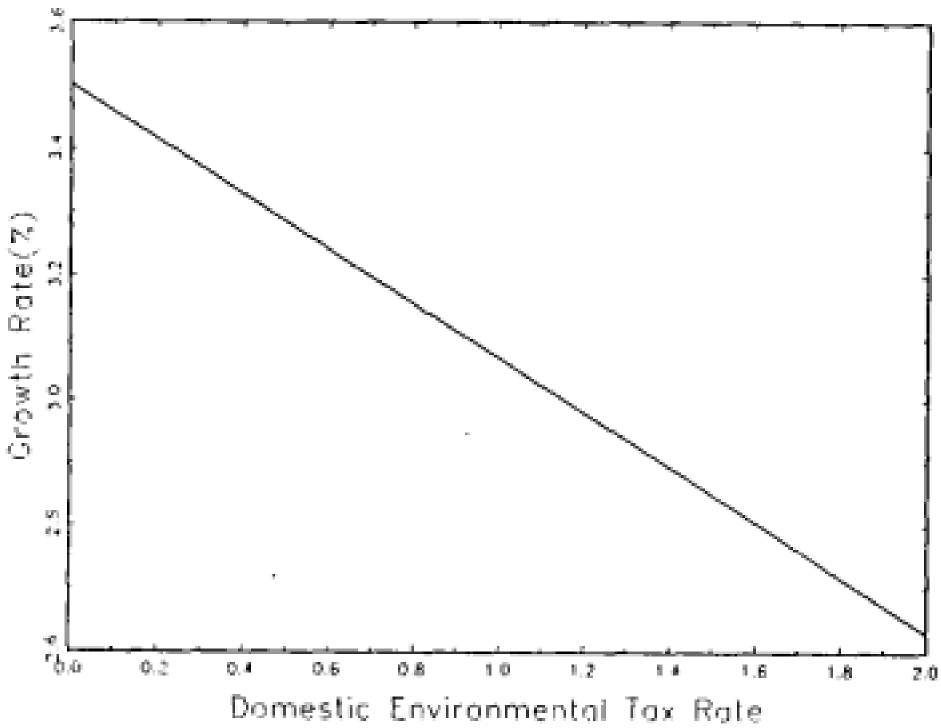


Figure 7 : Welfare Costs of Environmental Tax

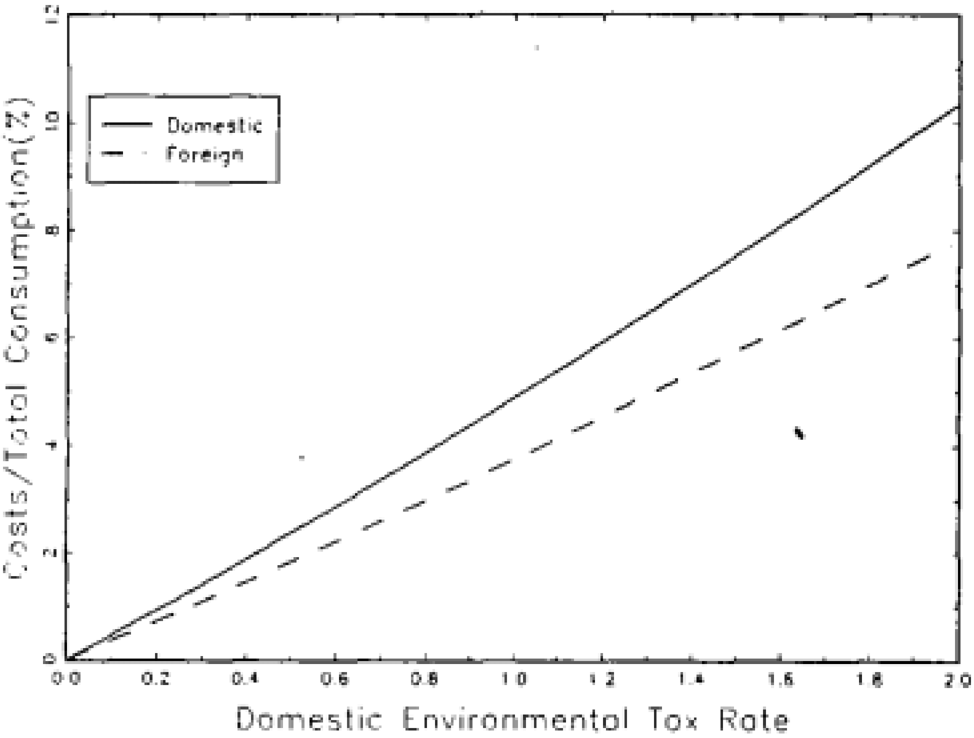


Figure 8 : Effects on Output

