

EFFECTS OF ENVIRONMENTAL REGULATION ON MACROECONOMIC PERFORMANCE AND WELFARE IN A SMALL OPEN ECONOMY

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This paper analyzes the effects of a stricter environmental policy on macroeconomic performance and welfare in a two-sector intertemporal optimizing model. The direct application of pollution as a productive and flow argument to both the instantaneous utility function and production function is the main difference from the previous literature. Utilizing this model, we perform both long-run steady state and short-run transitional analysis as well as welfare analysis. In the long-run analysis, both capital stock and the amount of labor supply are lowered, but the consumptions of two goods are ambiguous. In the short-run transitional dynamics, the temporary policy shock results in permanent effects and the effects of anticipated policy change are dampened. The interesting outcome in the welfare analysis is that the stricter environmental policy may improve the agent's welfare, which is contrast to the generally accepted negative welfare effect in the previous works.

JEL Classification: F41, Q28

Keywords: Environmental Regulation, Capital Accumulation, Current Account, Welfare

I. INTRODUCTION

Environment is no longer free good due to pollution discharged by production activities. Production activities generate an undesirable byproduct, pollution, in addition to the commodities, which in turn adversely affects the production of outputs and social welfare. Pollution and environmental degradation become an impediment to economic growth, while pollution is the perceived threat to many living organisms including human being itself. Over the last decade, increasingly

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strong advocacy of environmental preservation in the industrialized countries had led to the passage of environmental regulations and laws. Recently, the tougher environmental regulations have been adopted by some developing countries, for example, Korea, Taiwan, Singapore, etc. Then, the stricter environmental regulations apparently have considerable impacts on the human's behavior and economic performance, while they can control pollution and preserve environmental quality.

Naturally, many economists have analyzed the effects of environmental regulations. For the first time, Yohe (1979) examined the backward incidence of stronger pollution control onto the factors of production in a two-sector (one polluting, one not) general equilibrium model. Yu and Ingene (1982) in the model with unemployment, Beladi and Samanta (1988) in a two-sector model with factor market distortions, and Wang (1990) in a modified Harris-Todaro model all analyze the effects of more restrictive environmental policy. In addition, Keeler et al. (1972), Forster (1973), van der Ploeg and Withagen (1991), Tahvonen and Kuuluvainen (1993) have explored the effects of the environmental policy on economic growth and social welfare in the context of Neoclassical growth model. More recently, utilizing the endogenous growth model, Bovenberg and Smulders (1995, 1996) analyzed the effects of regulatory environmental measures to see the relationship between economic growth and environmental quality.

Most of the previous works, however, focus on the effects of stringent environmental regulation on the factor rewards, resource allocation, and the pattern of trade in a static context. They are lack of dynamic analysis on the current account and capital stock accumulation which seems to be more important in a rapidly changing open economy, except a few recent works [Bovenberg and Smulders (1995, 1996)]. Reflecting on these facts, the present paper will analyze the effects of stringent environmental policy mainly on the macroeconomic performance as well as social welfare in an intertemporal optimizing setup. For that purpose, this paper employs the dynamic open-economy model originated from Sen and Turnovsky (1989), Turnovsky and Sen (1991), Kim (1993), and Turnovsky and Fisher (1995).

The purpose of this paper is to show the effects of stricter environmental policy on the economy's current account and capital stock accumulation along with the changes in employment and consumption, and social welfare by directly incorporating the environmental factor into the production function as a productive public input and instantaneous utility function in a two-sector intertemporal optimizing model. The reason why we choose a two-sector model is to reflect the government's interventive role on environmental policies and the existence of non-polluting sector in the real economy. Utilizing this model, we perform both long-run steady state and short-run transitional analysis as well as welfare analysis. We will show the steady state relationship between the current account and the capital stock, and dynamic adjustment path in response to the

change in environmental policy.

The rest of the paper is organized as follows. Section II describes the analytical framework to incorporate the environmental factor, and the equilibrium dynamics and the steady state will be set out in the section III. Section IV analyzes the long run effects of stringent environmental regulation. The short run transitional dynamics of stricter environmental policy is examined in section V. In section VI, the welfare analysis is performed associated with the change in environmental policy. Section VII provides the summary and concluding remarks.

II. THE ANALYTICAL FRAMEWORK

The economy under consideration is inhabited by one single infinitely lived agent, who provides elastic labor supply at a competitive wage and accumulates capital stock for rental at a competitively determined rental rate. Following Yohe(1979), McGuire(1982), and Lopez(1994), the environmental factor, denoted by Z , is directly applied to the production function as a productive input like primary factors. This application is based upon the fact that the production activities pollute the environment, which can be interpreted as the use of environment in the process of production. In addition, the use of environment is determined by the degree of production activities so that the environment is regarded as a flow input like labor. This is similar to Barro (1990), Kim (1993), and Turnovsky and Fisher (1995) where the government expenditure put into the production function affects the productivity of capital and labor. Besides, reflecting on the fact that pollution negatively affects the representative utility, the environment is also incorporated into the instantaneous utility function.

The maximum allowance of pollution or maximum usage of environment, denoted by \bar{Z} , is exogenously determined by the government. Then Z is always binding to \bar{Z} , i. e., $Z \leq \bar{Z}$. Thus the government is assumed to maintain this constraint in any case by imposing penalty or using other policy instruments.¹ There are two sectors in the economy based upon the use of environmental factor; polluting and non-polluting sector. Manufacturing sector which uses the environmental factor for production is referred to as polluting sector. Unlike the polluting sector, the so-called non-polluting sector does not use the environmental factor for production. Then we have the following production functions for two sectors.²

For polluting sector, $F(K_1, L_1, Z)$ with the properties of $F_K > 0$, $F_L > 0$, $F_Z > 0$ is linearly homogeneous in primary inputs K, L , which implies $F = F_K K_1 +$

¹ In order to enforce the environmental regulation, the government may use subsidies, selective preferential financial supports, issuance of permits, etc.

