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INTERNATIONAL INCOME TRANSFERS AND ENVIRONMENTAL QUALITY: A NOTE

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Abstract: This note extends Niho's (1996) study of international income transfer and environmental quality by allowing for not only an interior Nash equilibrium but also corner solutions in his dynamic game model. It is shown that if countries sufficiently differ in resource endowments, there is a possibility of corner solutions in which the resource-poor country does not undertake cleanup activities. Moreover, in that case a transfer of resources from resource-rich country to resource-poor country deteriorate the quality of the environment. This result implies that an international income redistribution which enlarges an inequality in resource endowments improves the environmental quality.

1. INTRODUCTION

In his recent paper in this journal, Niho (1996) examines the global environmental problem as a voluntary provision of international public goods (or "bads") with stock effects on consumer's utility in a differential game framework. In particular, he investigates long-run and short-run effects of international redistribution of income on the environmental quality and welfare. He shows that if countries differ in efficiency in cleaning up of pollution, an income transfer from a country with a more efficient technology of cleanup to a country whose technology is less efficient causes a deterioration in the environmental quality and utility level of the donor as well as the recipient.[1] This result is in contrast with Warr's (1983) "neutrality theorem".

In his paper, however, an interior solution is assumed and a possibility that some country does not make a contribution (in the context of global environmental problem, some country does not allocate resources to clean up the pollution) is ignored. Assuming an interior solution, he analyzes effects of a *small* transfer, which maintains the interior solution even after the transfer. As discussed in Bergstrom et al. (1986), by contrast, a *large* transfer may change the set of contributors, i.e., may cause corner solutions, and affect the equilibrium provision of public goods. In the case of pollution control, reduction of greenhouse gases in particular, the possibility of corner solutions

[1] Ihori (1996) obtained the similar result in more general but a static model.

may be of great importance since developed countries are willing to participate in pollution control activity while developing economies may not.

This note thus extends Niho's study by allowing for not only an interior equilibrium but also corner solutions. It is shown that the combination of initial endowments of resources determines which of these equilibria emerges. In particular, if countries sufficiently differ in resource endowments, there is a possibility of corner solutions in which the resource-poor country does not undertake cleanup activities. Moreover, in that case a transfer of resources from resource-rich country to resource-poor country deteriorate the quality of the environment, independent of differences in cleanup technologies. This result implies that an international income redistribution which enlarges an inequality in resource endowments improves the environmental quality.

Niho himself investigates effects of a transfer not only on steady state values but also on transitional dynamics. The transitional dynamics can be characterized in the case of corner solutions, but the full characterization requires cumbersome works. Also, as shown by Niho, the short-run effect has similar implications to the long-run effect. Throughout this note, therefore, I focus attention on long-run effects of transfers.

2. NIHO'S MODEL

As a beginning I would like to review Niho's model briefly. There are two countries in the world. Each country produces a single good for its own consumption, i.e., there is no international trade. The production of consumption goods creates, as a by-product, pollution, which accumulates over time and deteriorates the environmental quality. The environmental quality is an international public good. Each country, however, can improve the environmental quality by allocating resources for cleanup of pollution.

Niho's model consists of following equations:

$$U_i = \int_0^\infty e^{-\rho t}[\alpha_i \log y_i(t) + (1-\alpha_i)\log Z(t)]dt\,, \quad \rho > 0\,,\ 0 < \alpha_i < 1\,,\ i = 1,2\,, \tag{1}$$

$$y_i(t) = \beta_i r_i(t)\,, \quad \beta_i > 0\,, \quad i = 1,2\,, \tag{2}$$

$$P(t) = \gamma_1 y_1(t) + \gamma_2 y_2(t)\,, \quad \gamma_1, \gamma_2 > 0\,, \tag{3}$$

$$C(t) = \theta_1 s_1(t) + \theta_2 s_2(t)\,, \quad \theta_1, \theta_2 > 0\,, \tag{4}$$

$$\dot{Z}(t) = -[P(t) - C(t)]\,, \quad Z(0) = Z_0 > 0\,, \tag{5}$$

$$r_i(t) + s_i(t) = w_i > 0\,, \quad i = 1,2\,, \tag{6}$$

where

- y_i: output of consumer goods in country i,
- r_i: resource allocation to the production of consumer goods in country i,
- s_i: resource allocation to the cleanup activity in country i,
- w_i: resource endowment in country i (assumed to be constant),
- Z: environmental quality,
- P: total amount (world-wide level) of pollution generated due to production,
- C: total amount of pollution cleaned up.