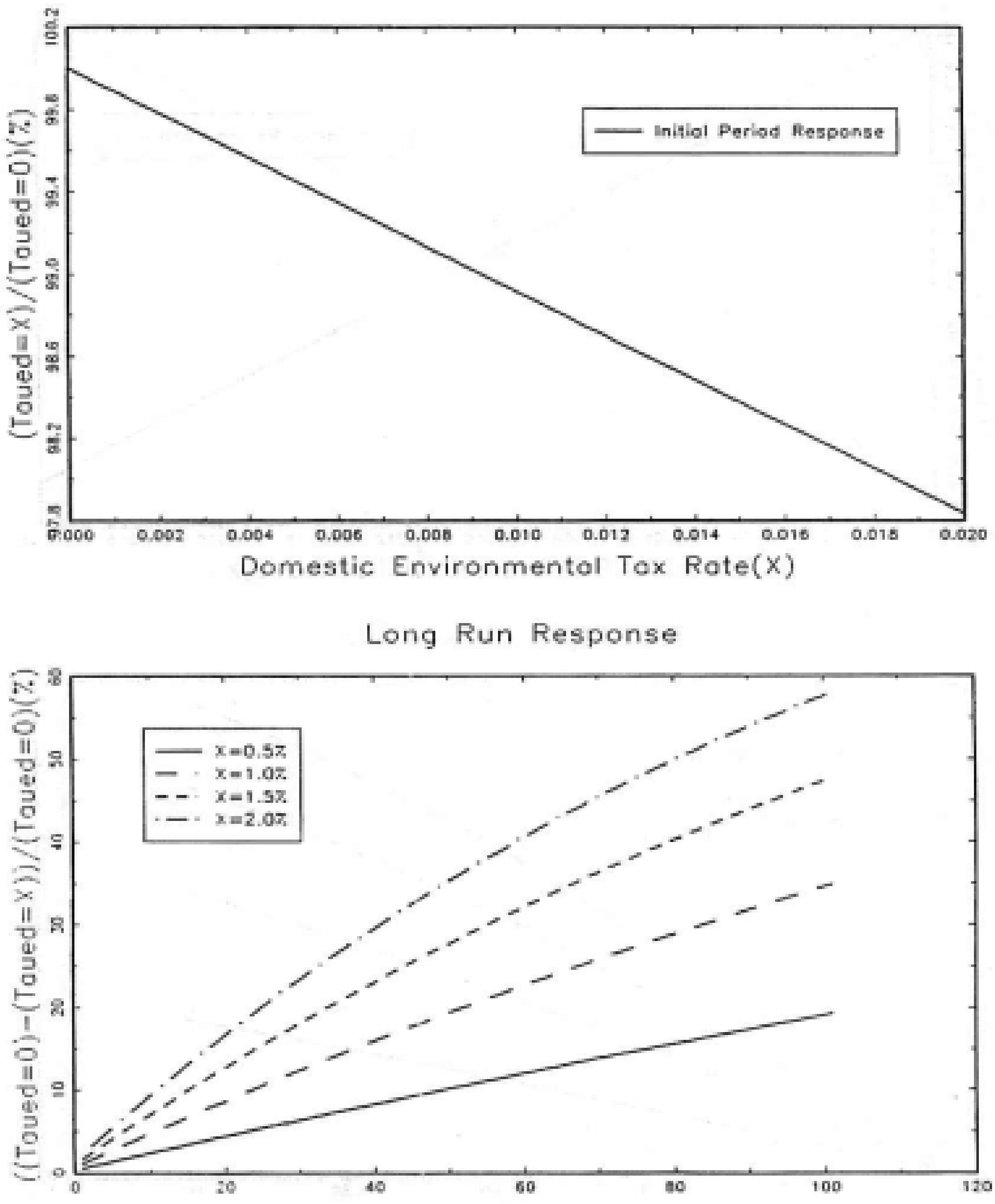


Figure 9 : Effects on Domestic Goods Consumption

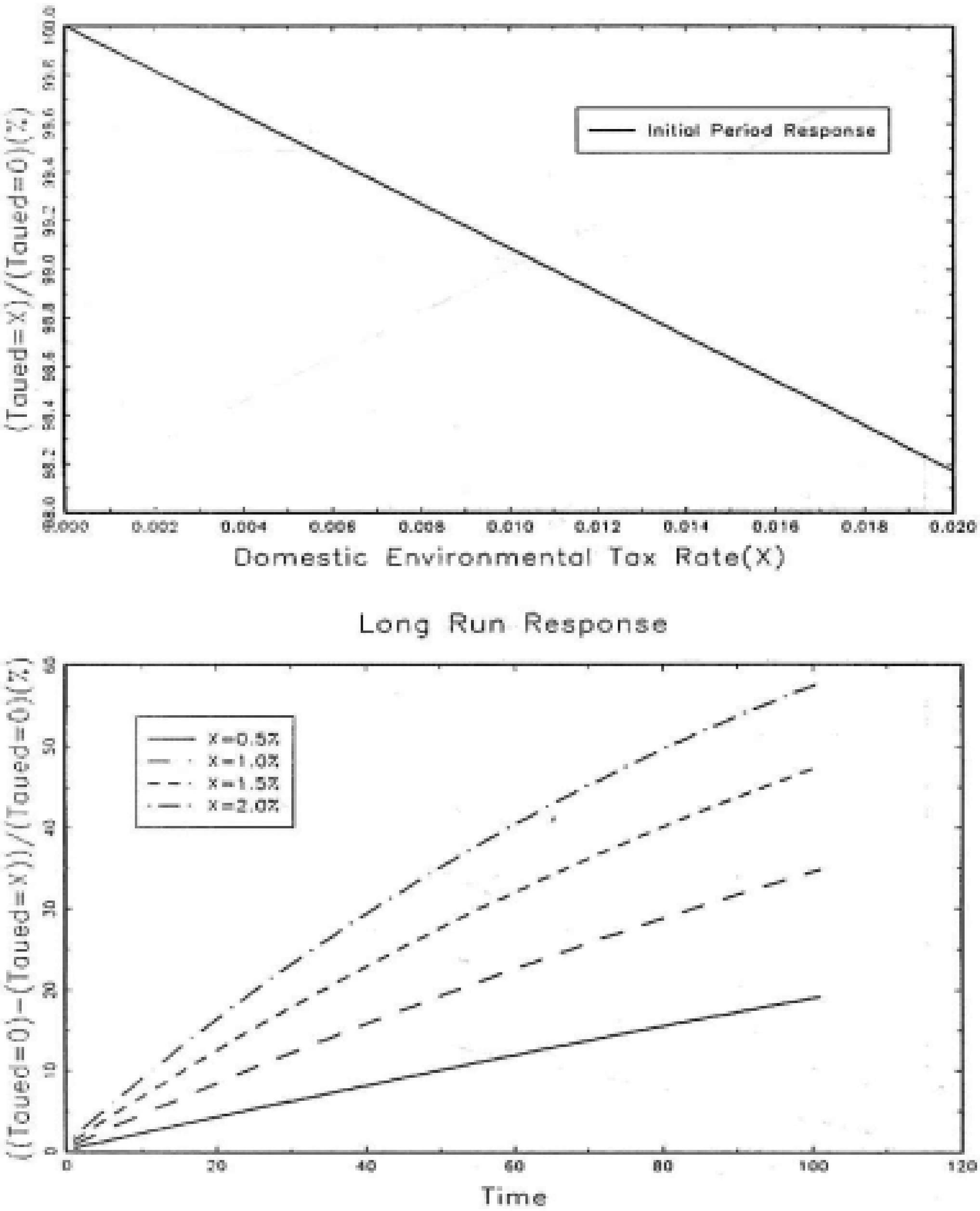


Figure 10 : Effects on Export