² If we introduce a social planner that maximizes the social welfare, the maximum allowance of pollution, which is currently assumed exogenously given, can be endogenously determined through the welfare maximization.

$F_L L_1$ and $F_Z = F_{KZ} K_1 + F_{LZ} L_1 > 0$ so that both $F_{KZ} < 0$ and $F_{LZ} < 0$ are not to hold simultaneously. In contrast, for non-polluting sector, we have $H(K_2, L_2)$, where $K = K_1 + K_2$ and $L = L_1 + L_2$. Since the polluting sector (the manufacturing sector) is generally known relatively more capital intensive rather than the non-polluting sector such as service or agricultural sector, we assume that the polluting sector is relatively more capital intensive than the non-polluting sector. That is, $k_F > k_H$, where k is the capital-labor ratio. The two private inputs are mobile across the sectors, but the environmental factor (Z) is sector-specific to the polluting sector. The capital stock evolves over time and the labor supply is varying according to the real wage rate. Both goods are assumed to be tradable and the relative price of non-polluting good (σ) in terms of polluting good, which is a numeraire, is exogenously fixed reflecting a small open economy.

In addition, there is an adjustment cost associated with investment, which is convex and increasing function, $\phi(I)$, with the properties of $\phi'(I) > 0$, $\phi''(I) > 0$. And $\phi(0) = \phi'(0) = 0$ are assumed by the choice of units. Lastly, the representative private agent can accumulate the tradable bond (b) which pays the fixed world interest rate, \bar{r} . Then we have the following representative instantaneous budget constraint:³

$$\dot{b} = F(K_1, L_1, Z) + \sigma H(K - K_1, L - L_1) + r b - x - \sigma y - \sigma [I + \phi(I)] \quad (1)$$

where x and y denote the consumption levels of polluting and non-polluting good, respectively. Besides, the capital stock accumulates without depreciation according to

$$\dot{K} = I. \quad (2)$$

Thus the consolidated representative agent is to choose the consumption of two goods (x, y), the amount of labor supply (L), the allocation of capital stock and labor between the two sectors, the rate of investment (I) and the bond holdings (b) to maximize the following intertemporal utility function:⁴

³ Assuming a small open economy, the price of investment good is also fixed so that the application of the fixed relative price of non-polluting good to the investment good, which may or may not be non-polluting good, makes little difference.

⁴ In order to significantly reduce the complexity of the model, we employ an additive separable utility function to incorporate the amount of labor and pollution with the consumption of two goods. Thus the dynamics of consumption is degenerate in spite of the endogenous labor supply.

$$\text{Max} \int_0^{\infty} [U(x, y) + V(L) + W(Z)] e^{-\beta t} dt \quad (3)$$

subject to equations (1) and (2), resource allocation constraints, and the initial conditions: $b(0) = b_0$, $K(0) = K_0$. We assume that the instantaneous utility function, $U(x, y)$ is strictly concave, i. e., $U_{xx} < 0$, $U_{yy} < 0$ and the two goods are Edgeworth complementary, so that $U_{xy} > 0$. The functions, $V(L)$ and $W(Z)$, represent disutility associated with the amount of labor and pollution, respectively, with the properties of $V' < 0$, $W' < 0$ and $V'' < 0$, $W'' < 0$.

The rate of time preference of the private agent (β) is a constant which, in a perfect capital mobility, must be equal to the given world interest rate to ensure the steady state. In order to solve the standard intertemporal optimization problem, we set up the current value Hamiltonian:

$$H = [U(x, y) + V(L) + W(Z)] + \lambda[F(K_1, L_1, Z) + \sigma H(K - K_1, L - L_1)] + \bar{r}b - x - \sigma y - \sigma I - \sigma \phi(I) + q'I \quad (4)$$

where λ and q' are two costate variables associated with domestic bond holding and capital stock. Letting $\frac{q'}{\lambda} \equiv q$ be the market value of installed capital, the usual first order optimality conditions for the agent are

$$U_x(x, y) = \lambda \quad (5a)$$

$$U_y(x, y) = \sigma \lambda \quad (5b)$$

$$-\frac{V'(L)}{\lambda} = \sigma H_L(K - K_1, L - L_1) \quad (5c)$$

$$q = \sigma[1 + \phi'(I)]. \quad (5d)$$

Equations (5a) and (5b) describe the usual optimality conditions for consumers, (equality of marginal rate of substitution between two goods and the relative price of non-polluting good in terms of polluting good). Equation (5c) states that the disutility of labor supply is equal to the real wage rate. Equation (5d) equates the marginal cost of investment to the market price of installed capital, which is essentially a Tobin q theory of investment.

In addition, the shadow value (marginal utility) of wealth and the market price of installed capital evolve according to

$$\dot{\lambda} = \lambda(\beta - \bar{r}) \quad (5e)$$

$$\dot{q} = \bar{r}q - r^k(K, L, \sigma, Z) \quad (5f)$$

where r^* is the rental price of capital. Thus the following efficiency conditions for production should be satisfied.

$$F_K(K_1, L_1, Z) = \sigma H_K(K - K_1, L - L_1) \equiv r^*(K, L, \sigma, Z) \quad (5g)$$

$$F_L(K_1, L_1, Z) = \sigma H_L(K - K_1, L - L_1) \equiv w(K, L, \sigma, Z) \quad (5f)$$

where w denotes the real wage rate. These two equations assert that the marginal value products of capital and labor must be equal across the two sectors to determine optimal allocation of capital and labor. The rental price of capital depends negatively upon capital stock and the relative price of non-polluting good given the assumption of factor intensity ranking, while it depends positively upon the maximum allowance of pollution because the increase in maximum allowance of pollution raises the productivity of capital. The equality of β and \bar{r} at steady state implies $\dot{\lambda} = 0$ everywhere. Thus λ , the marginal utility of wealth in the form of foreign traded bond, is always constant at its steady state value, i. e., $\bar{\lambda} = \lambda$ (λ is a steady state value, which will be determined below). Finally, we need to impose the transversality conditions to satisfy the agent's intertemporal budget constraint.