Expression (1) is country i's welfare, the discounted sum of instantaneous utility. (2) is production function of consumer goods. The differential equation (5) means that the environmental quality changes over time depending on the net emission of pollution, the difference between P given by (3) and C given by (4). (6) is country i's resource constraint.

Each country determines the path of its resource allocation so as to maximize (1) subject to (2), (3), (4), (5) and (6), taking other country's allocation path as given. In other words, I assume that each country uses an open-loop Nash strategy, as in Niho's analysis. The current value Hamiltonian is

$$\begin{aligned} H^i =& \alpha_i \log(\beta_i r_i) + (1-\alpha_i)\log Z \\ &- \lambda_i[\gamma_1\beta_1 r_1 + \gamma_2\beta_2 r_2 - \theta_1(w_1 - r_1) - \theta_2(w_2 - r_2)]\,, \quad i = 1, 2\,. \end{aligned}$$

Allowing for a possibility of corner solutions, the necessary conditions for the Nash equilibrium are given by (see for example Mehlmann, 1988)

$$H_r^i \equiv \frac{\partial H^i}{\partial r_i} = \alpha_i/r_i - \lambda_i(\gamma_i\beta_i + \theta_i) \geq 0\,, \quad i = 1, 2\,, \tag{7}$$

$$\dot{\lambda}_i = \rho\lambda_i - (1-\alpha_i)/Z\,, \quad i = 1, 2\,, \tag{8}$$

$$\lim_{t\to\infty} e^{-\rho t}\lambda_i(t) = 0\,, \quad i = 1, 2\,. \tag{9}$$

As stated in the introduction, I focus attention on the steady state equilibrium where $\dot{Z} = \dot{\lambda}_1 = \dot{\lambda}_2 = 0$. Let the steady state value of variables be denoted with an asterisk (*). Then, from (7) and (8), there are four possible cases:

Case I. $H_r^1 = H_r^2 = 0 \Rightarrow r_1^* < w_1$ and $r_2^* < w_2$ (i.e., $s_1^* > 0$ and $s_2^* > 0$),
Case II. $H_r^1 = 0$, $H_r^2 > 0 \Rightarrow r_1^* < w_1$ and $r_2^* = w_2$ (i.e., $s_1^* > 0$ and $s_2^* = 0$),
Case III. $H_r^1 > 0$, $H_r^2 = 0 \Rightarrow r_1^* = w_1$ and $r_2^* < w_2$ (i.e., $s_1^* = 0$ and $s_2^* > 0$),
Case IV. $H_r^1 > 0$, $H_r^2 > 0 \Rightarrow r_1^* = w_1$ and $r_2^* = w_2$ (i.e., $s_1^* = s_2^* = 0$).

Note, however, that the case IV is ruled out since it violates the transversality condition (9). In the next section I characterize the remaining three cases in turn.

3. STEADY STATE EQUILIBRIUM

In the steady state, the shadow price of environmental quality is is given by $\lambda_i = (1-\alpha_i)/(\rho Z)$. Then (7) is rewritten as

$$\frac{\alpha_i}{r_i} \geq \frac{1-\alpha_i}{\rho Z}(\gamma_i\beta_i + \theta_i)\,, \quad i = 1, 2\,. \tag{10}$$

Also, $\dot{Z} = 0$ implies that (5) is rewritten as

$$(\gamma_1\beta_1 + \theta_1)r_1 + (\gamma_2\beta_2 + \theta_2)r_2 = \theta_1 w_1 + \theta_2 w_2\,. \tag{11}$$

The set of stationary equilibrium values (Z^*, r_1^*, r_2^*) satisfies (10) and (11). Moreover, steady states are shown to be globally asymptotically stable for any of these cases.