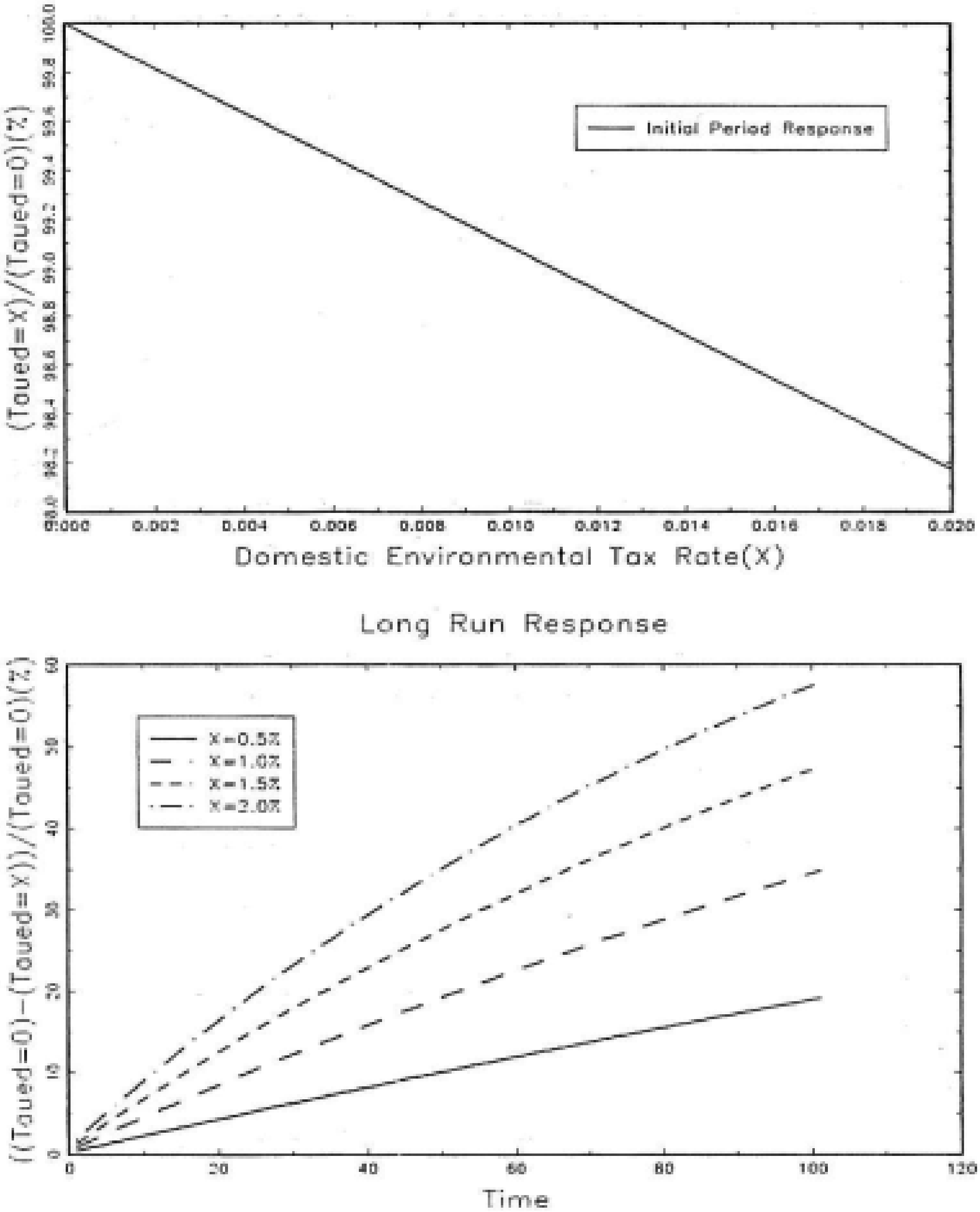


Figure 11 : Effects on Hours of Work

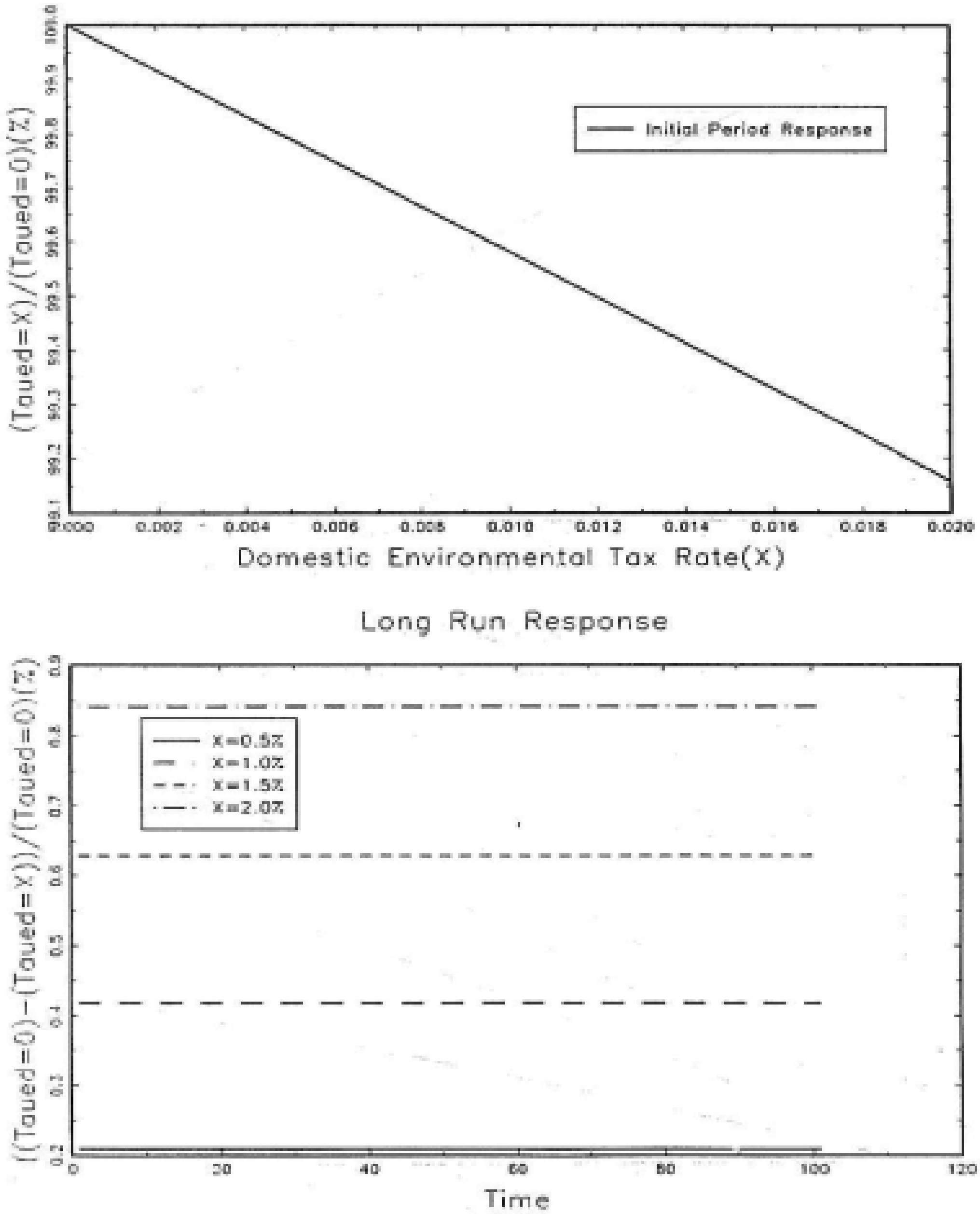


Figure 12 : Rete of Pollution Increase

