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North-South Capital Movement and Global Environment

Meeta K. Mehra

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School of International Studies

Jawaharlal Nehru University

India

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Abstract

The paper re-examines the hypothesis: free movement of capital from capital-rich "Northern" to capital-poor "Southern" countries worsens the global environment. Assuming that national governments regulate the pollution level optimally, by trading-off the marginal benefit of pollution against its marginal cost, it is found that, North is generally a larger polluter. Also, a zero to positive level of foreign direct investment worsens the global environment but a higher level of investment is not necessarily associated with more global pollution. As countries move from non-cooperation to cooperation in setting environment policies, world environment quality improves, and there is *more* foreign direct investment. With foreign direct investment the welfare implications for the North are not clear and South unambiguously gains. These results are derived assuming environment to be a neutral good. When environment is a normal good, a move from autarky to non-cooperative FDI equilibrium entails that even South may lose in welfare as the North, and in absolute terms, North will pollute less than the South. Further, in general, there is little rationale for harmonization of environmental policies across countries.

Journal of Economic Literature Classifications: F10, F13, F21, Q21, Q28.

Key Words: International capital mobility, global environment, North-South trade.

Address correspondence to:
Meeta K Mehra, Associate Professor, Centre for International Trade and Development, Room No. 208, School of International Studies, Jawaharlal Nehru University, New Meharauli Road, New Delhi 110067, INDIA.
Phone: 91-11-26704353; Email: meetakm@mail.jnu.ac.in

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1 Introduction

Similar to free trade in goods between "Northern" and "Southern" countries, free capital movement between these countries is believed to worsen global environment. It would induce the North to export capital to the South for two reasons. One is the greater abundance of capital in the North and the other is a more lenient pollution policy in the South, both of which lead to return on capital in the North to be lower than that in the South. As capital moves from North to South, driven by higher returns, pollution increases in the South, and if pollution is transnational, global environment is adversely affected.

It is somewhat surprising that very little formal economic analysis of North-South capital movement and environment exists to date, although there is a growing literature on North-South trade *in goods* and environment (e.g. Chichilinsky (1994), Copeland and Taylor (1994 and 1995)). This paper is an attempt toward filling the gap in theoretical analysis of the issue. Our framework of analysis is the closest to Rauscher (1992, 1997), both of which analyze the implications of capital mobility on the state of the environment under alternative assumptions of fixed and optimal environment policies, separately for both small and large open economies. Rauscher (1997), in particular, derives several possible outcomes – in terms of implications for FDI, regional pollution and welfare – depending on the interplay of various parameters and policy regimes. Our model differs from Rauscher (1997) in two significant ways. First, it incorporates a more defined structure of the economy, in terms of technology and preferences. Accordingly, our analysis generates more definitive predictions. Second, Rauscher's model assumes that environment is a neutral good, i.e., there are zero-income effects on the demand for environment. Against this, our analysis considers both – a basic model that incorporates zero-income effects on the demand for environment, and another where environment is a normal good. Further, while McGuire (1982), Merrifield (1988) and Copeland and Taylor (1997) consider both intersectoral and international capital mobility, by restricting analysis to a one-good economy, the analysis here focuses on the implications of international capital mobility alone.

Specifically, the paper revisits the "pollution haven" debate in the context of FDI by focusing on transfrontier pollution, where each region/ country is as much affected by its own pollution as that from the other.[1] Our basic point of departure from the layman perception of this issue (as capsuled above) is that pollution policy of South may be less stringent than North's not because of difference in preference toward environment but due to other differences such as endowment. In each country the government is conscious of the state of the environment and sets an optimal

[1]The examples of transfrontier pollution are emissions of carbon dioxide from energy production or use leading to concerns of global warming and climate change, or chlorofluorocarbons damaging the ozone layer.

pollution policy by weighing its marginal economic benefit and its marginal cost toward social welfare. Then, capital movement (from North to South) would affect the environment policies of countries. Hence, it is not *a priori* clear as to whether global pollution will increase or decrease - or whether more pollution is associated necessarily with higher level of FDI. Furthermore, given various attempts by countries to cooperate on global environmental issues, it is also natural to ask what pattern of pollution policies cooperation implies and whether it is a deterrent to direct foreign investment. Also it is not clear how FDI may affect the welfare of both the North and the South. All these issues call for formal scrutiny.

In this paper we analyze resource-based pollution, that is, pollution arising from the use of a factor of production.[2] Furthermore, the government in each country controls the total supply (release) of the polluting resource to the production sector, which then gets leased to the private sector in a competitive market. The private sector pays a market-determined per-unit 'pollution tax' to the government for the use of the resource. The environmental 'good' is proportional to how much is preserved of the resource, that is, the difference between the (exogenous) endowment of this resource and the amount released for production.

Our analysis captures the following mechanisms of how environment policy affects welfare. In the absence of capital movement between countries, the benefit from increasing the amount released of the resource lies in its expansionary impact on national output. This can be called the *output effect*. In the presence of capital movement, if we assume that governments behave non-cooperatively there is an additional effect, that is, the *factor terms-of-trade effect*. These effects, in relation to the marginal cost of pollution, influence the optimal pollution policy of a particular country. When, instead, regions cooperate the factor terms-of-trade effects wash out and the *public good* nature of global environment is fully internalized.

In general terms the conclusions of our analysis are that zero to positive level of FDI worsens global pollution. However, as countries move from non-cooperation to cooperation in setting environmental policies and world environment improves as a result, there is *more* FDI, not less. Thus, stringency in environment policy is not a disincentive to FDI, as is commonly feared. More specifically we obtain the following results.

1. Both in autarky and in the presence of capital flows, North's contribution to global pollution is higher than that of the South, irrespective of North's endowment of the natural resource relative to South's. An outflow of capital from the North induces it to reduce its pollution level, and correspondingly South's pollution increases. But not surprisingly, the sum of regional pollution, that is, global pollution, increases.

[2] Examples include the use of coal in power or steel plants, raw wood in furniture manufacturing etc.

2. As the economies move from autarky to free FDI equilibrium, South unambiguously gains in terms of welfare, whilst the North may or may not gain. In the special case where the endowment differences are small enough, such that the equilibrium level of FDI is low enough, North unambiguously suffers a loss in welfare. In general, the global welfare may be higher or lower. But, in the special case mentioned above, global welfare is less at the free FDI equilibrium than that under autarky.

3. The above conclusions hold when the governments regulate their environment in a non-cooperative fashion. In the cooperative free FDI equilibrium, the level of FDI is *greater* than at the non-cooperative free FDI equilibrium. Moreover, the cooperative solution involves a reduction in pollution originating from the North but *may not* entail a similar adjustment in the South. In the cooperative equilibrium global environment is better compared to non-cooperative free FDI or autarky equilibria.

4. The above results are derived assuming environment to be a neutral good. Instead, when environment is a normal good, in moving from autarky to non-cooperative free FDI equilibrium, similar to the North, South may or may not gain in welfare. Moreover, the ranking of countries in terms of their absolute level of pollution is reversed, in that, now South is a larger polluter at the free FDI equilibrium than the North.

We now turn to the formal analysis.

2 The model

The world consists of two countries: North and South. Each produces and consumes one and the same good (Y). Hence the standard commodity terms-of-trade effects and sectoral factor intensities are ignored and we focus entirely on the implications of international capital movement or FDI.

The production process uses three factors - labor (L), capital (K) and a pollution generating natural resource (T). Let the endowments be denoted by a bar on the top and the country, North or South, by the superscript N or S. For instance, $\bar{T}^S$ is the endowment of the natural resource in the South. Let the population in each country be normalized to one, and let $\bar{L}^j$ denote the (per capita) human capital coefficient of population in country j. It is realistic to suppose that $\bar{L}^N > \bar{L}^S$ (as in Copeland and Taylor (1994)).[3] But, for technical simplicity, we assume here that $\bar{L}^N = \bar{L}^S$, which we call as the symmetric case. However, most of our results hold when $\bar{L}^N > \bar{L}^S$, which we refer to as the asymmetric case; this is considered in section 3 of the paper. Most critically for our

[3]That is, North is sufficiently more skilled labor abundant so that in effective labor units, it is the labor abundant country.

purpose, we assume $\bar{K}^N > \bar{K}^S$, that is, North is more capital abundant.[4]

The production function, which is linearly homogeneous in the three inputs, Cobb-Douglas in form and same in both countries is denoted by

$$Y = K^\alpha T^\beta,\ \alpha,\ \beta > 0,\ \alpha + \beta < 1, \tag{1}$$

where the labor endowments are normalized to one, and, K and T are the total *use* of respective factors. When capital is not internationally mobile, $K = \bar{K}$; otherwise $K \neq \bar{K}$. Note that T is a policy variable. Let r and τ denote the price for the use of capital and natural resource respectively. Put differently, τ is the pollution tax. Perfect competition and profit maximization imply

$$r = Y_K = \alpha K^{\alpha-1} T^\beta; \quad \tau = Y_T = \beta K^\alpha T^{\beta-1}. \tag{2}$$

Let a country's social welfare function be defined as:

$$U = C + \gamma\Phi(\bar{T} - T^W),\ \Phi' > 0 > \Phi'',\ \gamma > 0, \tag{3}$$

where C is the aggregate national consumption of good Y, $\bar{T} = \bar{T}^N + \bar{T}^S$, the global endowment of the natural resource, $T^W = T^N + T^S$, the global use (release) of the natural resource, and $\gamma\Phi(\bar{T} - T^W)$ is the utility from environmental good. Note that the utility function is quasi-linear with respect to C and strictly concave with respect to the environment good, equal to $(\bar{T} - T^W)$. This implies that environment is a neutral good. We refer to this as our basic model or the zero-income effect model. (In section 4 we relax this assumption.) It is further assumed that γ is sufficiently large. This assumption is consistent with environment being our central issue. Also, we assume that the Inada conditions with respect to marginal utility from the environment good hold, that is, $\lim_{\bar{T}-T^W \to 0} \Phi'(\bar{T} - T^W) = \infty$. This ensures that $T^W < \bar{T}$ at the optimum.

The sequence of our analysis is as follows. The autarky or no-capital mobility equilibrium is examined first. This is followed by analysis of the free capital mobility equilibrium. Under the latter, two alternative cases – one that assumes Nash non-cooperative behavior in setting of pollution policies by the regional governments, and the other that assumes coordination of regional pollution policies – are examined.

We begin with autarky.

2.1 Autarky

Initially, suppose that the two countries are in isolation. Then, for any country $C = Y$. The welfare level is expressed as: $U = \bar{K}^\alpha T^\beta + \gamma\Phi(\bar{T} - T^W)$. Since the welfare of one country is dependent on its

[4] The ranking between $\bar{T}^N$ and $\bar{T}^S$ does not affect our analysis, so that $\bar{T}^N \gtreqless \bar{T}^S$.

own pollution as well as that of the other, there is a strategic interdependence in the setting of the optimum pollution policy. We assume here that T^N and T^S are determined in a non-cooperative Nash fashion. The rule for optimum T^j for country j is

$$\tau(\bar{K}^j, T^j) = \gamma\Phi'(\bar{T} - T^W), \quad j = N, S. \tag{4}$$

The l.h.s. is the marginal benefit, equal to the marginal product of the resource. This is the *output effect*. The r.h.s. is the marginal cost in terms of an increase in global pollution. These are respectively decreasing and increasing functions of the resource.