$$\lim_{t \rightarrow \infty} \lambda b e^{-\beta t} = \lim_{t \rightarrow \infty} q K e^{-\bar{r} t} = 0.$$

Setting $\lambda = \bar{\lambda}$ and with the accumulation equations (1) and (2), we can describe the macroeconomic equilibrium in the following set of equations:

$$U_x(x, y) = \bar{\lambda} \quad (6a)$$

$$U_y(x, y) = \sigma \bar{\lambda} \quad (6b)$$

$$-\frac{V'(L)}{\bar{\lambda}} = \sigma H_L(K - K_1, L - L_1) \quad (6c)$$

$$q = \sigma[1 + \phi'(I)] \quad (6d)$$

$$F_K(K_1, L_1, Z) = \sigma H_K(K - K_1, L - L_1) \equiv r^*(K, L, \sigma, Z) \quad (6e)$$

$$F_L(K_1, L_1, Z) = \sigma H_L(K - K_1, L - L_1) \equiv w(K, L, \sigma, Z) \quad (6f)$$

$$\dot{K} = I(q, \sigma) \quad (6g)$$

$$\dot{q} = \bar{r}q - r^*(K, L, \sigma, Z) \quad (6h)$$

$$\dot{b} = F(K_1, L_1, Z) + \sigma H(K - K_1, L - L_1) + \bar{r}b - x - \sigma y - \sigma[I + \phi(I)]. \quad (6i)$$

The first six equations represent the short-run static equilibrium. The first four equations, which constitute static part of the equilibrium, can be solved for x , y , L and I in terms of $\bar{\lambda}$, σ , K , Z and q .

$$x = x(\bar{\lambda}, \sigma) \quad x_{\bar{\lambda}} < 0, \quad x_{\sigma} < 0 \quad (7a)$$

$$y = y(\bar{\lambda}, \sigma) \quad y_{\bar{\lambda}} < 0, \quad y_{\sigma} < 0 \quad (7b)$$

$$L = L(K, \bar{\lambda}, \sigma, Z) \quad L_K > 0, \quad L_{\bar{\lambda}} \geq 0, \quad L_{\sigma} \geq 0, \quad L_Z > 0 \quad (7c)$$

$$I = I(q, \sigma) \quad I_q > 0, \quad I_{\sigma} < 0. \quad (7d)$$

An increase in the marginal utility of wealth leads to a reduction in the domestic consumption of both goods, since the two goods are normal and Edgeworth complementary. Thus, as the relative price of non-polluting good rises, the consumption of both goods also falls. The employment will be stimulated as the capital stock rises because the higher level of capital stock pushes up the productivity of labor, hence raising the labor supply with the increase in the wage rate. An increase in the marginal utility of wealth reduces the consumption of both goods, thus leading to change in employment through two possible channels; the fall in the domestic outputs and the rise in the exports. The fall in the domestic outputs reduces the employment, but the rise in the exports stimulates it. Thus the net effect on the employment depends upon the relative size of the two offsetting effects. If the former dominates the latter, then the increase in the marginal utility of wealth reduces the employment level.

The rise in the relative price of non-polluting good increases its output, but decreases the output of polluting good. As a result, the overall effects on the employment is ambiguous depending upon the relative magnitudes of the changes in the outputs of two sectors. Like an increase in the capital stock, the rise in maximum allowance of pollution (Z) leads to more employment by enhancing the productivity of capital and labor. Lastly, equation (7d) which determines the rate of investment is consistent with Tobin's q theory of investment. That is, the rate of investment depends positively on the market value of installed capital, and negatively on the relative price of non-polluting good. As the relative price of non-polluting good rises, the output of non-polluting good increases while the output of polluting good falls. Given the factor intensity assumption, this generates excess supply of capital, therefore lowering the rental price of capital. Then the rate of investment falls according to Tobin's q theory of investment.⁵

In short, the responses of consumption and the rate of investment in the short run are quite standard in these types of models, but the employment will be stimulated with the increase in capital stock and the environmental factor. The level of employment is unclear in response to the change in the marginal utility

⁵ Since the polluting sector is relatively more capital intensive than the non-polluting sector, more capital is released from the polluting sector than the non-polluting sector demands as the relative price of non-polluting good rises. This leads to a fall in the market price of installed capital through the decrease in the rental price of capital.

of wealth and the relative price. Given the assumption of factor intensity ranking, the output responses to the changes in production factors and the relative price of non-polluting good are determined by both Rybczynski theorem and Stolper-Samuelson theorem. The output of polluting sector depends positively upon the capital stock and the environmental factor, but negatively upon the relative price of non-polluting good and the employment under the assumption of factor intensity ranking. The output of non-polluting sector depends positively upon the employment and its own price (σ), but negatively on both capital stock and the environmental factor under the assumption of factor intensity ranking.

With the solutions, the economy's current account can be obtained as follows:

$$\begin{aligned} \dot{b} = & Y^F(K, L, \sigma, Z) + \sigma Y^H(K, L, \sigma, Z) + \bar{r}b - x(\bar{\lambda}, \sigma) \\ & - \sigma y(\bar{\lambda}, \sigma) - \sigma I(q, \sigma) - \sigma \phi(I(q, \sigma)). \end{aligned} \quad (8)$$

III. EQUILIBRIUM DYNAMICS

The dynamic structure of the economy is simply block recursive. Thus \dot{K} and \dot{q} constitute the core dynamics and \dot{b} is solved by substituting the solutions of K and q into \dot{b} . Linearizing \dot{K} and \dot{q} around the steady state makes two linear differential equations system.

$$\begin{pmatrix} \dot{K} \\ \dot{q} \end{pmatrix} = \begin{pmatrix} 0 & \frac{1}{\sigma\phi''} \\ -(\tau_K^k + \tau_L^k) & \bar{r} \end{pmatrix} \begin{pmatrix} K - \bar{K} \\ q - \bar{q} \end{pmatrix}. \quad (9)$$