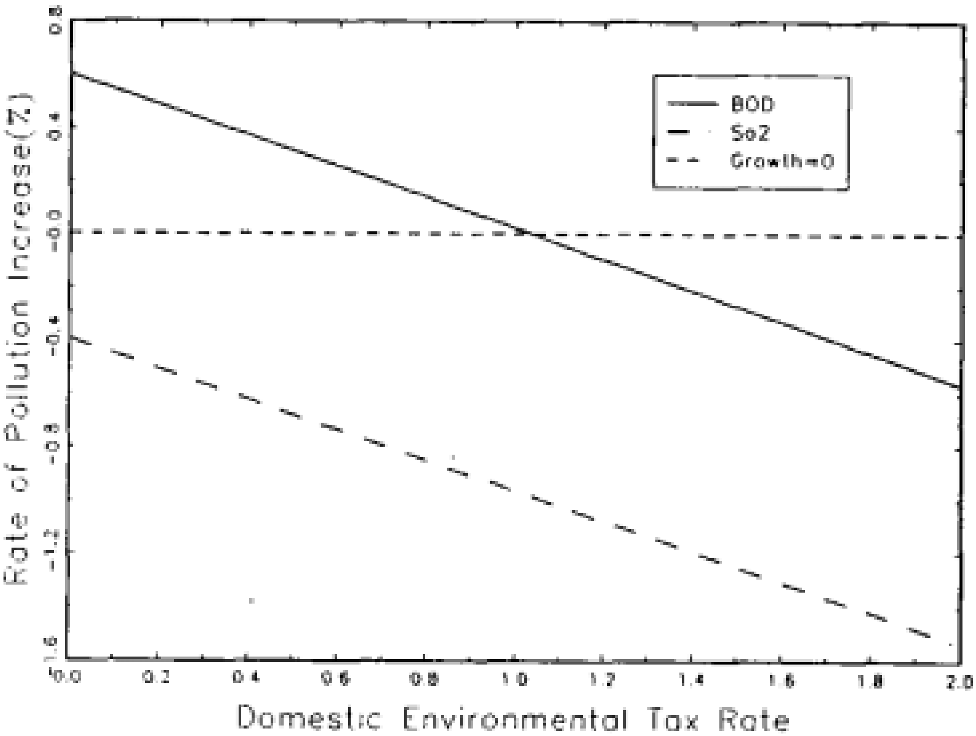


Figure 13 : Expenditure Efficiency and Pollution : BOD

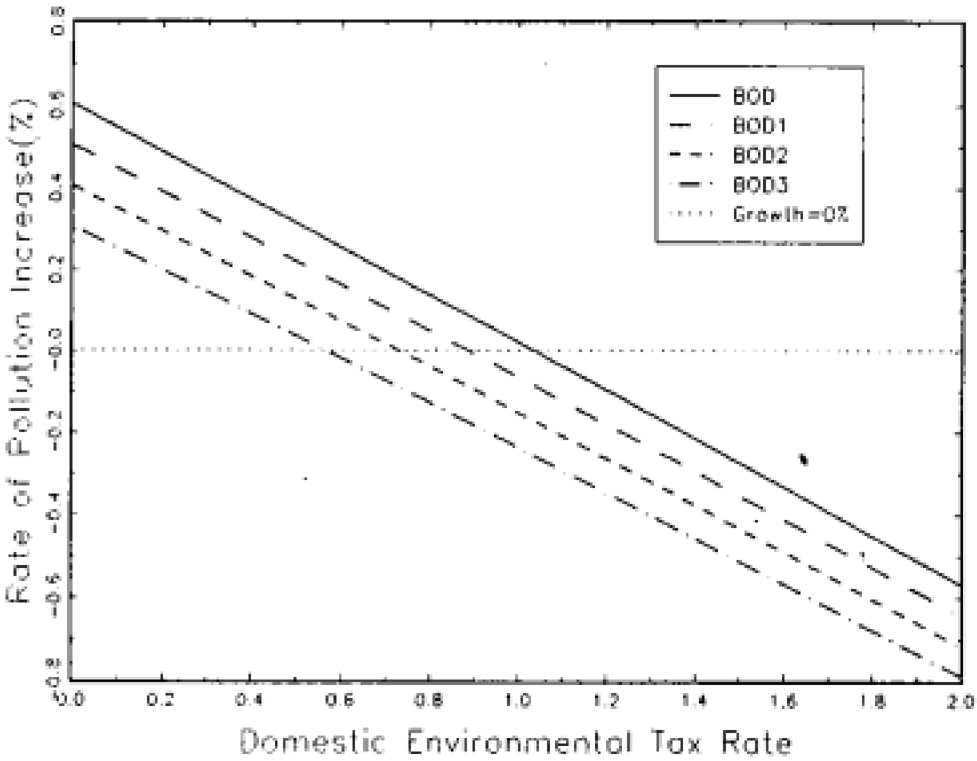


Figure 14 : Expenditure Efficiency and Pollution : SO2