At this point, it is important to observe that the Inada condition on the marginal utility from pollution ensures that $T^W < \bar{T}$. But, to be meaningful, it is also required that total use of the natural resource in *each* country be less than the respective endowment, that is, $T^j < \bar{T}$, $j = N, S$. A high enough value of γ ensures this.[5].

Next, in view of diminishing returns, $\partial\tau^j/\partial T^j < 0$ $(j = N, S)$, and $\Phi'' < 0$ by assumption. It is, therefore, straightforward to show that the second-order conditions are met. Now, turn to analyzing the regional pollution levels. We can write the first-order condition (4) as

$$\tau(\bar{K}^N, T^N) = \tau(\bar{K}^S, T^S) = \gamma\Phi'(\bar{T} - T^W). \tag{5}$$

Thus, the resource price/ tax is equal across the countries on account of common marginal costs.

In view of (4) again, $\bar{K}^N > \bar{K}^S$ implies that

$$T^{N^a} > T^{S^a}, \tag{6}$$

where superscript "a" denotes autarky. (Note that this holds whether $\bar{T}^N \gtrless \bar{T}^S$.) Thus, North uses more of the resource and hence contributes more to global pollution, even if North's endowment of the natural resource may be lower than that of the South.

Proposition 1: *In the autarky equilibrium, North's contribution to world pollution is higher than South's.*

The solution of T^{N^a} and T^{S^a} is illustrated in Figure 1. The curve $\tau^j = MB^{j^a}$ $(j = N, S)$ represents $\tau(\bar{K}^j, T^j)$ as a function of T^j; this is the respective marginal benefit curve. For any given T^j, the marginal benefit is higher in North than in South since North is more capital abundant and capital and natural resource are complementary inputs. Graphically, this is shown by the benefit curve for North, MB^{N^a}, lying to the right of that for the South, MB^{S^a}. The curve B^a is the *lateral* sum of the respective marginal benefit curves. The MC curve is the marginal cost of world pollution; it represents $\gamma\Phi'(\bar{T} - T^W)$ as a function of $T^W = T^N + T^S$. The intersection of the B^a and the

[5] This can be checked, for example, by supposing that $\Phi(\cdot) = \ln(\cdot)$

MC curves determines the equilibrium world pollution. The regions' contribution toward world pollution is read off the respective MB^a curves. Clearly, $T^{N^a} > T^{S^a}$.

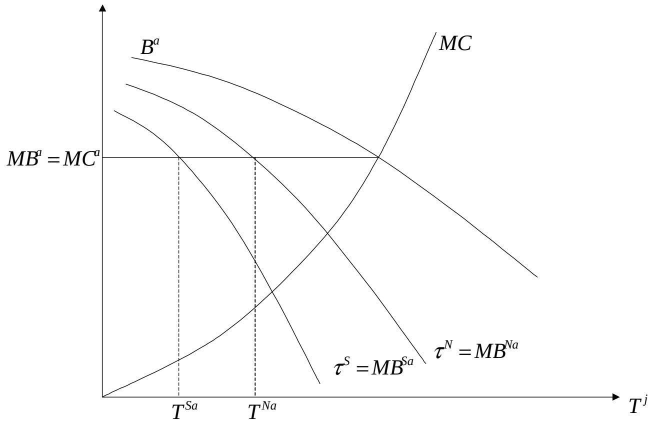

Figure 1: Autarky equilibrium

The autarky equilibrium provides a basis for capital to move from the North to the South. We have $\tau^{N^a} = \beta \bar{K^N}^{\alpha} {T^N}^{\beta-1} = \tau^{S^a} = \beta \bar{K^S}^{\alpha} {T^S}^{\beta-1}$ implying $T^{N^a}/T^{S^a} = \left(\bar{K}^N/\bar{K}^S\right)^{\frac{\alpha}{1-\beta}}$ Hence,

$$\frac{r^{N^a}}{r^{S^a}} = \left(\frac{\bar{K}^N}{\bar{K}^S}\right)^{\alpha-1}\left(\frac{T^{N^a}}{T^{S^a}}\right)^{\beta} = \left(\frac{\bar{K}^S}{\bar{K}^N}\right)^{\frac{1-\alpha-\beta}{1-\beta}} < 1, \quad \text{since } \bar{K}^N > \bar{K}^S.$$

Therefore, in autarky, capital earns a higher return in the South. This would imply that as capital movement is permitted across countries, North will export capital to South.

2.2 International capital mobility

Suppose the two countries allow free movement of good(s) and capital.[6] Consider first the short run during which the supplies of the resource are not readjusted, i.e. autarky pollution policies are unchanged. Since $r^{S^a} > r^{N^a}$, capital moves from North to South. In equilibrium, the rental rates are equalized. In turn South exports goods (good Y) to the North. There is no change in the pollution level in either country by definition and there are standard gains from capital movement (see MacDougall (1960)).

In response to movement of capital suppose the countries reset their pollution policies optimally (in the long run). Let I denote the export of capital from North to South or the level of FDI. The

[6] Allowing trade in goods but no movement of capital between the two countries does not have any real effects and replicates the autarky equilibria since there is no relative price change. Each country consumes whatever it produces.

capital mobility equilibrium is achieved when $r^N = r^S \equiv r$, that is

$$(\bar{K}^N - I)^{\alpha-1} T^{N\beta} = (\bar{K}^S + I)^{\alpha-1} T^{S\beta}, \tag{7}$$

where T^N and T^S are policy choices. This equation implicitly yields

$$I = I(\underset{(-)}{T^N}, \underset{(+)}{T^S}); \quad r = r(\underset{(+)}{T^N}, \underset{(+)}{T^S}), \tag{8}$$

where r is the (common) reward to capital in the world economy. Equation (7) indeed yields a closed-form solution of I in terms of T^N and T^S. Denoting $\theta \equiv \beta/(1-\alpha)$, $\eta \equiv {T^N}^\theta/({T^N}^\theta + {T^S}^\theta)$ and $\bar{K} \equiv \bar{K}^N + \bar{K}^S$,

$$I = \bar{K}^N - \eta \bar{K}. \tag{9}$$

The comparative statics in (8) can be explained as follows. Since capital and natural resource are complements, with an increase in T^N, the marginal product of capital increases. Consequently, there is less FDI, since the return on capital in the source country North is higher and some capital returns to the North. The reward to capital in the international economy is greater. If T^S is higher, the level of FDI responds in the opposite way but the reward to capital also rises. Thus, an increase in the resource use in either country implies that in the international economy capital is working with a higher level of a complementary input; its marginal product therefore increases.

Choice of pollution levels

In the presence of capital mobility, the gross domestic product and the gross national product are not the same, that is, $C^j \neq Y^j$. We have $C^N = Y^N + rI$ and $C^S = Y^S - rI$, where rI represents net factor income from abroad. Thus, the respective social welfare levels can be expressed as:

$$U^N(T^N, T^S) = (\bar{K}^N - I(T^N, T^S))^\alpha T^{N\beta} + r(T^N, T^S) I(T^N, T^S) + \gamma \Phi(\bar{T} - T^W); \tag{10}$$

$$U^S(T^N, T^S) = (\bar{K}^S + I(T^N, T^S))^\alpha T^{S\beta} - r(T^N, T^S) I(T^N, T^S) + \gamma \Phi(\bar{T} - T^W). \tag{11}$$

Evidently, unlike in autarky, the marginal benefit of a country's own pollution policy is a function of the other country's level of pollution as well. Hence, there exists even more strategic interdependence in the determination of pollution policies of the two countries. We continue to assume that pollution policies are set non-cooperatively. At the Nash equilibrium, $\partial U^N/\partial T^N = 0$ and $\partial U^S/\partial T^S = 0$. These first-order conditions are respectively spelt out as:

$$\tau(\bar{K}^N - I(\cdot), T^N) + I(\cdot)\frac{\partial r(\cdot)}{\partial T^N} = \gamma \Phi'(\bar{T} - T^W); \tag{12}$$

$$\tau(\bar{K}^S + I(\cdot), T^S) - I(\cdot)\frac{\partial r(\cdot)}{\partial T^S} = \gamma \Phi'(\bar{T} - T^W). \tag{13}$$

Compared to autarky, it is seen that besides the *output effect* there is an additional effect on the marginal benefit of T^j, namely, the *factor terms-of-trade effect.* This is captured by the terms $I\partial r/\partial T^N$ and $I\partial r/\partial T^S$. The North (South) being the creditor (debtor) country, an increase in r, due to an increase in the resource input use, implies a positive (negative) terms-of-trade effect for the North (South). These effects on the marginal benefits are critical in understanding how the optimal pollution policies differ from their autarky levels.

Recalling that $K^N \equiv \bar{K}^N - I$ and $K^S \equiv \bar{K}^S + I$ the expressions for I in (9) and those for the marginal product of capital in (2) imply

$$\frac{\partial r}{\partial T^N} = \frac{\alpha\tau^N}{\bar{K}}; \quad \frac{\partial r}{\partial T^S} = \frac{\alpha\tau^S}{\bar{K}}. \tag{14}$$

We now substitute (14) into (12) and (13) and rewrite the first-order conditions as:

$$\bar{f}^N(T^N, I(\cdot)) \equiv f^N(T^N, T^S) \equiv \tau(K^N, T^N)\left[1 + \frac{\alpha I(T^N, T^S)}{\bar{K}}\right] = \gamma\Phi'(\bar{T} - T^W); \tag{15}$$

$$\bar{f}^S(T^S, I(\cdot)) \equiv f^S(T^N, T^S) \equiv \tau(K^S, T^S)\left[1 - \frac{\alpha I(T^N, T^S)}{\bar{K}}\right] = \gamma\Phi'(\bar{T} - T^W). \tag{16}$$

In each equation the l.h.s. represents the marginal benefit and the r.h.s. is the marginal cost of T^j. The two equations give rise to negatively sloped reaction functions, to be denoted as R^N and R^S, for North and South. It is straightforward to establish that the respective second-order conditions hold under the following "regularity" condition (R1):[7]

$$\alpha < \frac{\bar{K}^N + \bar{K}^S}{2(\bar{K}^N - \bar{K}^S)}. \tag{R1}$$

Note that if $\bar{K}^N - \bar{K}^S \leq 2/3\bar{K}^N$, the r.h.s. of (R1) is greater than or equal to one; since $\alpha < 1$, the condition (R1) is not binding. It is binding if and only if $\bar{K}^N - \bar{K}^S > 2/3\bar{K}^N$. In this case the upper limit on α ensures that the direct effect on the marginal benefits, $\bar{f}^j(T^j, I)$ $(j = N, S)$, of increase in pollution, T^j, which is negative in sign, outweighs the positive (indirect) effect on $\bar{f}^j$ through its impact on the level of FDI, I.

We assume that (R1) holds. Moreover, under (R1) the Nash equilibrium is unique and T^N and T^S are strategic substitutes of each other. The detailed derivations are available with the authors.