Case I. Interior solution

In this case (10) holds with equality for both country 1 and 2. Given this and (11), the steady state values of environmental quality and the amount of resources allocated to cleanup activity are solved as

$$Z^* = \frac{\theta_1 w_1 + \theta_2 w_2}{\rho(\sigma_1 + \sigma_2)}, \quad r_i^* = \frac{\sigma_i}{\sigma_1 + \sigma_2} \frac{\theta_1 w_1 + \theta_2 w_2}{\gamma_i \beta_i + \theta_i}, \quad i = 1, 2, \tag{12}$$

where $\sigma_i \equiv \alpha_i/(1 - \alpha_i)$.

Case II. Only country 1 undertakes cleanup activity

In this case (10) holds with equality for both country 1 only. Substituting $r_2^* = w_2$ into (11), r_1^* is solved. Then Z^* is solved from (10). To summarize, the stationary solutions are

$$Z^* = \frac{\theta_1 w_1 - \gamma_2 \beta_2 w_2}{\sigma_1 \rho}, \quad r_1^* = \frac{\theta_1 w_1 - \gamma_2 \beta_2 w_2}{\gamma_1 \beta_1 + \theta_1}, \quad r_2^* = w_2 . \tag{13}$$

Country 2 does not allocate resources to pollution control because the marginal benefit from the improved environment, RHS of (10), is smaller than the marginal cost of pollution control (opportunity cost of reducing consumption), LHS of (10) for any $r_2 < w_2$.

Case III. Only country 2 undertakes cleanup activity

In this case (10) holds with equality for both country 2 only. Changing variables for country 1 and 2 each other, the stationary solutions are solved as

$$Z^* = \frac{\theta_2 w_2 - \gamma_1 \beta_1 w_1}{\sigma_2 \rho}, \quad r_1^* = w_1, \quad r_2^* = \frac{\theta_2 w_2 - \gamma_1 \beta_1 w_1}{\gamma_2 \beta_2 + \theta_2} . \tag{14}$$

The intuitive interpretation is similar to that of Case II.

The first-order condition (10) implies that the following inequality must hold for satisfying the interior solution:

$$\frac{w_2}{\phi_1} < w_1 < \phi_2 w_2, \quad \phi_i \equiv \frac{(\sigma_1 + \sigma_2)\gamma_i \beta_i + \sigma_j \theta_i}{\sigma_i \theta_j}, \quad j \neq i . \tag{15}$$

This condition depends on the pair of resource endowments (w_1, w_2) as well as parameters representing preference and technology. To classify the long-run equilibria in terms of resource endowments, let us define the sets Ω_1, Ω_2 and Ω_3 as follows:

$$\Omega_1 \equiv \{(w_1, w_2) \in R^2_{++} \mid w_2/\phi_1 < w_1 < \phi_2 w_2\},$$
$$\Omega_2 \equiv \{(w_1, w_2) \in R^2_{++} \mid w_1 \geq \phi_2 w_2\},$$
$$\Omega_3 \equiv \{(w_1, w_2) \in R^2_{++} \mid w_2/\phi_1 \geq w_1\}.$$

These sets are shown in Figure 1. If $(w_1, w_2) \in \Omega_1$, the Case I, an interior Nash equilibrium emerges. If $(w_1, w_2) \in \Omega_2$ and $(w_1, w_2) \in \Omega_3$, the Case II and III emerge, respectively.