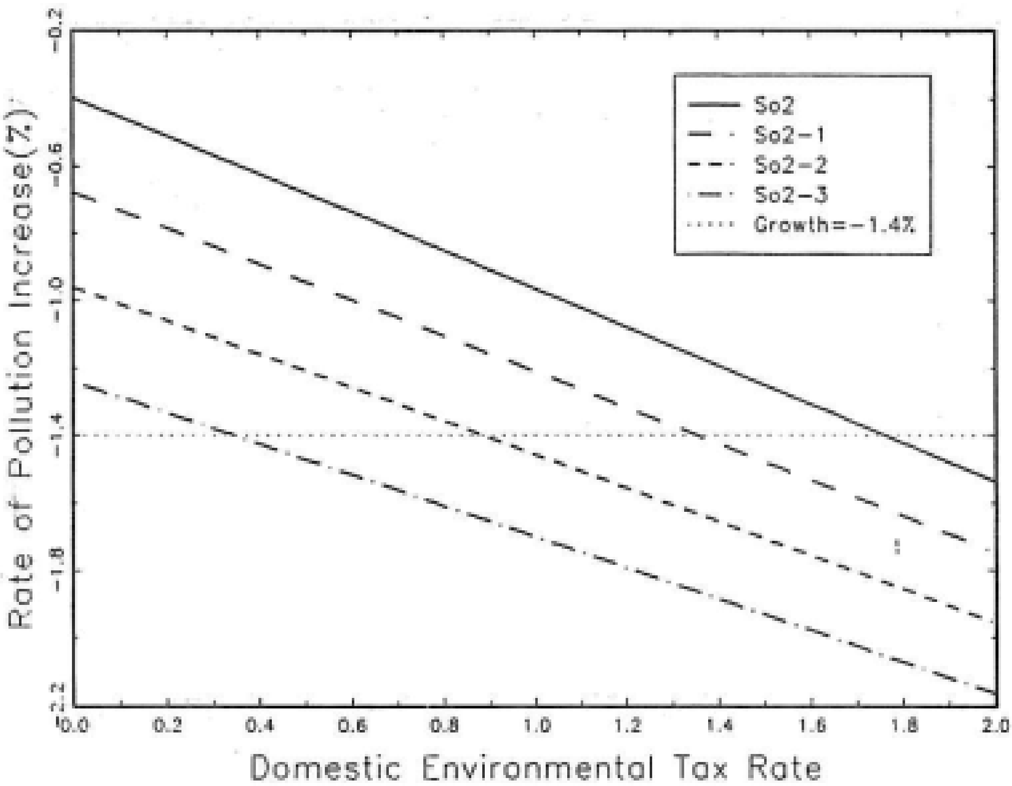


Figure 15 : Expenditure Efficiency and Growth

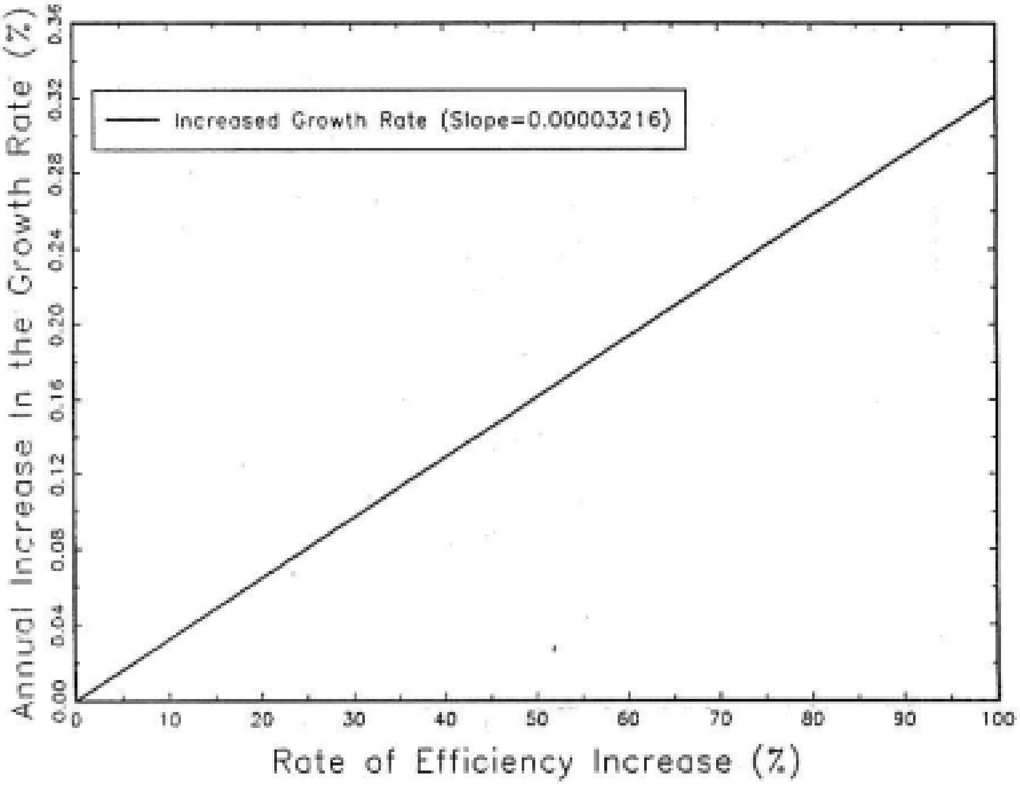


Figure 16 : Expenditure Efficiency and Welfare Costs