Pollution levels and the level of FDI

We now turn to the equilibrium FDI. Observe that the first-order conditions (15) and (16) together with the capital market clearing equation (7) constitute the equilibrium conditions under capital mobility. These are three equations in three variables: I, T^N and T^S. It will be mathematically

[7] For brevity the proof is not included here, but it can be obtained from the author.

convenient to collapse these three into two equations in two variables, I and η, where recall that $\eta = {T^N}^\theta/({T^N}^\theta + {T^S}^\theta)$. The first equation, which is (9), is derived from the capital market clearing condition (7). The second is derived by taking the ratio of the two first-order conditions (15) and (16) and substituting the capital market equation (7) in it. That is:

$$\left(\frac{1+\frac{\alpha I}{\bar{K}}}{1-\frac{\alpha I}{\bar{K}}}\right)^{\frac{1}{1-\beta}} = \left(\frac{T^N}{T^S}\right)^{\frac{1-\alpha-\beta}{(1-\alpha)(1-\beta)}} = \left(\frac{\eta}{1-\eta}\right)^{\frac{1-\alpha-\beta}{\beta(1-\beta)}}. \tag{17}$$

Equations (9) and (17) solve I and η. By definition η is positively related to T^N/T^S. Hence these equations solve I and T^N/T^S. These solutions are illustrated graphically in Figure 2. The curve FDI_1 graphs eq. (9) whilst FDI_2 graphs eq. (17). It is straightforward to see that eqs. (9) and (17) respectively generate negatively and positively sloped schedules in I and T^N/T^S space.[8]

As shown in Figure 2, FDI_1 has the vertical intercept at $\bar{K}^N$ and it is asymptotic to the horizontal axis at $-\bar{K}^S$. The FDI_2 curve has the vertical intercept at $-\bar{K}/\alpha$ and is asymptotic to the horizontal axis at $\bar{K}/\alpha$. Thus a solution exists and it is unique – at point O. It follows directly from eq. (17) that as long as $I > 0$, ${T^N}^o/{T^S}^o > 1$, where superscript "o" denotes non-cooperation. Given ${T^N}^o > {T^S}^o$, it follows from (7) that ${K^N}^o > {K^S}^o$. Hence,

Proposition 2: *At the free FDI equilibrium,*
(i) the pollution contribution of the North is higher than that of the South, and (ii) (despite capital outflow from North to South) capital in use in the North exceeds that in the South.

That

$${K^N}^o > {K^S}^o \Rightarrow I^o < \frac{\bar{K}^N - \bar{K}^S}{2}. \tag{18}$$

The last inequality will be used later to compare FDI at the non-cooperative equilibrium with that at the cooperative equilibrium.

Comparison with autarky

The groundwork is now ready to compare the pollution level to that in the absence of FDI. Note that if we substitute $I = 0$ in the marginal benefit expressions (l.h.s.) in (15) and (16), these

[8]Using the definition of η, (9) could be expressed in terms of T^N/T^S as:

$$I = \bar{K}^N - \frac{(T^N/T^S)^\theta}{1+(T^N/T^S)^\theta}\bar{K}.$$

Hence, $\lim_{T^N/T^S\to\infty} I = -\bar{K}^S$; $\lim_{T^N/T^S\to 0} I = \bar{K}^N$. These limits define the shape of FDI_1 curve. Turning next to (17),

$$\left(\frac{1+\frac{\alpha I}{\bar{K}}}{1-\frac{\alpha I}{\bar{K}}}\right) = \left(\frac{T^N}{T^S}\right)^{1-\theta} \Rightarrow \frac{\alpha}{\bar{K}}I = 1 - \frac{2}{1+(T^N/T^S)^\theta}$$

In the limit, $\lim_{T^N/T^S\to\infty} I = \bar{K}/\alpha$; $\lim_{T^N/T^S\to 0} I = -\bar{K}/\alpha$, which defines the shape of the FDI_2 curve.

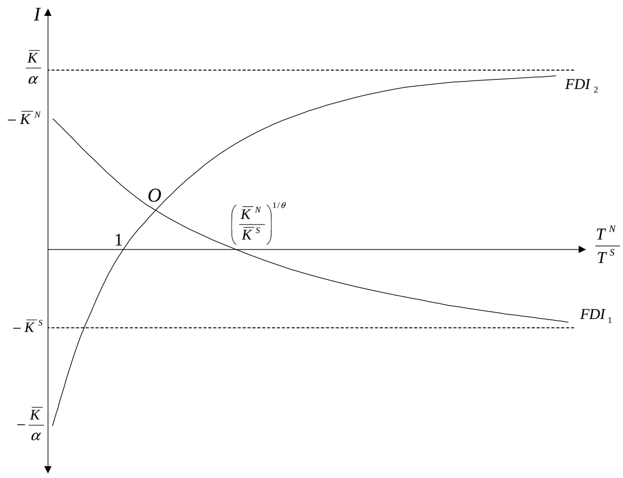

Figure 2: Locus of FDI_1 and FDI_2

equations reduce to their counterparts in autarky. On the other hand, the marginal cost schedule is the same between autarky and free movement of capital. Therefore, the comparison between autarky and capital mobility can be characterized by an exogenous change in I even if it is an endogenous variable.

Ceteris paribus, if the marginal benefit of T^j increases or decreases with I, the equilibrium T^j in the presence of capital movement is greater or smaller than in the absence of capital movement. In Appendix A, we derive that, for any $I > 0$, $\partial \bar{f}^N/\partial I < 0$ and $\partial \bar{f}^S/\partial I > 0$. That is, everything else the same, FDI causes the marginal benefit schedule for North to shift down and that for South to shift up. At the same time, since marginal costs are a function of aggregate world pollution, capital mobility will induce a movement along the marginal cost curve. This will also impact the equilibrium level of pollution. Taking into account these effects, on both the marginal cost and marginal benefits, we show that the overall change in regional pollution levels in response to FDI is that $dT^N/dI < 0$ and $dT^S/dI > 0$ (see Appendix A for the mathematical proof). Hence,

Proposition 3: *As economies move from autarky to free FDI equilibrium, the pollution generation from the North decreases and that from the South goes up.*

Intuitively, since capital and resource input are complements of each other in production, South accommodates capital inflow by releasing more of the resource input and North responds to capital outflow by releasing less of the resource input to the market.

We next look at the global pollution level at the free FDI non-cooperative equilibrium in comparison with that at the autarky equilibrium. Consider the free FDI first-order conditions (15) and (16). Substituting the expressions for τ^N and τ^S from (2) in the l.h.s. of each, manipulating and adding up, it is obtained that

$$(\bar{K}^N - I)^{\frac{\alpha}{1-\beta}}\left(1+\frac{\alpha I}{\bar{K}}\right)^{\frac{1}{1-\beta}} + (\bar{K}^S + I)^{\frac{\alpha}{1-\beta}}\left(1-\frac{\alpha I}{\bar{K}}\right)^{\frac{1}{1-\beta}} = T^W\left[\frac{\gamma}{\beta}\Phi'(\bar{T}-T^W)\right]^{\frac{1}{1-\beta}} \equiv g(T^W). \tag{19}$$

Next, express the l.h.s. of the above equation in terms of η, by using (9) and (17):

$$h(\eta) \equiv \frac{2^{\frac{1}{1-\beta}}\left[\eta^{\frac{1-\alpha}{\beta}} + (1-\eta)^{\frac{1-\alpha}{\beta}}\right]}{\left[\eta^{\frac{1-\alpha-\beta}{\beta}} + (1-\eta)^{\frac{1-\alpha-\beta}{\beta}}\right]^{\frac{1}{1-\beta}}}\bar{K}^{\frac{\alpha}{1-\beta}}.$$

Hence, (19) can be re-stated as

$$h(\eta) = g(T^W).$$

Now turn to the autarky first-order condition (eq. (4)), which could be similarly manipulated and summed up to yield

$$\Lambda \equiv \bar{K^N}^{\frac{\alpha}{1-\beta}} + \bar{K^S}^{\frac{\alpha}{1-\beta}} = g(T^W). \tag{20}$$

Since $g(\cdot)$ is increasing in T^W, it follows that $T^{W^o} \gtreqless T^{W^a}$ as $h(\eta) \gtreqless \lambda$. It is shown in Appendix B that $h(\eta) > \lambda$. Hence, as one would expect,

Proposition 4: *As compared to autarky, global pollution is higher with capital mobility.*

2.3 Welfare implications

In general, the welfare effects take the form of *direct* and *indirect* effects of FDI on the factor terms-of-trade, the latter arising due to the effect of capital flows on the environment policies of countries that, in turn, affect the factor terms-of-trade. Moreover, with pollution impacting welfare directly, the change in the *own* and *other country's* environment policy also has a *direct* bearing on the welfare of a particular country.[9]

As in Rauscher (1997), we show below that welfare losses are possible, both at regional and global levels, even as countries adjust their environmental policies in an optimal fashion. We can state the respective welfare functions as: $U^N(T^N, T^S; I) = Y(\bar{K}^N - I, T^N) + r(\bar{K}^N - I, T^N)I + \gamma\Phi(\bar{T} - T^W)$; $U^S(T^N, T^S; I) = Y(\bar{K}^S + I, T^S) - r(\bar{K}^S + I, T^S)I + \gamma\Phi(\bar{T} - T^W)$. In both $U^N(\cdot)$ and $U^S(\cdot)$ the first two terms equal the consumption of the product and the last term represents utility from the environmental good.

[9]These effects are similar to those analyzed by Killinger (2000).

The welfare effects of FDI can be evaluated by dU^j/dI (even though I is an endogenous variable). We have

$$\frac{dU^N}{dI} = \underbrace{\underset{(+)}{\frac{\partial r^N}{\partial I}}I + \underset{(+)}{\frac{\partial r^N}{\partial T^N}}\underset{(-)}{\frac{dT^N}{dI}}I}_{(+)} + \underset{(-)}{\left(\tau^N - \gamma\Phi'\right)}\underset{(-)}{\frac{dT^N}{dI}} - \gamma\Phi'\underset{(+)}{\frac{dT^S}{dI}} \gtrless 0;; \tag{21}$$

$$\frac{dU^S}{dI} = \underbrace{-\underset{(-)}{\frac{\partial r^S}{\partial I}}I - \underset{(+)}{\frac{\partial r^S}{\partial T^S}}\underset{(+)}{\frac{dT^S}{dI}}I}_{(+)} + \underset{(+)}{\left(\tau^S - \gamma\Phi'\right)}\underset{(+)}{\frac{dT^S}{dI}} - \gamma\Phi'\underset{(-)}{\frac{dT^N}{dI}} > 0. \tag{22}$$

There are four effects at play, represented by the four terms in the r.h.s. of each equation. The first is the direct effect of investment on the factor terms-of-trade. Both the countries have a gain on this account due to better allocation of capital between them. The second is the indirect effect on the factor terms-of-trade as countries adjust their environmental policies in response to change in the level of FDI, which in turn affects the return on capital. Complementarity between productive inputs implies that $\partial r^j/\partial T^j > 0$. This, together with $dT^N/dI < 0$ and $dT^S/dI > 0$ implies that the second effect is negative for both the countries. The sum of the *direct and indirect effects* may be positive or negative. However, as is shown in Appendix C, the sum of these two effects is unambiguously positive for both the countries. The third is the *direct* welfare effect through a change in the country's *own emissions*. This is the net effect given by the difference in the marginal benefit and marginal cost of own pollution, and how T^N and T^S is affected by I. In view of (15) and (16), $\tau^N < \gamma\Phi' < \tau^S$, which yields that the sign of this effect is positive for both North and South.[10] It is positive because of optimal adjustment of environmental policies by the individual country governments. The last is the *transboundary pollution effect* that arises due to the *spillover of pollution from the partner country*. Clearly, since North reduces its pollution and South increases it, the sign of this effect is negative (positive) for the North (South).