The system represents a saddle point with eigenvalues $\mu_1 < 0$ and $\mu_2 > 0$, assuming that the direct effect dominates the indirect effect induced by the change in the labor supply in response to the change in capital stock because the determinant of the coefficient matrix in the above system, $\frac{(\tau_K^k + \tau_L^k)}{\sigma\phi''}$, is negative and the trace, \bar{r} , is positive under the given factor intensity assumption. The market price of installed capital (q) may jump according to new information, but the capital stock (K) always evolves gradually. Therefore, the stable solutions for K and q are given by

$$K(t) = \bar{K} + (K_0 - \bar{K})e^{\mu_1 t} \quad (10a)$$

$$q(t) = \bar{q} + \sigma\mu_1\phi''(K_0 - \bar{K})e^{\mu_1 t} = \bar{q} + \sigma\mu_1\phi''(K - \bar{K}). \quad (10b)$$

To determine the dynamics of the economy's current account, we linearize equation (8) around steady state to get

$$\dot{b} = [Y_K^F + \sigma Y_K^H + (Y_L^F + \sigma Y_L^H)L_K](K - \bar{K}) - \sigma I_q(q - \bar{q}) + \bar{r}(b - \bar{b}) \quad (11)$$

The coefficients in equation (11) are evaluated at steady state. Substituting the solutions of K and q into equation (11), we obtain:

$$\dot{b} = \bar{r}b - \bar{r}\bar{b} + \Omega(K_0 - \bar{K})e^{\mu_1 t}$$

where $\Omega \equiv [Y_K^F + \sigma Y_K^H + (Y_L^F + \sigma Y_L^H)L_K - \sigma\mu_1]$ describes two channels that a change in capital stock affects the outputs of both goods. Assuming that the economy starts out with an initial stock of external debt $b(0) = b_0$, the solution to \dot{b} is:

$$b(t) = \bar{b} + \frac{\Omega(K_0 - \bar{K})}{\mu_1 - \bar{r}} e^{\mu_1 t} + [b_0 - \bar{b} - \frac{\Omega}{\mu_1 - \bar{r}}(K_0 - \bar{K})]e^{\bar{r}t}. \quad (12)$$

Making the solution consistent with intertemporal budget constraint, we obtain:

$$b_0 - \bar{b} = \frac{\Omega}{\mu_1 - \bar{r}}(K_0 - \bar{K}) \quad (13)$$

Then, the solution becomes:

$$b(t) = \bar{b} + \frac{\Omega(K_0 - \bar{K})}{\mu_1 - \bar{r}} e^{\mu_1 t} = \bar{b} + \frac{\Omega}{\mu_1 - \bar{r}} (K(t) - \bar{K}). \quad (14)$$

Equation (14) describes the relationship between the holding of foreign traded bond and the accumulation of capital stock. Here, it is important to determine the sign of Ω . Ω reflects the effects of the change in capital stock on the outputs of polluting and nonpolluting sector both directly and indirectly through the change in the labor supply.

Given the assumption of factor intensity ranking, the change in the output of polluting sector in response to the change in the capital stock is positive, while that of nonpolluting sector is negative. While either sign is possible, we assume that the direct effects dominate the indirect effects through the change in the labor supply. Thus $\Omega > 0$, as discussed in Turnovsky and Sen (1991).⁶ With $\Omega > 0$, equation (14) represents a negative relationship between the accumulation of capital stock and the holding of foreign traded bond. Note that equation (13) describes the steady state relationship between the stock of foreign traded bond and capital stock, in which steady state values (\bar{K}, \bar{b}) depend upon the initial values (K_0, b_0) . This implies that the temporary shock produces permanent

effects.⁷

For steady state equilibrium, the dynamic variables should stop to evolve, i. e., $\dot{K} = \dot{q} = \dot{b} = 0$. With the assumption of no depreciation in the capital stock, the rate of investment at a steady state is zero, $\dot{I} = 0$. Using equation (6d), the market price of installed capital at a steady state becomes σ due to $\phi'(0) = 0$. Then the steady state equilibrium of the economy is given by the following set of equations:

$$U_x(\tilde{x}, \tilde{y}) = \lambda \quad (15a)$$

$$U_y(\tilde{x}, \tilde{y}) = \sigma\lambda \quad (15b)$$

$$-V'(\tilde{L}) = w(\tilde{K}, \tilde{L}, \sigma, Z) \quad (15c)$$

$$\sigma\bar{r} = r^k(\tilde{K}, \tilde{L}, \sigma, Z) \quad (15d)$$

$$\bar{r}\tilde{b} = \tilde{x} + \sigma\tilde{y} - Y^F(\tilde{K}, \tilde{L}, \sigma, Z) - \sigma Y^H(\tilde{K}, \tilde{L}, \sigma, Z) \quad (15e)$$

$$\tilde{b} - b_0 = \frac{\Omega}{\mu_1 - r} (\tilde{K} - K_0). \quad (15f)$$

The above six equations jointly determine the steady values of \tilde{x} , \tilde{y} , λ , \tilde{K} , \tilde{L} , and \tilde{b} . A few aspects of the steady state should be highlighted. To begin with, the rental price of capital is a constant at $\sigma\bar{r}$ so that the steady state value of capital stock should be adjusted to the change in environmental factor according to equation (15d). This implies that the change in maximum allowance of pollution (\bar{Z}) affects the steady state value of capital stock through the induced change in the rental price of capital, and thus the foreign traded bond holdings following equation (15f). This is the channel that the policy instrument can affect the dynamic variables such as capital stock and foreign traded bond. In addition, the employment is affected by the change in Z because it alters the real wage rate in accordance with equation (15c).

IV. LONG RUN ANALYSIS

The dynamics of the system involves forward-looking behavior. Thus the short run transition is determined in part by the long run steady state. Therefore, we will start with the long run analysis. The long run effects of the stricter environmental policy (the reduction in the maximum allowance) are analyzed and then discussed in turn. The results are summarized as follows.

⁷ The dependence of steady state values on the initial conditions is the source of the temporary policy change having permanent effect. This is emphasized by Sen and Turnovsky (1989), and Turnovsky and Sen (1991).