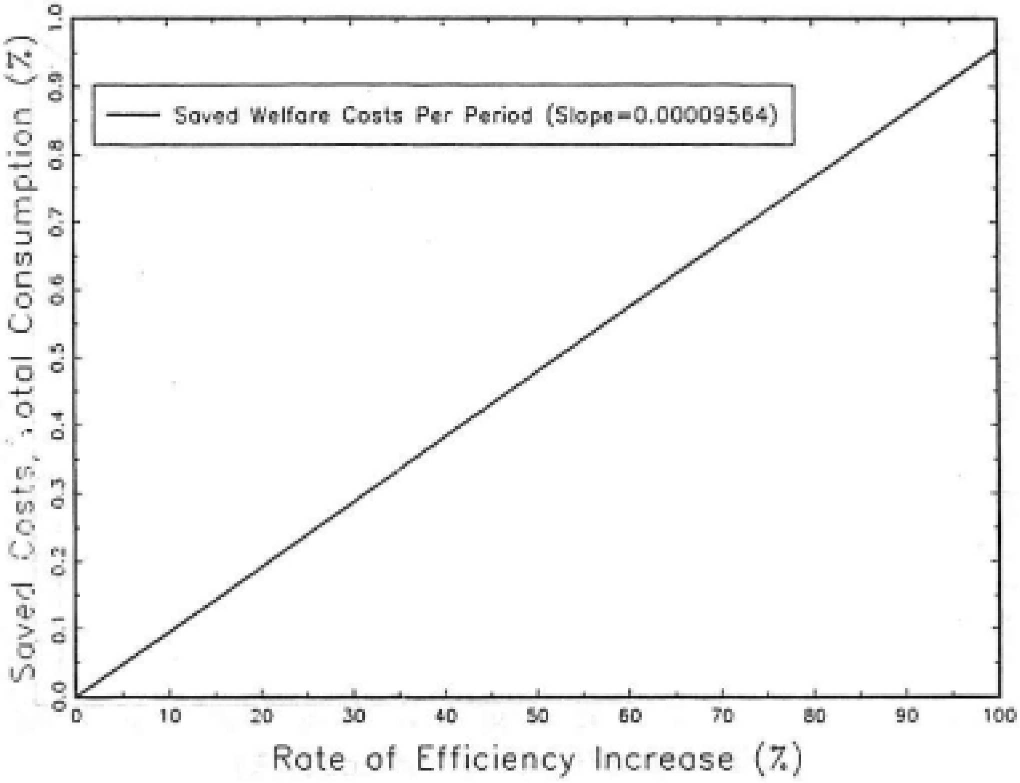


Figure 17 : Total Discounted Sum of Saved Welfare Costs

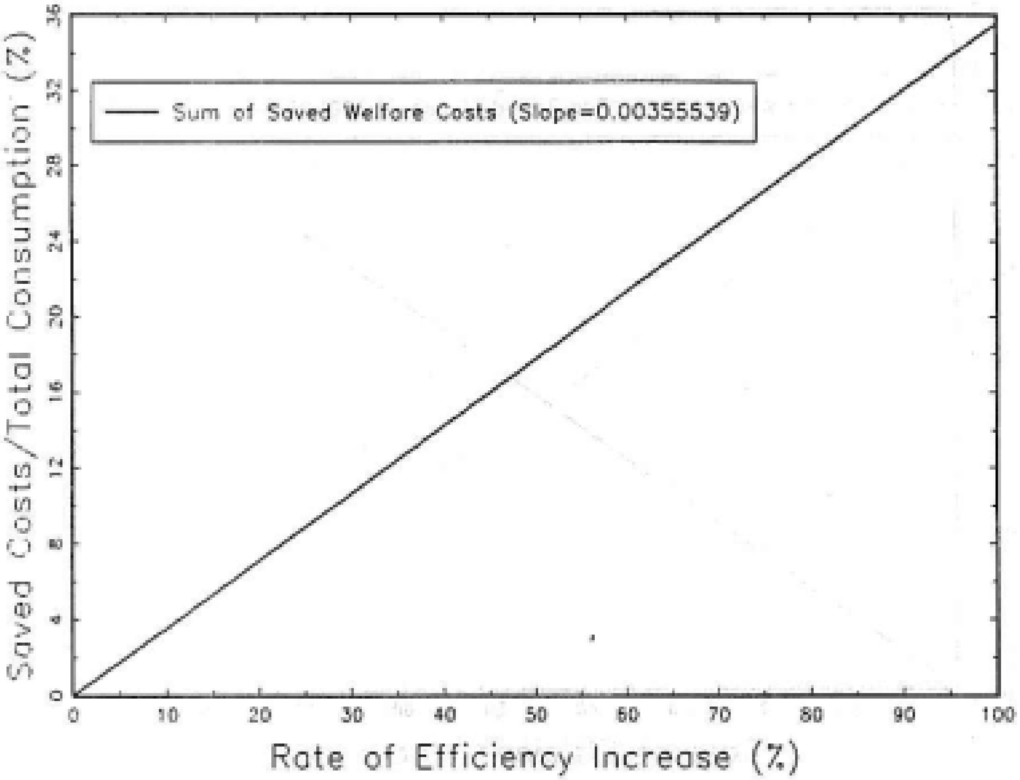