In sum, it is found that South would always experience an increase in its welfare from FDI. This is because the sum of the direct and indirect factor terms-of-trade effects, the own pollution change effect and the transboundary pollution effect are all positive for the South. It is derived (in Appendix C) that even for the North the direct factor terms-of-trade gains dominate the indirect losses in it, such that North also experiences net factor terms-of-trade gains. Moreover, as the

[10]Note that from (15) and (16) we have

$$\begin{aligned} \tau^N < \tau^N\left(1 + \frac{\alpha I}{\bar{K}}\right) &= \gamma\Phi' \\ \tau^S > \tau^N\left(1 - \frac{\alpha I}{\bar{K}}\right) &= \gamma\Phi'. \end{aligned}$$

South, North also has gains on account of own pollution change effect. However, inspite of these positive effects, the overall change in North's welfare may still be inconclusive as North has an additional source of welfare loss, which is due to the negative spillover effect of higher pollution in the South. Hence, in general, North may lose or gain from FDI.

However, if the capital endowment differences between the North and South are small enough, and such that the equilibrium FDI is small enough, North unambiguously incurs a welfare loss. The different effects work as follows. As $\bar{K}^N \rightarrow \bar{K}^S$, then $I \rightarrow 0$ and the direct and indirect factor terms-of-trade effects in (21) and (22) wash out. Given optimal pollution policy setting behavior the own pollution effect (the third term) also vanishes (as $I \rightarrow 0$) as this is equivalent to a move toward autarky equilibrium. This leaves the pollution spillover effect, which could be expressed for the North as: $\lim_{I \rightarrow 0} dU^N/dI = -\gamma\Phi'(dT^S/dI) < 0$. Thus, in the limiting case of FDI being very small, North loses from capital mobility unambiguously.

Another intuitive way to think of this result is as done by Copeland and Taylor (1995) and Copeland (2000), both of which are in the context of global pollution. Although both papers are about trade in goods and not factor mobility, the logic used therein might be useful to explain the welfare effects in our model.

Since pollution is a global externality, an increase in pollution in the South raises its marginal damage for the North, through the transboundary pollution spillover effect, inducing the North to reduce its pollution. Hence, North's and South's pollution levels are strategic substitutes of each other. Given that capital, K, and polluting input, T, are complements in production, in the free capital mobility regime, as capital moves from North to South this increases the marginal benefit of pollution in the South and, hence, South's pollution rises. On the other hand, North experiences a decline in the marginal benefit from the polluting input and, hence, its pollution falls.

Thus, a direct effect of free capital mobility is that it commits countries to different environment policies. Free FDI commits South to credibly commit to pollute more. Thus, South not merely experiences standard factor terms-of-trade gains, but also gets a strategic advantage in the environment policy game as free capital mobility induces a credible commitment by the North to pollute less (as T^N and T^S are strategic substitutes). Therefore, free capital mobility puts North at a strategic disadvantage in the environment policy game. Consequently, North's gains in standard factor terms-of-trade are offset by its losses in the environment game due to higher transboundary pollution spillovers from the South. In the special case where the level of FDI is small enough and hence the standard gains from trade in capital are small enough, North could even lose from capital mobility.

We now analyze the effect of FDI on world welfare, $U^W = C^N + C^S + 2\gamma\Phi(\bar{T} - T^W)$. Totally differentiating U^W with respect to I, we get

$$\frac{dU^W}{dI} = \underbrace{\left(\frac{\partial r^N}{\partial} + \frac{\partial r^N}{\partial T^N}\frac{dT^N}{dI}\right) I}_{(+)} + \underbrace{\left(-\frac{\partial r^S}{\partial I} - \frac{\partial r^S}{\partial T^S}\frac{dT^S}{dI}\right) I}_{(+)} + \underbrace{(\tau^N - \gamma\Phi')\frac{dT^N}{dI}}_{(+)} + \underbrace{(\tau^S - \gamma\Phi')\frac{dT^S}{dI}}_{(+)} \underbrace{- \gamma\Phi'\frac{dT^W}{dI}}_{(-)} \gtreqless 0. \quad (23)$$

We have already seen that the net factor terms-of-trade change is positive for both the countries, implying that the first two collection of terms in the r.h.s. of (23) are positive. Moreover, optimal adjustment of environmental policies implies that the respective own pollution effects (depicted by the next two terms) are positive. But, the increase in global pollution implies a welfare loss, leaving the change in aggregate global welfare unclear. However, in the special case of capital endowment differences between the North being small enough, such that equilibrium I being small enough, the factor terms-of-trade and the own pollution effects vanish; only the transboundary pollution effect remains. Since, even if $I \to 0$, $dT^W/dI > 0$, the world welfare declines.

The various welfare implications are summarized below.

Proposition 5: *As countries move from autarky to free capital mobility:*
(i) North may lose or gain in terms of welfare. In the special case where $\bar{K}^N - \bar{K}^S$ is sufficiently small such that the equilibrium FDI is small enough, North suffers a welfare loss. On the other hand, South unambiguously gains irrespective of the equilibrium level of FDI. (ii) In general, the effect on global welfare is ambiguous. In the special case discussed in (i) above, global welfare is less than in the autarky equilibrium.

2.4 Cooperation between regions

Evidently the countries of the world are striving toward cooperation with each other on transboundary environmental issues. For example, the Montreal Protocol to deal with ozone depleting substances, the Kyoto Protocol to address issues of greenhouse gas emissions and climate change, and the Convention on Biological Diversity to tackle the loss in flora and fauna, all emphasize the imperatives of international cooperation in dealing with the environmental concerns. We now analyze the effect of environment policy cooperation between the governments of North and South.Cooperation implies that the regional governments set policies that are consistent with maximization of their joint welfare. Hence, by definition, global welfare is higher under cooperation than that under non-cooperation.[11] In what follows, the effect of cooperation on the level of FDI and (regional and global) pollution levels are analyzed.

Global welfare is expressed algebraically by

$$U^W = C^N + C^S + 2\gamma\Phi(\bar{T} - T^W), \quad (24)$$

[11] If appropriate lumpsum side payments are made then each country is better off.

the sum of individual country welfares. Substituting for $C^N = Y^N + rI$ and $C^S = Y^S - rI$ into this,

$$U^W = Y(\bar{K}^N - I, T^N) + r(\bar{K}^N - I, T^N)I + Y(\bar{K}^S + I, T^S) - r(\bar{K}^S + I, T^S)I + 2\gamma\Phi(\bar{T} - T^N - T^S). \quad (25)$$

When this is maximized with respect to T^N and T^S, the two first-order conditions are:

$$\tau^N = \tau^S(\equiv \tau) = 2\gamma\Phi'(\bar{T} - T^W). \quad (26)$$

Utilizing $\partial\tau^j/\partial T^j < 0$, $j = N, S$ and $\Phi'' < 0$, it is easy to show that the second-order conditions hold.

The first-order conditions (in (26)) imply that the equilibrium charge on pollution is equalized between the North and the South. This is because, in joint welfare maximization, the factor terms-of-trade effects cancel out between the two regions. Also, capital market clearing implies $r^N = r^S = r$. Hence, global efficiency (through capital mobility and joint welfare maximization) implies factor rewards, τ and r, be equalized between North and South. This, in turn, implies the same level of employment of natural resource use by the two countries, that is, $T^{N^c} = T^{S^c}$ (superscript "c" denotes cooperation). The integration of global economy also entails that both the countries choose the same amount of capital, namely $K^{N^c} = K^{S^c}$.

In the non-cooperative equilibrium considered earlier, the factor terms-of-trade effects explain the difference in the pollution charge and the optimal level of pollution chosen by countries, such that North employs more capital (and natural resource) than the South. In the cooperative equilibrium, since the factor terms-of-trade effects wash out (technology being the same between the two countries), $T^{N^c} = T^{S^c}$ and $K^{N^c} = K^{S^c}$.[12]

Since, by definition, $K^{N^c} = \bar{K}^N - I$, and $K^{S^c} = \bar{K}^S + I$, $K^{N^c} = K^{S^c}$ implies that

$$I^c = \frac{\bar{K}^N - \bar{K}^S}{2}. \quad (27)$$

Recall that in the non-cooperative equilibrium, $I^o < (\bar{K}^N - \bar{K}^S)/2$ (eq. (18)). Hence,

Proposition 6: *In moving from non-cooperative to cooperative equilibrium, the level of FDI increases.*

This is interesting as it amounts to saying that tightening of environmental policies through cooperation is conducive and *not* an impediment to FDI.

Proposition 6 is intuitively explained in the course of analyzing the effects of cooperation on regional pollution levels.

[12]Does $T^{N^c} = T^{S^c}$ mean a case for international harmonization of environmental policies? As will be seen, this result is sensitive to the assumptions of symmetric labor endowments and absence of income effects on the demand for environmental quality in this model. Relaxation of either of these assumptions implies that $T^{N^c} \neq T^{S^c}$. Hence, there is little justification for harmonization. Many other implications of our basic model are, however, robust.

Effects on regional pollution levels

Deriving the impact of the regime change on T^N and T^S is a more difficult task. Consider the following pair of equations:

$$\tau^N \left(1 + \frac{\alpha I(T^N, T^S)}{\bar{K}}(1-b)\right) = (1+b)\gamma\Phi'(\bar{T} - T^W); \tag{28}$$

$$\tau^S \left(1 - \frac{\alpha I(T^N, T^S)}{\bar{K}}(1-b)\right) = (1+b)\gamma\Phi'(\bar{T} - T^W). \tag{29}$$

Note that these equations represent the non-cooperative equilibrium or the cooperative equilibrium as $b = 0$ or 1. Hence, the movement from non-cooperation to cooperation can be captured through a comparative statics with respect to b in the interval $[0, 1]$. Furthermore, let the eqs. (28) and (29) be viewed as having two endogenous variables, T^N and T^S, and two parameters, b and I (even though I is endogenous). Since we already know that I increases as the global economy moves from non-cooperative to cooperative equilibrium, we can assume $dI/db > 0 \; \forall \; b \in [0, 1]$. Effectively then, eqs. (28)-(29) implicitly define

$$T^N = T^N(b, I(b)); \;\; T^S = T^S(b, I(b)), \;\; \text{where } \frac{dI}{db} > 0. \tag{30}$$

The partials $\partial T^N/\partial b$ and $\partial T^S/\partial b$ capture the *direct effects* of the regime change at given I. The partials $(\partial T^j/\partial b)(dI/db)$, $j = N, S$ indicate the *indirect effects* through the accompanying change in I. These effects are now analyzed in turn. Particularly, as will be seen, the direct effects explain why FDI is higher in the cooperative equilibrium.