1. Stock of capital: $\frac{d\tilde{K}}{dZ} = -\frac{r_Z^k}{r_K^k} > 0$
2. Stock of foreign traded bond: $\frac{d\tilde{b}}{dZ} = -\frac{\Omega}{\mu_1 - r} \frac{r_Z^k}{r_K^k} < 0$
3. Labor Supply: $\frac{d\tilde{L}}{dZ} = \frac{r_Z^k w_K - r_K^k w_Z}{r_K^k (V'' + w_L)} > 0$
4. Consumption of polluting good: $\frac{d\tilde{x}}{dZ} = -\frac{\phi}{D} (\sigma U_{xy} - U_{yy}) \geq 0$
5. Consumption of non-polluting good: $\frac{d\tilde{y}}{dZ} = \frac{\phi}{D} (\sigma U_{xx} + U_{yx}) \geq 0$
6. Marginal utility of wealth: $\frac{d\tilde{\lambda}}{dZ} = \frac{\phi}{D} (U_{xx} U_{yy} - U_{xy}^2) \geq 0$

where $\phi \equiv Y_Z^F + \sigma Y_Z^H - (Y_K^F + \sigma Y_K^H) \frac{r_Z^k}{r_K^k} + (Y_L^F + \sigma Y_L^H)$

$$\frac{(r_Z^k w_K - r_K^k w_Z)}{r_K^k (V'' + w_L)} - \frac{\Omega}{\mu_1 - r} \frac{r_Z^k}{r_K^k} \geq 0,$$

$$D \equiv \sigma (U_{xx} - U_{xy}) + (U_{yy} - U_{yx}) < 0.$$

The above outcomes are consistent with the generally accepted negative results of environmental policy on the economy, even in the open economy dynamic setup with the inclusion of capital accumulation. That is, the value of capital stock at a new steady state should be lowered to maintain equation (15d) due to $r_Z^k > 0$. This can be explained by the fact that a stricter environmental policy leads to the fall in rental price of capital, which determines the rate of investment and thus gives rise to a lower level of capital stock. In a new steady state, however, the current account improves as the steady state value of capital stock is lowered while foreign traded bond is higher at a fixed world interest rate according to equation (15f) because of $\frac{\Omega}{(\mu_1 - r)} < 0$. Besides, the employment at a new steady state is reduced in accordance with equation (15c), which makes the real wage rate go down due to the reduction in maximum allowance of pollution (Z).

As the government regulates the usage of environment more strictly by reducing the maximum allowance of pollution, the capital stock accumulation slows down. As a result, the stock of foreign traded bond at a new steady state is higher, but the marginal utility of wealth is ambiguous because of $Y_Z^F > 0$, $Y_Z^H < 0$ as well as $Y_K^F > 0$, $Y_K^H < 0$ and $Y_L^F < 0$, $Y_L^H > 0$. Thus the consumption of two goods is also unclear. Under the restrictive case, however, we can decide the signs of consumption and the marginal utility of wealth. With the assumption of $Y_Z^F + \sigma Y_Z^H > 0$, $Y_K^F + \sigma Y_K^H > 0$, and $Y_L^F + \sigma Y_L^H > 0$, the consumption of both goods falls since the marginal utility of wealth rises with a stricter environmental policy. The interpretation of this outcome is that pollution plays a

productive input in the production function, which thus affects the accumulation of capital stock by changing the market price of installed capital in response to the policy change like the change in government expenditure in the previous works.⁸ These results are well observed in a real economy where firms would rather install the purification system than choose to discharge pollutants illegally, so that they take additional costs associated with the system required by the environmental law. This implies that the stricter environmental policy raises the production cost, thus leading to the reduction of investment and the slower accumulation of capital stock. Due to the reduced investment, the current account improves.

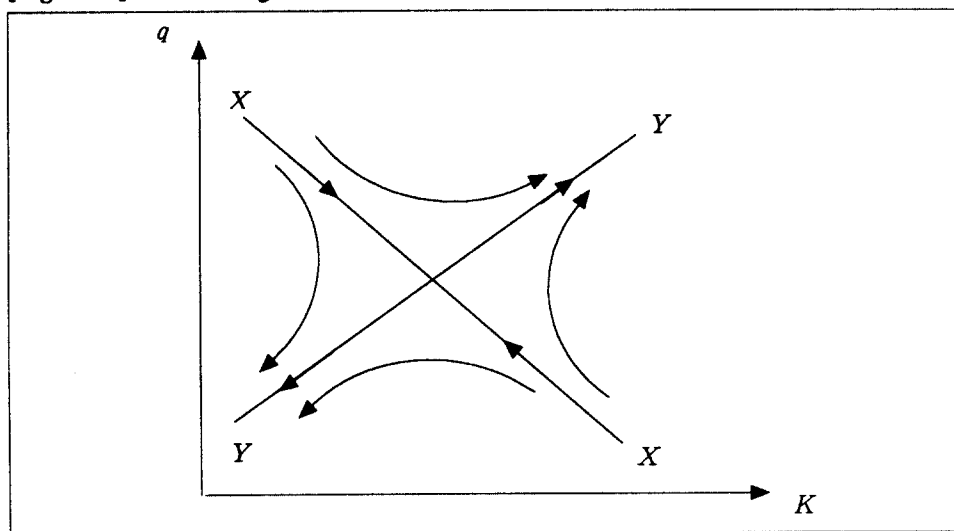
V. SHORT RUN TRANSITIONAL DYNAMICS

In this section, the short-run transitional dynamics in response to the stricter environmental policy will be analyzed in accordance with three types of changes; unanticipated permanent and temporary change, and anticipated permanent change. The dynamics of K and q are described by a saddle point in $K-q$ space in the previous section, which is illustrated in Figure 1. In Figure 1, XX is the stable arm, while YY is the unstable arm in the dynamic adjustment of K and q .