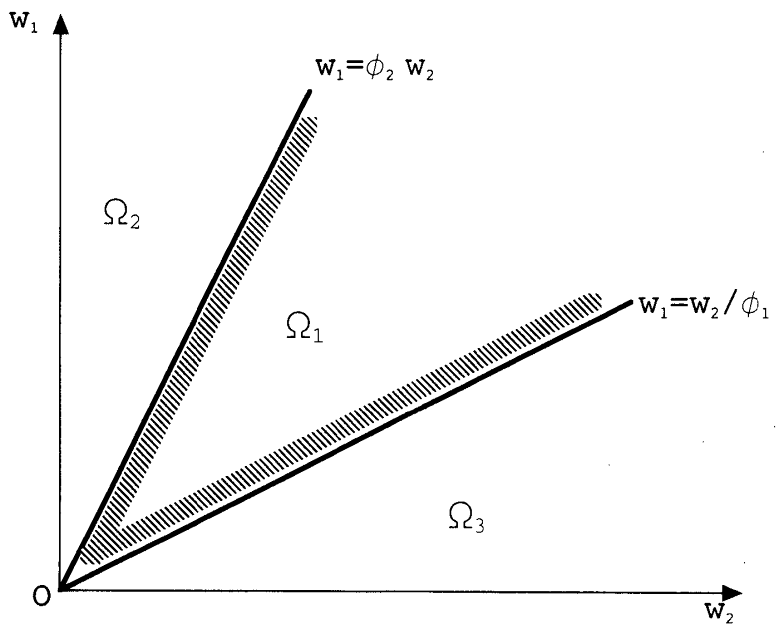

FIGURE 1.

4. EFFECTS OF INCOME TRANSFER

Effects of an international income transfer also depend on where the pair of initial endowments (w_1, w_2) lies in. For the moment I assume the case where the transfer is so small that (w_1, w_2) still lies in the same set Ω_i after that transfer.

Case I. It is obvious from (12) that the environmental quality as well as the amount of resources allocated to production in the steady state depend on $\theta_1 w_1 + \theta_2 w_2$. Consider country 1 transfers its resources to country 2. Then such a transfer improves the quality of the environment, increases both country's consumption and hence improves welfare in the steady state if $\theta_1 < \theta_2$, i.e., the recipient has higher technology for cleanup than the donor. The opposite occurs when $\theta_1 > \theta_2$ and the "neutrality theorem" (Warr, 1983) holds when $\theta_1 = \theta_2$. For more complete analysis, see Niho's original paper.

Case II. In this case, (13) implies that the transfer from country 1 to country 2 deteriorates the environment, decreases country 1's consumption and hence country 1, the donor, worse off by transferring its resources to country 2. Then the transfer deteriorates the quality of the global environment and the welfare in country 1, the donor. The effect on country 2's welfare is, however, ambiguous since it increases its consumption.

Intuitively, $(w_1, w_2) \in \Omega_2$ means that country 2 uses the resources only for production of the consumer goods. By transferring resources to country 2, country 1 reduces the cleanup expenditure as well as its consumption. Country 2, by contrast, does not spend the resources for the cleanup activity. As a result, in the steady state the global environment will be deteriorated.

Case III. In this case, (13) implies that the transfer from country 1 to country 2 improves the quality of the global environment and the welfare in country 2, the recipient. The effect on the country 1's welfare is, however, ambiguous since it reduces its consumption.

Intuitively, since the donor allocates no resources to the cleanup activity while country 2 undertakes that activity when $(w_1, w_2) \in \Omega_3$, the transfer reduces country 1's consumption and hence the pollution. Country 2 increases the expenditure for cleanup by the transfer and hence the global environmental quality can be improved.

I have so far assumed a small transfer, i.e., the effects of the transfer were investigated locally around the equilibrium point. How about the long-run effects of a large transfer? The relation between Z^* and w_2, under the constraint of $w_1 + w_2 = \bar{w}$, are depicted