It is proven in Appendix D that

$$\frac{\partial T^N}{\partial b} < 0; \quad \frac{\partial T^S}{\partial b} \gtrless 0. \tag{31}$$

That is, the direct effects of cooperation are that North adopts a stricter environment policy whilst South may adopt a stricter or a more lenient policy.

Intuitively, there are two direct effects due to cooperation: internalization of the public good aspect of global pollution and nullification of factor terms-of-trade effects, which work as follows. When governments act non-cooperatively, they take into account the disutility-cost of pollution imposed on its nationals only. By comparison, in the cooperative equilibrium optimal pollution generation from each country is determined by taking into consideration the disutility-cost of pollution of the other country as well. Hence less pollution is released to the market in each country, i.e. T^N and T^S both fall.

Also, under non-cooperation there are terms-of-trade effects (on r) of a change in T^N or T^S. This is positive for the North and negative for the South.[13] Under cooperative behavior, however,

[13] As shown earlier, both $\partial r/\partial T^N$ and $\partial r/\partial T^S$ are positive; but an increase in r means an improvement (a deterioration) of factor terms-of-trade for the North (South).

joint welfare is considered and, therefore, there are no terms-of-trade effects. Hence, the absence of terms-of-trade effects implies that T^N will be smaller and T^S will be larger.

The net direct effect of cooperation without any change in FDI is then that T^N *falls unambiguously whilst* T^S *may increase or decrease.*

These direct effects on T^N and T^S at given I explain why FDI increases from the non-cooperative to the cooperative equilibrium. As T^N falls, at the original level of FDI, the marginal product of capital in the North falls (since capital and resource input are complementary to each other). In the South, suppose T^S rises. Then, at the original level of FDI, the marginal product of capital rises. Hence, starting from $r^N = r^S$, the changes in T^S and T^S imply $r^N < r^S$. This induces further outflow of capital from the North to the South. Even when T^N falls, we have seen that it is an outcome of internalization and terms-of-trade effects which work in opposite ways. Hence, it is expected that the magnitude of decrease in T^S is relatively small. Indeed, it is shown in Appendix D that $\left|\partial T^S/\partial b\right| < \left|\partial T^N/\partial b\right|$, when $\partial T^S/\partial b < 0$. Thus, even though r^S falls as T^S increases, $r^N - r^S < 0$, at the original level of FDI. This induces FDI to increase. In summary, irrespective of whether T^S increases or decreases, the movement from non-cooperation to cooperation implies higher FDI.

We next ascertain the *indirect effects* of the regime change through the change in FDI. It is derived in Appendix D that for any given b, $\partial T^N/\partial I < 0$ and $\partial T^S/\partial I > 0$. Intuitively, an increase in I means less capital at work in the North, a lower marginal product of T^N and, thus, a lower marginal benefit from T^N. As a result, T^N falls. Just the opposite holds in the South, and T^S tends to rise as I increases.[14] In summary, we then have that T^N falls whilst T^S may increase or decrease, on account of the regime change at given FDI. An increase in FDI induces T^N to fall and T^S to rise. Combining the two effects,

Proposition 7: *Compared to non-cooperation, at the cooperative equilibrium the pollution generated from North is less and that from South may be more or less.*

Effects on global pollution

Because of conflicting effects on it, the change in T^S is likely to be small. With T^N declining unambiguously one would conjecture that global pollution would decline. This is correct. Indeed, a stronger result holds, i.e.,

Proposition 8: *The global pollution at the cooperative FDI equilibrium is less than that under*

[14] In more detail, referring back to eqs. (15) and (16), these are the output effects of an increase in T^j. There are also the factor terms-of-trade effects, captured by the terms $\alpha I/\bar{K}$ for the North and $-\alpha I/\bar{K}$ for the South. An increase in I increases $\left|\alpha I/\bar{K}\right|$. Hence, the marginal benefit from T^N tends to increase for the North and that from T^S tends to decrease for the South. Thus, the factor terms-of-trade effects run counter to the output effects. However, the latter remain dominant.

autarky.

This proposition holds a strong message for staunch environmentalists who are typically opposed to freer FDI movement in the global economy. It says that even when global environment is the sole concern, it is better in a regime of free FDI, accompanied by global cooperation (coordination) on pollution policies than in the absence of FDI.

Proposition 8 is proved in Appendix E.

By substituting τ^N and τ^S given in (2) into (26) and manipulating, we first obtain $(\bar{K}^N - I^c)^{\frac{\alpha}{1-\beta}} + (\bar{K}^S + I^c)^{\frac{\alpha}{1-\beta}} = 2^{\frac{1}{1-\beta}} T^W \left[\frac{\gamma}{\beta}\Phi'(\bar{T} - T^W)\right]^{\frac{1}{1-\beta}}$. Using $I^c = (\bar{K}^N - \bar{K}^S)/2$, this is simplified to

$$\Omega \equiv 2^{-\frac{(\alpha+\beta)}{1-\beta}} \bar{K}^{\frac{\alpha}{1-\beta}} = \left[\frac{\gamma}{\beta}\Phi'(\bar{T} - T^W)\right]^{\frac{1}{1-\beta}} T^W \equiv g(T^W). \tag{32}$$

This equation solves for T^{W^c}.

Recall that under autarky, a similar manipulation of the first-order conditions yielded $\Lambda \equiv \bar{K^N}^{\frac{\alpha}{1-\beta}} + \bar{K^S}^{\frac{\alpha}{1-\beta}} = g(T^W)$; see (20). It is derived in Appendix E that $\Omega < \Lambda$. Given that $g'(T^W) > 0$, it then follows that $T^{W^c} < T^{W^a}$. Hence, the full internalization of the global environmental externality entails that aggregate world pollution is even lower than under autarky.

The analysis of our basic model of FDI and environment is complete at this stage. In what follows, we relax some assumptions in turn and analyze their implications.

3 Asymmetry in labor endowments

First, we relax the assumption on symmetry of labor endowments. Specifically, let North be the human-capital (or skilled-labor) abundant country in comparison with the South, i.e. $\bar{L}^N > \bar{L}^S$. It will be shown that most of the results of our basic model continue to hold.

Recall that the production functions are: $Y^N = \bar{L^N}^{1-\alpha-\beta} {K^N}^{\alpha} {T^N}^{\beta}$ and $Y^S = \bar{L^S}^{1-\alpha-\beta} {K^S}^{\alpha} {T^S}^{\beta}$.

3.1 Autarky

In autarky, the first-order conditions with respect to T^N and T^S are the same as (4), except that $\bar{L}^N$ and $\bar{L}^S$ may not be equal to 1. We would now have: $\tau^N (\equiv \beta \bar{L^N}^{1-\alpha-\beta} \bar{K^N}^{\alpha} {T^N}^{\beta-1}) = \gamma\Phi'(\bar{T} - T^W)$ and $\tau^S (\equiv \beta \bar{L^S}^{1-\alpha-\beta} \bar{K^S}^{\alpha} {T^S}^{\beta-1}) = \gamma\Phi'(\bar{T} - T^W)$. Dividing these conditions yields $\frac{{T^N}^a}{{T^S}^a} = \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{1-\frac{\alpha}{1-\beta}} \left(\frac{\bar{K}^N}{\bar{K}^S}\right)^{\frac{\alpha}{1-\beta}} > 1$, since $\bar{L}^N > \bar{L}^S$ and $\bar{K}^N > \bar{K}^S$. Thus, North pollutes more than the South and Proposition 1 continues to hold.

Note, however, that when $\bar{L}^N > \bar{L}^S$ an additional condition is required for capital to move from North to South, namely, $\bar{K}^N/\bar{L}^N > \bar{K}^S/\bar{L}^S$. This is equivalent to relative capital endowment ratio of the North to be higher than that of the South. This would imply $r^{N^a} < r^{S^a}$.[15] The reason being, everything else the same, a higher labor endowment implies a relatively higher marginal product of capital in the North. Only when the relative capital endowment of North to that of the South is larger than the corresponding ratio of the labor endowments would capital earn a higher return in the South, and form the basis for North to export capital to the South.

3.2 Free capital mobility

Non-cooperation in respect of environment policy

Analogous to the symmetric labor-endowment model, the solution to the level of FDI is obtained from the capital market clearing condition, $r^N = r^S$. This is equivalent to:

$$\begin{aligned} \bar{L^N}^{1-\alpha-\beta}(\bar{K}^N - I)^{\alpha-1}{T^N}^{\beta} &= \bar{L^S}^{1-\alpha-\beta}(\bar{K}^S - I)^{\alpha-1}{T^S}^{\beta} \\ \Leftrightarrow \frac{\bar{K}^N - I}{\bar{K}^S + I} &= \left(\frac{T^N}{T^S}\right)^{\frac{\beta}{1-\alpha}} \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{\frac{1-\alpha-\beta}{1-\alpha}} \qquad (33) \\ \Rightarrow I &= \bar{K}^N - \eta' \bar{K}, \qquad (34) \end{aligned}$$

where $\eta' = \frac{l^{1-\theta}{T^N}^{\theta}}{l^{1-\theta}{T^N}^{\theta} + {T^S}^{\theta}}$ and $l \equiv \bar{L}^N/\bar{L}^S$ by definition. Eq. (34) is the analog of (9).

Assuming non-cooperative behavior in respect to environment policy it is now shown that Propositions 2 and 3 also hold.[16]

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[15] This is proved by substituting equality of τ^js from the first-order conditions (that are similar to (4)) into the ratio of marginal products of capital, such that

$$\frac{r^{N^a}}{r^{S^a}} = \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{1-\alpha-\beta} \left(\frac{\bar{K}^N}{\bar{K}^S}\right)^{\alpha-1} \left(\frac{T^N}{T^S}\right)^{\beta} = \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{1-\alpha-\beta} \left(\frac{\bar{K}^N}{\bar{K}^S}\right)^{\alpha-1} \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{\beta\left(\frac{1-\alpha-\beta}{1-\beta}\right)} \left(\frac{\bar{K}^N}{\bar{K}^S}\right)^{\beta\left(\frac{\alpha}{1-\beta}\right)} = \left(\frac{\bar{L}^N/\bar{L}^S}{\bar{K}^N/\bar{K}^S}\right)^{\frac{1-\alpha-\beta}{1-\beta}}.$$

This is less than 1 when $\bar{L}^N/\bar{L}^S < \bar{K}^N/\bar{K}^S$.

[16] The method of proof for deriving pollution reduction in the North and an increase in the South is similar to that in the baseline model. Further, parallel to the calculations in the symmetric case, the first-order conditions of the free capital mobility equilibrium could be collapsed into

$$\begin{aligned} \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{1-\alpha-\beta} \left(\frac{K^N}{K^S}\right)^{\alpha} \left(\frac{T^N}{T^S}\right)^{\beta-1} &= \frac{1-\alpha I/\bar{K}}{1+\alpha I/\bar{K}} \\ \Leftrightarrow \left(\frac{T^N}{T^S}\right) &= \left(\frac{1-\alpha I/\bar{K}}{1+\alpha I/\bar{K}}\right)^{-\frac{1}{1-\beta}} \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{\frac{1-\alpha-\beta}{1-\beta}} \left(\frac{K^N}{K^S}\right)^{\frac{\alpha}{1-\beta}}. \end{aligned}$$

Substituting for the ratio K^N/K^S from (33) into the r.h.s., the above reduces to

$$\left(\frac{T^N}{T^S}\right)^{\frac{1-\alpha-\beta}{1-\alpha}} = \left(\frac{1+\alpha I/\bar{K}}{1-\alpha I/\bar{K}}\right) \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{\frac{1-\alpha-\beta}{1-\alpha}}.$$

Since $\bar{L}^N > \bar{L}^S$ the r.h.s. exceeds one. Hence $T^{N^o} > T^{S^o}$. Further, complementarity of resource and capital entails

As for the impact on global pollution, the conclusion derived in Proposition 4 does not change when we consider differences in labor endowments between countries. That is, in relation to autarky, global pollution rises.