1. Unanticipated Permanent Reduction in \bar{Z}

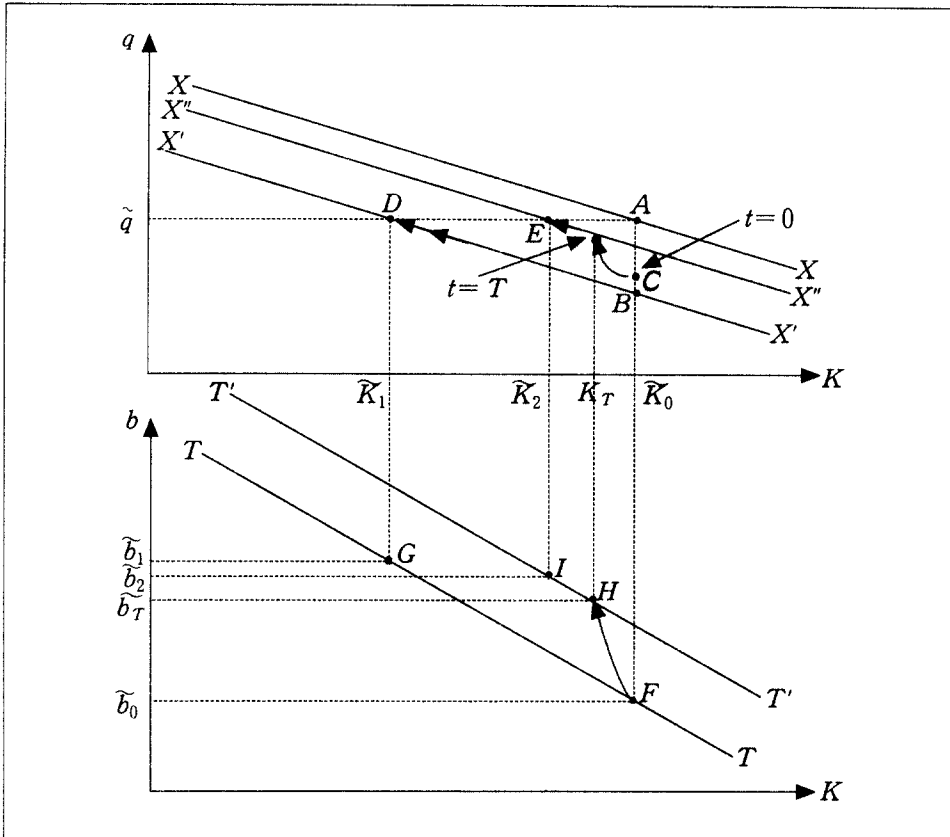
The economy lies at the initial steady state, point A of the stable arm XX

[Figure 1] Phase Diagram



⁸ Barro (1990), Kim (1993), and Turnovsky and Fisher (1995) employ government expenditure as a productive input in their models for different purposes as we do pollution in the production function. This makes the channel that the change in environmental policy affects the accumulation of capital stock through the induced change in the market price of installed capital.

[Figure 2] Unanticipated Policy Change



in Figure 2 with the initial capital stock, \bar{K}_0 . The initial drop in $q(0)$, following an unanticipated permanent reduction in \bar{Z} is

$$\frac{dq(0)}{dZ} = -\sigma\mu_1\phi'' \frac{d\bar{K}}{dZ} > 0. \quad (16)$$

The long-run fall in the capital stock is seen to give rise to a short-run drop in the market price of installed capital. Figure 2 illustrates the dynamics following an anticipated permanent reduction in \bar{Z} . Immediately following the policy change, q drops from point A to point B on the new stable locus $X'X'$. Upon reaching point B , q begins to rise again. This leads to a new steady state equilibrium, point D , with a lower value of capital stock and no change in q . In response to the stricter environmental policy, capital stock is decumulated as q drops according to equation (6g). The initial response on the employment is given by

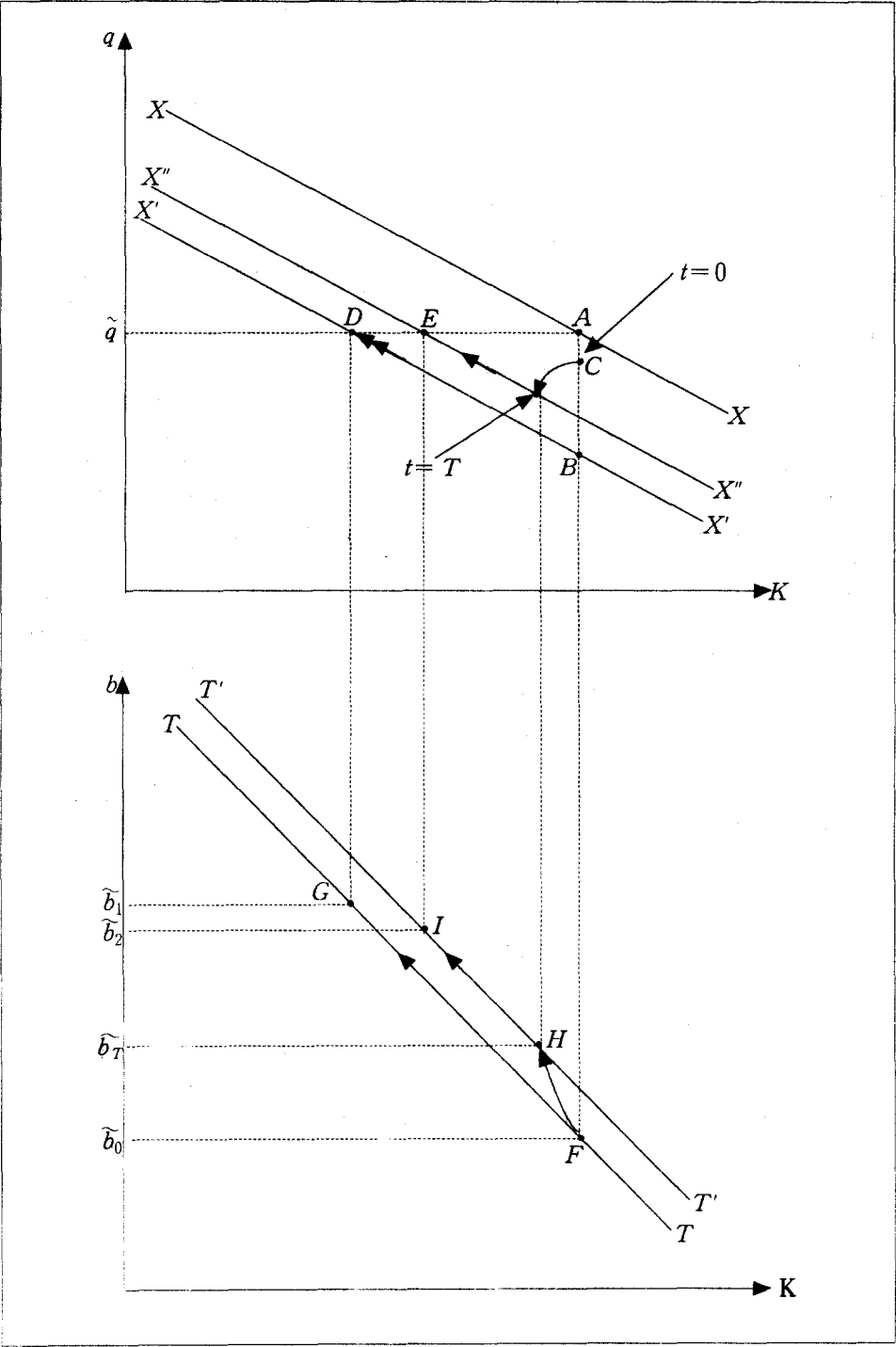
$$\frac{dL(0)}{dZ} = \frac{\partial L}{\partial Z} + \frac{\partial L}{\partial \bar{\lambda}} \frac{d\bar{\lambda}}{dZ} \quad (16)$$