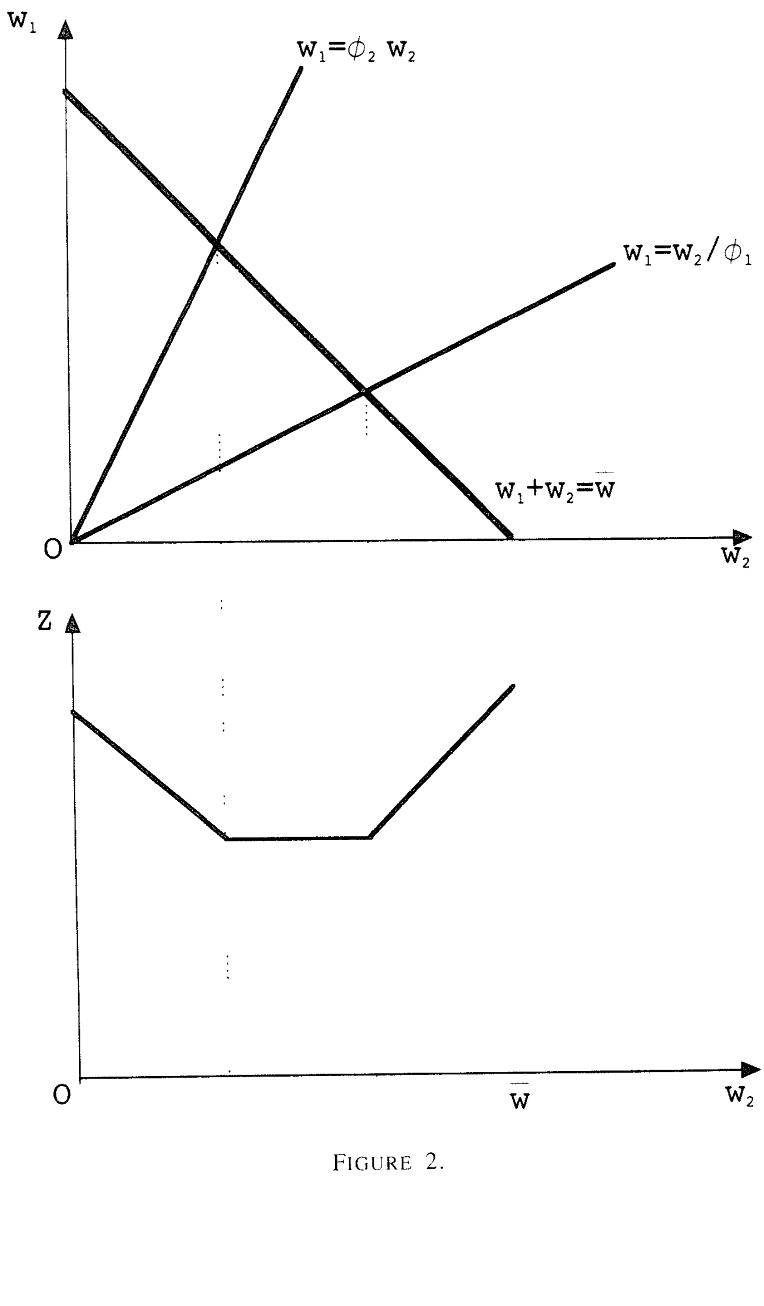

FIGURE 2.

in Figure 2, in which $\theta_1 = \theta_2$ is assumed. Figure 2 shows that the environmental quality is higher in corner solution cases, i.e., the pair of initial endowments (w_1, w_2) is in Ω_2 or Ω_3, than in interior solution cases where $(w_1, w_2) \in \Omega_1$. If the initial distribution of resources is in Ω_2, then an international income transfer that brings about the distribution in Ω_1 deteriorates the environment. If the initial distribution is in Ω_1, by contrast, an international income transfer that leads to the distribution in Ω_3 improves the environment. These results are independent of preference and technology parameter including θ_i.

The above results indicate that an international income redistribution which enlarges an inequality in resource endowments improves the environmental quality. The intuition is as follows. In the presence of a large inequality in resource endowments, the resource poor country does not control the pollution. As long as it does not undertake the control of pollution, any increases (decreases) of resources in that country cause more (less) pollution. Finally, as stated in the case of a small transfer, the effect of such transfers on each country's welfare is ambiguous.

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