Cooperation between countries

Unlike in the symmetric case, the pollution ranking in the cooperative equilibrium differs between the two countries. Specifically, now North pollutes more than the South.[17] The underlying reason is as follows. Since labor is complementary to capital and natural resource, (and in the symmetric case the natural resource and capital levels were the same between North and South,) now that $\bar{L}^N > \bar{L}^S \Rightarrow T^{Nc} > T^{Sc}$ and $K^{Nc} > K^{Sc}$ at the cooperative equilibrium. The latter implies $I^c < (\bar{K}^N - \bar{K}^S)/2$, i.e., similar to the basic model, inspite of capital mobility the level of FDI is well below its natural upper limit, which is $\bar{K}^N$. However, the result that cooperation leads to higher FDI than non-cooperation also holds even when $\bar{L}^N > \bar{L}^S$; that is, Proposition 6 also continues to be true.[18] The impact on regional as well as global pollution levels are also qualitatively similar to the symmetric case.

To repeat, all the results of the basic model for the autarky and free FDI equilibria (under non-cooperation) hold even when labor endowment differences are introduced. Further, even when there is cooperation in environment policies, most of the implications of the symmetric labor endowment model hold even when $\bar{L}^N > \bar{L}^S$. The differences under cooperation arise in respect of the ranking of pollution levels and capital use between the two countries. In the basic model cooperation led to equality of utilization of the two factor inputs, natural resource and capital. In particular, the equality in the use of the natural resource between the two countries meant harmonization. However, with asymmetry in labor endowments, at the cooperative equilibrium, North uses a higher level of natural resource (and hence pollutes more) than the South. This means that harmonization is not implied when labor endowments differ. Moreover, complementarity between factor inputs implies that it also employs a larger quantity of capital than the South.

that $K^{No} > K^{So}$. Mathematically, this could be seen from eq. (33), whose r.h.s. has both $T^{No}/T^{So} > 1$ and $\bar{L}^N/\bar{L}^S > 1$, implying $K^{No} > K^{So}$.

[17]In the cooperative setting, capital market clearing condition, $r^{Nc} = r^{Sc}$, entails $\frac{K^{Nc}}{K^{Sc}} = \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{\frac{1-\alpha-\beta}{1-\alpha}} \left(\frac{T^{Nc}}{T^{Sc}}\right)^{\frac{\beta}{1-\alpha}}$. Next, the first-order conditions of the cooperative equilibrium imply $\frac{K^{Nc}}{K^{Sc}} = \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{-\frac{1-\alpha-\beta}{\alpha}} \left(\frac{T^{Nc}}{T^{Sc}}\right)^{\frac{1-\beta}{\alpha}}$. Equating the r.h.s. of the above two equations, $T^{Nc}/T^{Sc} = \bar{L}^N/\bar{L}^S > 1$. Utilizing this result in the capital market clearing condition (the first of the above two) we get $K^{Nc}/K^{Sc} = \bar{L}^N/\bar{L}^S > 1$.

[18]The method of proof is analogous to the symmetric case.

4 Environment: a normal good

We now return to the neutral assumption on labor endowments, that $\bar{L}^N = \bar{L}^S$, and normalize them to unity. But we abandon our assumption of a quasi-linear utility function that implies no direct income effects on the demand for environmental good. We wish to capture that environment is a normal good. Toward this end, we postulate a utility function that is strictly concave in both the consumption and the environmental good. For tractability, let the utility function be log-linear.

$$\widetilde{U} = \ln C + \gamma \ln (\bar{T} - T^N - T^S); \quad \gamma > 0. \tag{35}$$

Note that the $\Phi(\cdot)$ function in the basic model takes a specific functional form here.

4.1 Autarky

As $C^j = Y^j,\ j = N, S$, we have $\widetilde{U}^j = \ln(Y^j) + \gamma \ln(\bar{T} - T^W)$. The optimal T^j is governed by

$$\frac{1}{Y(\bar{K}^j, T^j)} \frac{\partial Y(\bar{K}^j, T^j)}{\partial T^j} = \frac{\gamma}{\bar{T} - T^W} \Leftrightarrow \frac{\tau(\bar{K}^j, T^j)}{Y(\bar{K}^j, T^j)} = \frac{\gamma}{\bar{T} - T^W}. \tag{36}$$

The l.h.s. and the r.h.s. of (36) are respectively the marginal benefit and marginal cost of pollution. Given a logarithmic utility function, the marginal benefit from pollution is equal to the ratio of the marginal product of the natural resource input, τ^j and the initial level of output, Y^j. Hence, the marginal benefit (i) increases with the marginal product of the resource, and (ii) decreases with the initial level of output. As earlier, (i) is the *output effect.* We call (ii) as the *income effect.* It is (ii) that was absent in the previous model, which captures that environment is a normal good. However, similar to the previous model, the marginal cost is increasing in total global pollution, T^W. Eq. (36) is equivalent to

$$\tau(\bar{K}^j, T^j) = \frac{\gamma}{(\bar{T} - T^W)} Y^j, \tag{37}$$

which is the analog of (4). Note that the optimum resource charge/price, besides depending on the marginal utility from the environmental good, depends on the level of income, Y^j. It is in this sense that there are positive income-effects on the demand for environment.

From the production side, we have $Y^j = \bar{K^j}^{\alpha} {T^j}^{\beta}$ and $\tau^j = \beta \bar{K^j}^{\alpha} {T^j}^{\beta}$. Substitution of this into eq. (36) gives

$$\frac{\beta}{T^N} = \frac{\beta}{T^S} = \frac{\gamma}{\bar{T} - T^W}. \tag{38}$$

This yields the two best response functions: $T^N = \frac{\beta(\bar{T} - T^S)}{\beta + \gamma}$; $\quad T^S = \frac{\beta(\bar{T} - T^N)}{\beta + \gamma}$ These are two linear equations in T^N and T^S. The solutions are: ${T^N}^a = {T^S}^a = \frac{\gamma\beta}{2\gamma\beta + \gamma^2}\bar{T}$. Thus, in the autarky equilibrium, the pollution level is the same between the two countries. It is easy to show that the respective second-order conditions are satisfied, T^N and T^S are strategic substitutes and the Nash equilibrium is unique.[19]

Intuitively, when the utility is log-linear, the income effect of a particular country's pollution policy change exactly offsets its output effect. Hence, the equilibrium pollution contributions of the two countries are equalized.[20] However, the equality of pollution levels in equilibrium does *not* imply that τ^js are equalized. Since North is richer in capital, and capital is combined with the same quantity of the resource as in the South, the respective marginal products are such that $\tau^{N^a} > \tau^{S^a}$ and $r^{N^a} < r^{S^a}$. Therefore,

Proposition 9: *When environment is a normal good, unlike the case of environment being a neutral good, in autarky*
(i) the log-linear form of utility entails that the pollution levels of the two countries are equalized, and (ii) the pollution charge in the North is higher than in the South.

4.2 Free capital mobility

Since $\bar{K}^N > \bar{K}^S$ and $T^{N^a} = T^{S^a}$, it also follows that $r^{N^a} < r^{S^a}$. Thus, when the two countries open up capital mobility, North exports capital to the South. In equilibrium, $r^N = r^S (\equiv r)$. This implicitly yields $I = I(T^N, T^S)$, and, this function is the same as in the zero-income effect case.

In the presence of capital mobility, the welfare expressions are: $\tilde{U}^N(T^N, T^S) = \ln(Y^N + rI) + \gamma \ln(\bar{T} - T^W)$ and $\tilde{U}^S(T^N, T^S) = \ln(Y^S - rI) + \gamma \ln(\bar{T} - T^W)$. In comparison with the first-order conditions (15) and (16) for the zero-income effect model, we now have the following (non-cooperative) Nash equilibrium conditions:

$$\tilde{f}^N(T^N, T^S) \equiv \frac{\tau^N \left(1 + \frac{\alpha I(T^N, T^S)}{\bar{K}}\right)}{Y^N + rI} \quad = \quad \frac{\gamma}{\bar{T} - T^W}; \tag{39}$$

$$\tilde{f}^S(T^N, T^S) \equiv \frac{\tau^S \left(1 - \frac{\alpha I(T^N, T^S)}{\bar{K}}\right)}{Y^S - rI} \quad = \quad \frac{\gamma}{\bar{T} - T^W}. \tag{40}$$

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[19]Defining the l.h.s. of (38) as $\tilde{f}^j$ $(j = N, S)$, the partial with respect to T^j, R^j_j would be

$$R^j_j \equiv \tilde{f}^j_j - \frac{\gamma}{(\bar{T} - T^W)^2} = -\frac{\beta}{T^{j2}} - \frac{\gamma}{(\bar{T} - T^W)^2} < 0.$$

Moreover, $R^N_S = R^S_N = -\gamma/(\bar{T} - T^W)^2 < 0$. From these expressions for the partials, the determinant $\begin{vmatrix} \tilde{f}^N_N - \frac{\gamma}{(\bar{T}-T^W)^2} & -\frac{\gamma}{(\bar{T}-T^W)^2} \\ -\frac{\gamma}{(\bar{T}-T^W)^2} & \tilde{f}^S_S - \frac{\gamma}{(\bar{T}-T^W)^2} \end{vmatrix} \equiv \tilde{f}^N_N \tilde{f}^S_S - (\tilde{f}^N_N + \tilde{f}^S_S)\frac{\gamma}{(\bar{T}-T^W)^2} > 0$. Thus, at the autarky equilibrium, the second-order conditions hold and the equilibrium is stable (and unique).

[20]This result holds irrespective of how the resource endowments, the capital endowments or even the labor endowments of the two countries compare with each other. But it is sensitive to our assumptions of Cobb-Douglas technology.