which consists of two kinds of effects; the direct effect given by the partial derivatives, $\frac{\partial L}{\partial Z}$, and the indirect effect associated with the induced change in $\bar{\lambda}$. The direct effect of the reduction in \bar{Z} is contractionary due to the fact that the fall in \bar{Z} generates a short-run reduction in the market price of installed capital. Then it lowers the real wage rate, which gives rise to a fall in employment according to equation (6c). The indirect effect is not clear, though. The reason is that marginal utility of wealth is ambiguous in response to the fall in Z . Thus the overall effect on employment is unclear. However, we can establish that the employment on impact will fall in response to the reduction in \bar{Z} in a restrictive case described in section IV. This is because q drops immediately and then begins to rise, thus lowering the real wage rate, while capital starts to fall; $dq(0) < 0$, $d\dot{q}(0) > 0$, $d\dot{K}(0) < 0$. The resulting increase of capital-labor ratio means a higher short-run real wage rate. Over time, however, as capital is decumulated, the capital-labor ratio falls and the real wage returns to the original long-run level. At the same time, the foreign traded bond (b) begins to accumulate as capital is decumulated along TT and ends up with \bar{b}_1 higher than \bar{b}_0 , moving point F to point G in Figure 2. This is due to equation (13) with the assumption of $\Omega > 0$. The accumulation of foreign traded bond implies that the trade balance improves.

2. Unanticipated Temporary Reduction in \bar{Z}

When the economy is hit by the unanticipated reduction in \bar{Z} , but perceived to be temporarily from time 0 to time T , the stable arm XX will drop instantaneously to $X'X'$, while q falls to point C , which is above $X'X'$, not on $X'X'$. Since the immediate drop in q , following the temporary policy change, is less than that in the case of permanent reduction in Z , the fall in initial investment is moderate. The same is true of employment. Thus capital begins to decumulate and q starts to rise after the initial jump down, which leads to the accumulation of foreign traded bond (b). At time T when \bar{Z} is restored to its original level, the stock of capital and foreign traded bond will have reached point H with K_T and b_T in Figure 2. Then point H will now serve as initial conditions for the dynamics beyond time T . As explained in Section III, K_T and b_T will therefore in part determine the new steady state equilibrium when the temporary policy change is over at time T so that the relevant locus is $X''X''$ lying below the original stable locus XX . Likewise, the relevant locus linking the accumulation of capital and foreign traded bond is now $T'T'$, which leads to the new steady state, point I with \bar{K}_2 and \bar{b}_2 . In the new steady state, the market price of installed capital reverts to its original level, but with a lower stock of capital and a higher stock of foreign traded bond than originally.

[Figure 3] Anticipated Policy Change



The striking feature of the adjustment is that the temporary policy change leads to a permanent reduction in the stock of capital, accompanied by a higher stock of foreign traded bonds. This is because during the transitional adjustment period when the policy change is in effect, the accumulation of capital and bonds will influence subsequent initial conditions, which in turn affects the subsequent steady state.

3. Anticipated Permanent Reduction in \bar{Z}

Now, we briefly discuss an anticipated permanent reduction in \bar{Z} , which is announced at time 0 to take effect at time T . At the time of announcement, q drops instantaneously to point C , which lies above point B on $X'X'$ illustrated in Figure 3. As the drop in q is smaller than that in case of unanticipated reduction in \bar{Z} , the initial decumulation in capital is also smaller. Thus we have analogous effects on employment and output following the announcement. Before reaching time T , q continues to fall as capital is decumulated. At time T when the announced reduction in \bar{Z} actually occurs, the stocks of capital and foreign traded bonds at time T , K_T and b_T , will determine the stable path $X'X'$ and

$T'T'$ relevant for the subsequent adjustments, beyond T . Because of the changed initial conditions at time T , from time 0 these paths will not coincide with $X'X'$ and TT , the corresponding paths for unannounced changes. This implies that the long-run contraction in the capital stock following the anticipated reduction in \bar{Z} is dampened by announcing the change in environmental policy in advance. According to the environmental policy change, the short-run responses of the agent will be different depending upon the types of policy change. If the policy change is perceived to be permanent, the agent will take a permanent action such as the installation of purification system, the implementation of environmentally sound technology, rescheduling the production scheme, etc. In the similar fashion, whether the policy change is anticipated or not, the agent's response will be different as we observe in the real economy.