Figure 18 : Market Production Efficiency and Growth

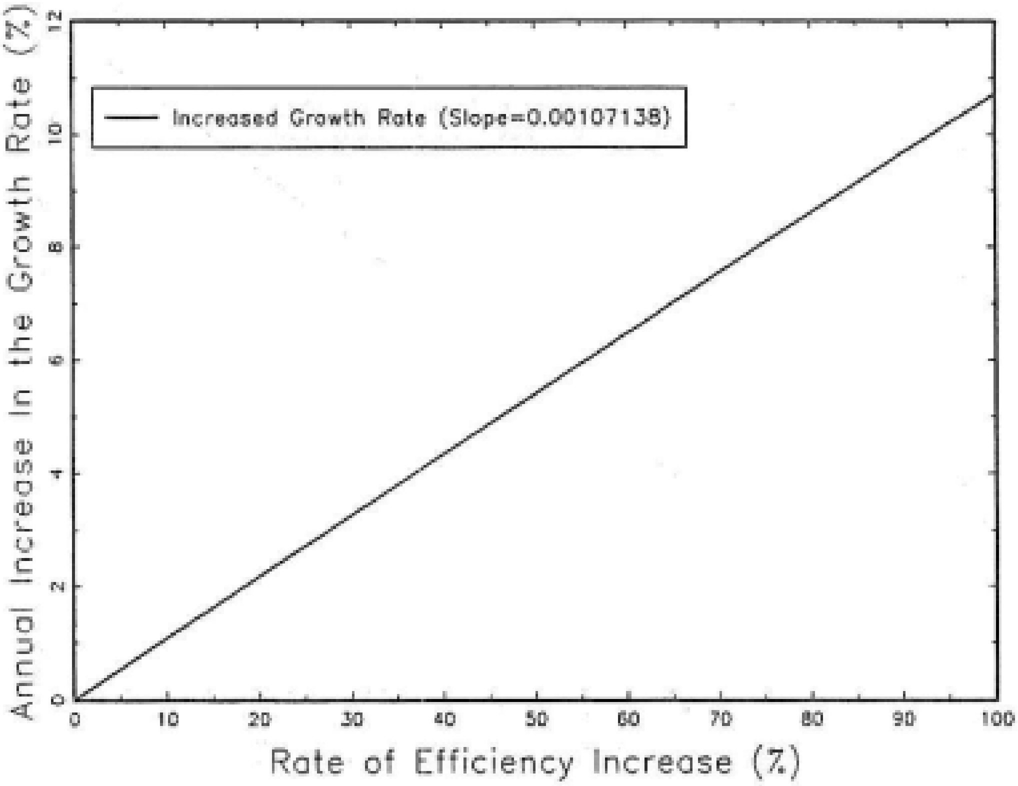


Figure 19 : Market Production Efficiency and Welfare Costs

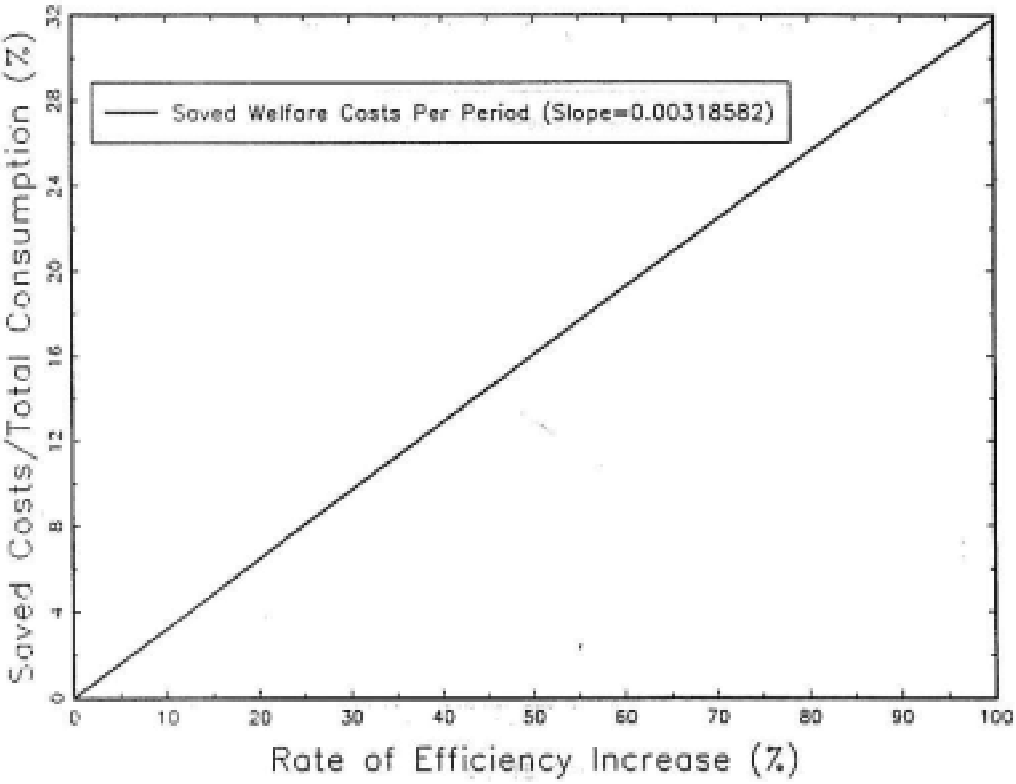