Note that in contrast to the zero-income effect (eqs. (15) and (16)), the marginal benefit from pollution emanating from either country is "discounted" by the total national income, $Y^N + rI$ and $Y^S - rI$ respectively for North and South. One can show that the second-order conditions hold and the Nash equilibrium is unique and "stable" under the regularity condition

$$\alpha < \frac{\bar{K}^N \bar{K}^S + \bar{K^S}^2}{\bar{K^N}^2}. \tag{R2}$$

This is similar to (R1) in that it is restrictive only when $\bar{K}^N - \bar{K}^S$ is large enough. But it may be more or less restrictive than (R1). We assume that (R2) holds.[21]

Given Cobb-Douglas technology, eqs. (39) and (40) reduce to

$$\frac{\beta}{T^N}\left(\frac{1+\frac{\alpha I(\cdot)}{\bar{K}}}{1+\frac{\alpha I(\cdot)}{\bar{K}^N}}\right) = \frac{\gamma}{\bar{T}-T^W}; \tag{41}$$

$$\frac{\beta}{T^S}\left(\frac{1-\frac{\alpha I(\cdot)}{\bar{K}}}{1-\frac{\alpha I(\cdot)}{\bar{K}^S}}\right) = \frac{\gamma}{\bar{T}-T^W}. \tag{42}$$

As compared to the first-order conditions in the autarky equilibrium (in (38)), the l.h.s. (that captures the marginal benefit) of each of (41) and (42) now has an additional term because of FDI. Let these be defined as $p^N(I) \equiv \left(1+\frac{\alpha I(\cdot)}{\bar{K}}\right) \Big/ \left(1+\frac{\alpha I(\cdot)}{\bar{K}^N}\right)$ and $p^S(I) \equiv \left(1-\frac{\alpha I(\cdot)}{\bar{K}}\right) \Big/ \left(1-\frac{\alpha I(\cdot)}{\bar{K}^S}\right)$ for the North and South respectively. Observe that $p^N(\cdot) < 1$ and $p^S(\cdot) > 1$; these are respective factor terms-of-trade effects, adjusted for the marginal utility of income. We can henceforth call them the *income-adjusted factor terms-of-trade effects.*

Since $\bar{K}^N > \bar{K}^S$ (and $\bar{L}^N = \bar{L}^S$), the total income in North's economy is greater than that in the South. Hence, the income-adjusted factor terms-of-trade effect of an increase in pollution is less for the North than for the South. i.e. $p^N < p^S$. This implies that at any common level of pollution, the marginal benefit from an increase in pollution is less in the North than in the South. Hence,

Proposition 10: *At the non-cooperative free capital mobility equilibrium, the pollution emanating from the North is less than the pollution emanating from the South.*

Formally, just divide (41) by (42) and obtain $\frac{T^{N^o}}{T^{S^o}} = \left(\frac{1-\frac{\alpha I}{\bar{K}^S}}{1-\frac{\alpha I}{\bar{K}}}\right)\left(\frac{1+\frac{\alpha I}{\bar{K}}}{1+\frac{\alpha I}{\bar{K}^N}}\right)$, where recall that the superscript "o" denotes non-cooperation. Both the ratios in the r.h.s. are less than one, implying $T^{N^o} < T^{S^o}$. Proposition 10 contrasts with the zero-income effect case where the pollution contributions in non-cooperative free FDI equilibrium were the just the opposite in terms of their ranking

[21] The proofs are not included here, but can be obtained from the author.

between the North and South.[22] Given $T^{N^o} < T^{S^o}$, the capital mobility equilibrium condition $K^{N^o 1-\alpha} T^{N^o \beta} = K^{S^o 1-\alpha} T^{S^o \beta}$ implies that $K^{N^o} < K^{S^o}$. That is,

Proposition 11: *North uses less capital than the South at the non-cooperative free capital mobility equilibrium.*

This also contrasts with the zero-income effect case.

Comparison with autarky

Propositions 10 and 11 characterize the FDI non-cooperative equilibrium. How does this equilibrium compare with autarky? The implications are similar to the zero-income effect case, i.e.,

Proposition 12: *Compared to autarky, North pollutes less, South pollutes more and global pollution is higher.*

Appendix F provides the proof.

Welfare effects of capital mobility

Unlike the zero-income effect case, in the presence of income effects, the impact of FDI on welfare change is ambiguous for both North and South.

As in the basic model, four effects due to FDI, namely, direct and indirect factor terms-of-trade effects, own pollution policy change effect and transboundary pollution spillover effect determine the overall change in a country's welfare. It is found, however, that whilst the direction of change of own and spillover pollution effects is the same as in the basic (zero-income effect) model, unlike there, the signs of the sum of the two factor terms-of-trade effects remain ambiguous here. This leaves the overall welfare change unclear. The impact on global welfare is also unclear, therefore. All mathematical expressions are given in Appendix G.

Intuitively, present income-effects, the marginal benefits of pollution are discounted by the level of income (compare eqs. (39) and (40) with those in the zero-income effect case, i.e., (15) and (16)). Ceteris paribus, this implies a relatively lower release of the pollution-intensive resource, T^j, by either country j ($j = N, S$) than if the income effects were absent. Complementarity between productive factors dictates that, in the world economy, the market clearing rate of return on capital is comparatively lower, and, hence, the factor terms-of-trade gains from capital mobility relatively smaller for each country than if the income effects were absent. Coupled with the welfare loss from increase in global pollution, the net effect on the welfare of either country remains ambiguous.

However, when the capital endowment difference between the North and the South is sufficiently small and, hence, the level of FDI is small enough, the change in welfare is qualitatively similar to

[22]Further, it is straightforward, but lengthy, to show that $(2-\alpha)I^o < \bar{K}^N - \bar{K}^S \Leftrightarrow I^o < \frac{\bar{K}^N - \bar{K}^S}{2-\alpha}$, that is despite the natural upper bound of $\bar{K}^N$, the actual upper limit on the level of FDI is much lower.

the zero-income effect model. Specifically, North loses, South gains and world welfare is reduced. As FDI commits countries to differing pollution policies, consequent to which, as South credibly commits itself to pollute more, it puts the North in a strategically disadvantageous position in the environment game. This induces the North to reduce its pollution, such that North's real income gains are offset by the losses in welfare on account of higher pollution spillover effect from the South. In particular, when the level of FDI is sufficiently small and, hence, the terms-of-trade gains are small enough, the loss on account of the pollution spillover effect will outweigh the real income gains such that North will incur a welfare loss from capital mobility.

4.3 Cooperation between regions

When the regional governments coordinate their pollution policies and maximize aggregate world welfare, $\tilde{U}^W = \tilde{U}^N + \tilde{U}^S$, where $\tilde{U}^N$ and $\tilde{U}^S$ are as defined earlier in section 4.2, the two first-order conditions are:

$$\frac{\partial \tilde{U}^W}{\partial T^N} = 0 \Leftrightarrow \frac{\tau^N(\bar{K}^N - I, T^N) + I\frac{\partial r}{\partial T^N}}{Y^N(\bar{K}^N - I, T^N) + r.I} - \frac{I\frac{\partial r}{\partial T^N}}{Y^S(\bar{K}^S + I, T^S) - r.I} = \frac{2\gamma}{\bar{T} - T^W}; \tag{43}$$

$$\frac{\partial \tilde{U}^W}{\partial T^S} = 0 \Leftrightarrow \frac{I\frac{\partial r}{\partial T^S}}{Y^N(\bar{K}^N - I, T^N) + r.I} + \frac{\tau^S(\bar{K}^S + I, T^S) - I\frac{\partial r}{\partial T^N}}{Y^S(\bar{K}^S + I, T^S) - r.I} = \frac{2\gamma}{\bar{T} - T^W}. \tag{44}$$

In comparison with the first-order conditions under non-cooperation (eqs. (39) and (40)) there is now an additional term in the l.h.s. (or the benefit side) that represents the effect on the (income adjusted) factor terms-of-trade of the partner country due to change in each country's *own* pollution policy. For the North this is captured by the second term in (43) and for the South by the first term in (44) in the respective benefit sides. These effects arise because, unlike the neutral-good case, the own- and partner-country's factor terms-of-trade effects under cooperative behavior do not wash out against each other. This is because the country size (in terms of aggregate output/income) influences the marginal benefit from pollution and country sizes differ.

Substituting for the partials, and expressing income, $Y^j \equiv {K^j}^{\alpha}{T^j}^{\beta}$, $(j = N, S)$, (43) and (44) reduce to their respective analogs in equation (26)

$$\frac{\beta}{T^N}\left(\frac{1+\frac{\alpha I}{\bar{K}}}{1+\frac{\alpha I}{K^N}}\right) - \frac{\beta}{T^N}\frac{Y^N}{Y^S}\left(\frac{\frac{\alpha I}{\bar{K}}}{1-\frac{\alpha I}{K^S}}\right) = \frac{2\gamma}{\bar{T} - T^W} \tag{45}$$

$$\frac{\beta}{T^S}\left(\frac{1-\frac{\alpha I}{\bar{K}}}{1-\frac{\alpha I}{K^S}}\right) + \frac{\beta}{T^S}\frac{Y^S}{Y^N}\left(\frac{\frac{\alpha I}{\bar{K}}}{1+\frac{\alpha I}{K^N}}\right) = \frac{2\gamma}{\bar{T} - T^W}. \tag{46}$$

Further, the capital market equilibrium condition (7) together with the fact that $K^N = \eta\bar{K}$ and $K^S = (1-\eta)\bar{K}$ yields $Y^N/Y^S = \eta/(1-\eta)$. Utilizing this expression in the l.h.s. of eqs. (45) and

(46) one gets:

$$\tilde{f^N}^c(T^N, T^S) \equiv \frac{\beta}{T^N}\eta\left(\frac{\bar{K}+\alpha I}{K^N+\alpha I} - \frac{\alpha I}{K^S-\alpha I}\right) = \frac{2\gamma}{\bar{T}-T^W}; \tag{47}$$

$$\tilde{f^S}^c(T^N, T^S) \equiv \frac{\beta}{T^S}(1-\eta)\left(\frac{\bar{K}-\alpha I}{K^S-\alpha I} + \frac{\alpha I}{K^N+\alpha I}\right) = \frac{2\gamma}{\bar{T}-T^W}, \tag{48}$$

where $\tilde{f^N}^c$ and $\tilde{f^S}^c$ represent the respective marginal benefits from pollution.

It is shown in Appendix H that at the cooperative equilibrium as well, $T^{N^c} < T^{S^c}$ and $K^{N^c} < K^{S^c}$, where recall that superscript "c" denotes cooperation.

Proposition 13: *At the cooperative free FDI equilibrium, North pollutes less as well as uses less capital than the South.*

This contrasts with the zero-income effect case where, at the cooperative equilibrium, both North and South had the same pollution levels and used the same level of capital.

The second-order conditions associated with (47) and (48) are met under the following regularity condition:

$$\alpha < \frac{\bar{K}^N\bar{K}^S + \bar{K^S}^2}{\bar{K^N}^2 + \bar{K^S}^2}. \tag{$R3$}$$

The underlying intuition for (R3) is similar to that for (R1) and (R2), and observe that (R3) is more restrictive than (R2). We assume that (R3) holds. Under (R3) the cooperative equilibrium is found to be unique (and stable).[23]

As for the effects of cooperation on FDI, regional and global pollution levels, similar conclusions as in the neutral-good model hold qualitatively. That is,

Proposition 14: *As countries cooperate on environment policies, (i) there is more FDI, (ii) North's pollution falls, and South's may rise or fall, and (ii) global pollution decreases even below the autarky level.*

Again, see Appendix G for the mathematical proofs.

With positive-income effects on the demand for environment, most of the results that relate to the direction of change of regional pollution due to FDI flows (under both non-cooperative and cooperative regimes), the effect on magnitude of FDI in moving from non-cooperation to cooperation, and the welfare implications are qualitatively the same as in the zero-income effect model, except two differences. First, in moving from autarky to non-cooperative FDI equilibrium, even South may gain or lose as the North, whereas in the zero-income effect case at least the South had unambiguous welfare gains.