VI. WELFARE ANALYSIS

So far, we have been describing the adjustment of the economy to the change in the environmental policy. Since the change in the environmental policy affects both the productivity of two private inputs and the representative agent's utility in this model, it is of particular importance to investigate the effects of reduction in \bar{Z} on the welfare of the agent in the economy. This can be conveniently analyzed by considering the effect on the intertemporal utility function (with $\beta = \bar{r}$):

$$\Phi \equiv \int_0^{\infty} [U(x, y) + V(L) + W(Z)] e^{-\bar{r}t} dt. \quad (18)$$

In this section, we briefly consider the welfare effects associated with the reduction in the maximum allowance of pollution by the government, when the employment follows the solution given by equation (7c),⁹ where K and q evolve in accordance with the dynamic paths (10a) and (10b).

The evaluation is based on a linear approximation to Φ . For that purpose, we begin with the linear approximation of the instantaneous utility function around steady state, with no consumption dynamics.

$$V(L) \cong V(\bar{L}) + V'(L - \bar{L}) \quad (19)$$

where V' is evaluated at steady state. The transitional path followed by the employment may be linearly approximated by

$$L(t) \cong \bar{L} + (L(0) - \bar{L})e^{\mu_1 t}. \quad (20)$$

Then we can readily show that the welfare, Φ , may be linearly approximated with Z constant by

$$\Phi \cong \frac{1}{\bar{r}} [U(\tilde{x}, \tilde{y}) + V(\bar{L}) + W(Z)] + \frac{V'(L(0) - \bar{L})}{\bar{r} - \mu_1}. \quad (21)$$

The first term in equation (21) represents the level of welfare, if the steady state were attained instantaneously. The second term reflects the adjustment to this since only employment evolves over time following the transitional path, due to the fact that the levels of consumption are constant at the values of steady state and Z is exogenously given.

Using the equilibrium conditions (6a)-(6c), the effect of a reduction in \bar{Z} on total welfare is given by

$$\frac{d\Phi}{dZ} = \frac{1}{\bar{r}} \frac{dW}{dZ} + \frac{U_x}{\bar{r}} \left[\frac{d\tilde{x}}{dZ} + \sigma \frac{d\tilde{y}}{dZ} + \frac{\mu_1 \sigma H_L}{\bar{r} - \mu_1} \frac{d\bar{L}}{dZ} \right] - \frac{\mu_1 \sigma H_L}{\bar{r} - \mu_1} \frac{dL(0)}{dZ}. \quad (22)$$

In this model, there are two channels that the change in the environmental policy affects the welfare; one is the direct effect associated with the change in the environmental policy, $\frac{dW}{dZ}$, the other is indirect effects through the change in the productivity of capital and labor, which in turn influences the outputs and so the consumption, and the disutility induced by the change in the employment. The first term in equation (22) is the direct effect, which being permanent, is capitalized at the constant rate \bar{r} . This effect is welfare improving. The second

⁹ The current model with endogenous labor supply represents quite simple dynamic adjustments to the policy change due to the constant consumption of both goods. Therefore, this also significantly simplifies the welfare analysis associated with the corresponding policy change.

are indirect effects which operate through private consumption and employment. These in turn comprise the steady state effects and effect along the transitional path. Since the transitional adjustment path is characterized in terms of the initial points and steady state, these effects can be expressed with the initial impact on the employment and the corresponding steady state values \hat{x} , \hat{y} and \hat{L} .

The indirect effects are not clear due to unclear responses of consumption and initial employment to the reduction in \bar{Z} . Thus the overall welfare effect depends on the relative magnitudes of those effects. In a restrictive case as we discussed in the previous sections, the fall in consumption reduces the welfare, while the fall in employment both initially and at steady state improves the welfare. Therefore, if this indirect positive effects coupled with the positive direct effect dominate the indirect negative effect, the welfare may improve. This outcome is contrast to the generally accepted negative welfare effect in the previous works. This fact can be explained by the direct application of both labor supply and the amount of pollution into the instantaneous utility function. Then the instantaneous utility function is influenced by the change in environmental policy both directly and indirectly.

VI. SUMMARY AND CONCLUDING REMARKS

This paper analyzes the effects of the stricter environmental policy on macroeconomic performance and welfare in a two-sector intertemporal optimizing model modifying and extending the models developed by Sen and Turnovsky (1989), Turnovsky and Sen (1991), Kim (1993), and Turnovsky and Fisher (1995). The direct application of environment as a productive and flow argument to both the instantaneous utility function and production function is the main difference from the previous literature. This difference may result in different outcomes particularly on the welfare effect.

The main results are as follows. In the long-run analysis, both capital stock and the amount of labor supply are lowered to the reduction in the maximum allowance of pollution by decreasing the market value of installed capital which determines the rate of investment. The consumption of two goods, however, is ambiguous due to the unclear response of marginal utility of wealth. While the stock of foreign traded bond increases so that current account improves. In the short-run transitional dynamics, we perform three types of policy changes; both unanticipated permanent and temporary change, and the anticipated policy change. Two points should be mentioned. First, the temporary policy change results in permanent effects because of the dependence of steady state values on the initial conditions as we have shown. Second, the effects of anticipated policy change is dampened by the agent's adjustment before the policy change is actually implemented. That is, the changes both in capital stock and foreign traded bond are smaller than those in an unanticipated case. In welfare analysis, the stricter environmental policy may improve the agent's welfare because of the direction

application of environment as a productive input to both the instantaneous utility function and production function. This outcome is contrast to the generally accepted negative welfare effect in the previous works.

The model, however, has some limitations. First, endogenous relative price could be considered by assuming a semi-small open economy rather than the fixed relative price. Then the dynamics of consumption is not degenerate so that we can expect more fruitful results. Second, in order to reflect the government's interventive role in some developing countries, we may set up two polluting sectors in which the government can allocate the maximum allowance of pollution(the usage of environment) across sectors.

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