Figure 20 : Home Production Efficiency and Growth

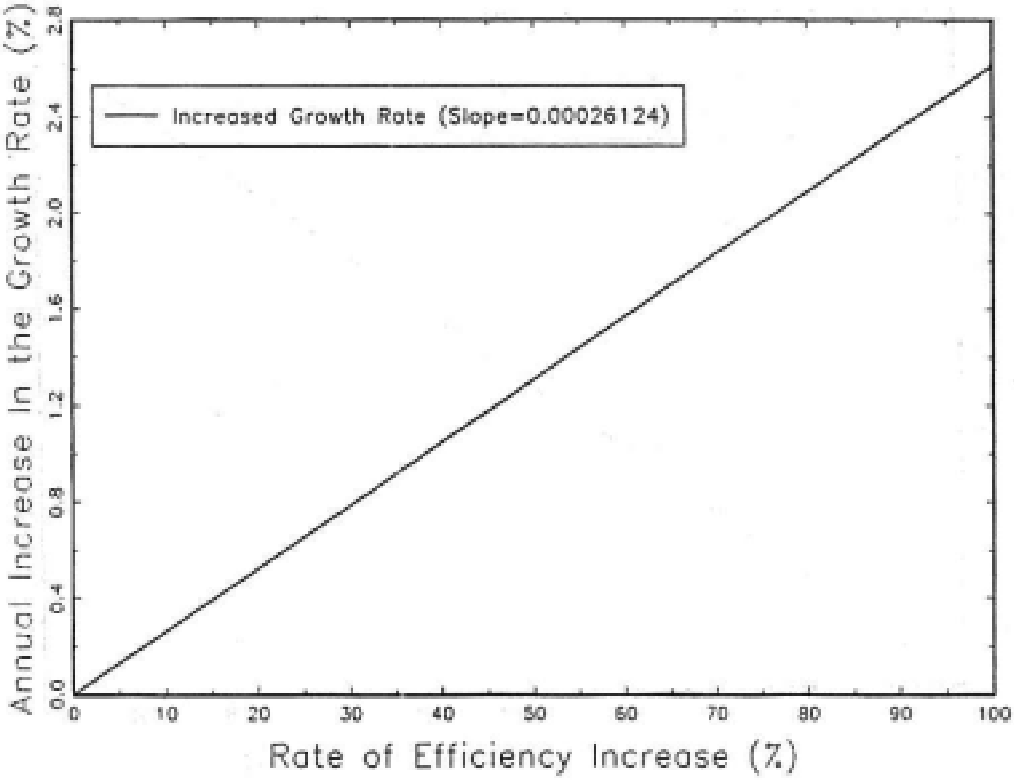


Figure 21 : Home Production Efficiency and Welfare Costs