[23]Again, the proofs are not included here for brevity.

Second, the ranking of countries in terms of their absolute pollution levels differs. In contrast to the zero-income effect model, where North was a larger polluter in autarky, in the positive-income effect case, the autarky pollution levels are equalized. At the free FDI non-cooperation equilibrium, there is a reversal of ranking of North and South in terms of their contribution to aggregate world pollution. That is, whilst in the zero-income effect case North was a larger polluter, it is the South which is now a larger polluter. Even at the cooperative equilibrium, North pollutes less than the South.

5 Conclusions

This paper contains an analysis of FDI and global environment. Capital moves from "capital-abundant" North to "capital-scarce" South. Pollution arises in the course of production. We first looked at the autarky situation, where there was no international capital mobility. Next, the FDI flows with no cooperation in environmental policies was examined. Finally, we considered the implications of capital mobility or FDI when countries coordinate in respect of their environmental policies.

It is found that in moving from autarky to the FDI regime (with non-cooperation in pollution policy) North reduces and South increases its pollution level. Despite North's and South's pollution levels changing in opposite directions, the net effect of FDI on global environment is negative, i.e. aggregate global pollution rises. As for the effect on welfare levels, South always has gains from FDI whilst North may gain or lose. The change in the sum of the individual country welfares, i.e., global welfare, also remains ambiguous. However, at low enough level of FDI, North suffers a clear welfare loss and global welfare also falls.

The above results hold when the regional governments do not coordinate their environment policies. If instead governments cooperate with each other in regulating their environment quality (or maximize their joint welfare) very different implications emerge: world environment quality improves and there is more FDI. Thus, contrary to common perception, a stricter environment policy may not be an impediment to international capital flows. Environment quality is even better than under autarky. In terms of regional policies, North is induced to reduce its pollution even further and South's response remains ambiguous.

The above results are derived assuming zero-income effects on the demand for environmental good. Instead, with positive income effects on the demand for environment, a move from autarky to non-cooperative free FDI equilibrium may inflict a welfare loss on the South, as on the North. Moreover, the ranking of countries in terms of their absolute level of pollution is reversed, in that, now South is a larger polluter at the free FDI equilibrium than the North.

Further, in general, there is little rationale behind international harmonization of environment policies.

Appendix A

This refers to the zero-income effect case. The effect of capital mobility on regional pollution levels, in moving from autarky to capital mobility (in the absence of cooperation), is derived. To begin with, refer to the two first-order conditions (15) and (16). Recall that in both I can be treated as exogenous such that at $I = 0$, the two eqs. reduce to the autarky equilibrium condition (4). Hence, comparison between autarky and free capital mobility regimes can be characterized by an exogenous change in I.

Totally differentiating (15) and (16) with respect to I, the following system of equations is derived:

$$\begin{pmatrix} \frac{\partial \tau^N}{\partial T^N}\left(1+\frac{\alpha I}{\bar{K}}\right)+\gamma\Phi'' & \gamma\Phi'' \\ \gamma\Phi'' & \frac{\partial \tau^S}{\partial T^S}\left(1-\frac{\alpha I}{\bar{K}}\right)+\gamma\Phi'' \end{pmatrix} \begin{bmatrix} \frac{dT^N}{dI} \\ \frac{dT^S}{dI} \end{bmatrix} = \begin{bmatrix} -\frac{\partial \bar{f}^N}{\partial I} \\ -\frac{\partial \bar{f}^S}{\partial I} \end{bmatrix}$$

Let X be the first matrix in the l.h.s.. Given diminishing returns, $\partial \tau^j/\partial T^j < 0$, and we have assumed $\Phi'' < 0$. Using these, it is straightforward to derive that $|X| > 0$.

Also, from (15) and (16) $\frac{\partial \bar{f}^N}{\partial I} = -\frac{\alpha(K^S+\alpha I)}{\bar{K}(K^N+\eta\alpha I)}\bar{f}^N < 0$ and $\frac{\partial \bar{f}^S}{\partial I} = \frac{\alpha(K^N-\alpha I)}{\bar{K}(K^S-(1-\eta)\alpha I)}\bar{f}^S > 0$.

Application of the Cramer's rule and taking into account the signs of the various terms,

$$\frac{dT^N}{dI} = \left[-\underset{(-)}{\frac{\partial \bar{f}^N}{\partial I}}\left(\underset{(-)}{\gamma\Phi''}+\underset{(-)}{\frac{\partial \tau^S}{\partial T^S}}\underset{(+)}{\left(1-\frac{\alpha I}{\bar{K}}\right)}\right)+\underset{(+)}{\frac{\partial \bar{f}^S}{\partial I}}\underset{(-)}{\gamma\Phi''}\right]\Big/\underset{(+)}{|X|} < 0;$$

$$\frac{dT^S}{dI} = \left[-\underset{(+)}{\frac{\partial \bar{f}^S}{\partial I}}\left(\underset{(-)}{\gamma\Phi''}+\underset{(-)}{\frac{\partial \tau^N}{\partial T^N}}\underset{(+)}{\left(1+\frac{\alpha I}{\bar{K}}\right)}\right)+\underset{(-)}{\frac{\partial \bar{f}^N}{\partial I}}\underset{(-)}{\gamma\Phi''}\right]\Big/\underset{(+)}{|X|} > 0.$$

Appendix B

For the zero-income effects model, the effect of FDI flows under non-cooperative environment policy setting is derived. It is shown that a move from autarky to free FDI non-cooperative equilibrium will lead to an increase in global pollution, for which it is shown that $h(\eta) > \lambda$, which is equivalent to

$$\frac{2^{\frac{1}{1-\beta}}\left[\eta^{\frac{1-\alpha}{\beta}}+(1-\eta)^{\frac{1-\alpha}{\beta}}\right]}{\left[\eta^{\frac{1-\alpha-\beta}{\beta}}+(1-\eta)^{\frac{1-\alpha-\beta}{\beta}}\right]^{\frac{1}{1-\beta}}}\bar{K}^{\frac{\alpha}{1-\beta}} > \bar{K^N}^{\frac{\alpha}{1-\beta}}+\bar{K^S}^{\frac{\alpha}{1-\beta}}. \tag{B1}$$

Let the r.h.s. of the above be expressed as $q^a(\bar{K}^N) \equiv \bar{K^N}^{\frac{\alpha}{1-\beta}} + (\bar{K} - \bar{K}^N)^{\frac{\alpha}{1-\beta}}$. Then, $\frac{dq^a}{d\bar{K}^N} = \frac{\alpha}{1-\beta}\left(\frac{1}{\bar{K^N}^{\frac{1-\alpha-\beta}{1-\beta}}} - \frac{1}{\bar{K^S}^{\frac{1-\alpha-\beta}{1-\beta}}}\right) < 0$, since $\bar{K}^N > \bar{K}^S$. Moreover, given $\bar{K}^N > \bar{K}^S$, it follows that $\bar{K}^N > \bar{K}/2$. Hence $dq^a/d\bar{K}^N < 0$ implies that,

$$q^a(\bar{K}^N) < q^a\left(\frac{\bar{K}^N}{2}\right) = \frac{\bar{K}}{2}^{\frac{\alpha}{1-\beta}} + \left(\bar{K} - \frac{\bar{K}}{2}\right)^{\frac{\alpha}{1-\beta}} = 2^{\frac{1-\alpha-\beta}{1-\beta}}\,\bar{K}^{\frac{\alpha}{1-\beta}}. \tag{B2}$$

Hence, for (B1) to hold it suffices to prove that $h(\eta) > 2^{\frac{1-\alpha-\beta}{1-\beta}}$. This is equivalent to $q(\eta) \equiv \frac{\left[\eta^{\frac{1-\alpha}{\beta}} + (1-\eta)^{\frac{1-\alpha}{\beta}}\right]^{1-\beta}}{\left[\eta^{\frac{1-\alpha-\beta}{\beta}} + (1-\eta)^{\frac{1-\alpha-\beta}{\beta}}\right]} > \frac{1}{2^{\alpha+\beta}}$. Log-differentiating the l.h.s. and noting that $\eta > 1-\eta$, it is straightforward to derive that $q'(\eta) > 0$. Hence, it follows that $q(\eta) > q\left(\frac{1}{2}\right) = \frac{1}{2^{\alpha+\beta}}$. Thus, $q(\eta) > 1/(2^{\alpha+\beta})$, implying that $h(\eta) > \lambda$.

Appendix C

For the zero-income effect model, the change in South's and North's welfare (in moving from autarky to free capital mobility and non-cooperation) due to net change in the factor terms-of-trade effects of FDI are analyzed here. It is shown that both countries would have welfare gains on account of sum of the direct and indirect factor terms-of-trade effects. In eqns. (21) and (22), the welfare change on account of these effects are represented by the sum of the first two terms in the r.h.s.. Explicitly, these could be expressed as

$$F^N = (1-\alpha)\frac{r^N}{K^N}I + \beta\frac{r^N}{T^N}\frac{dT^N}{dI}I; \tag{C1}$$

$$F^S = (1-\alpha)\frac{r^S}{K^S}I - \beta\frac{r^S}{T^S}\frac{dT^S}{dI}I. \tag{C2}$$

We first require the expressions for dT^N/dI and dT^S/dI to be worked out. By differentiating the first-order conditions (15) and (16) with respect to I, we have

$$-\left(\frac{1-\beta}{T^N} - \frac{\Phi''}{\Phi'}\right)\frac{dT^N}{dI} + \frac{\Phi''}{\Phi'}\frac{dT^S}{dI} = \alpha\left(\frac{1}{K^N} - \frac{1}{\bar{K}+\alpha I}\right); \tag{C3}$$

$$\frac{\Phi''}{\Phi'}\frac{dT^N}{dI} - \left(\frac{1-\beta}{T^S} - \frac{\Phi''}{\Phi'}\right)\frac{dT^S}{dI} = -\alpha\left(\frac{1}{K^S} - \frac{1}{\bar{K}-\alpha I}\right). \tag{C4}$$

Solving these simultaneously, one gets

$$\frac{dT^N}{dI}\frac{1}{T^N} = \frac{\alpha\kappa\frac{\Phi''}{\Phi' T^N} - \alpha\frac{(1-\beta)}{T^N T^S}\left(\frac{1}{K^N} - \frac{1}{\bar{K}+\alpha I}\right)}{\frac{(1-\beta)^2}{T^N T^S} - \frac{\Phi''}{\Phi'}(1-\beta)\left(\frac{1}{T^N} + \frac{1}{T^S}\right)} < 0; \tag{C5}$$

$$\frac{dT^S}{dI}\frac{1}{T^S} = \frac{-\alpha\kappa\frac{\Phi''}{\Phi' T^S} + \frac{\alpha(1-\beta)}{T^N T^S}\left(\frac{1}{K^S} - \frac{1}{\bar{K}-\alpha I}\right)}{\frac{(1-\beta)^2}{T^N T^S} - \frac{\Phi''}{\Phi'}(1-\beta)\left(\frac{1}{T^N} + \frac{1}{T^S}\right)} > 0, \tag{C6}$$

where $\kappa \equiv \left(\frac{1}{K^N} - \frac{1}{\bar{K}+\alpha I} + \frac{1}{K^S} - \frac{1}{\bar{K}-\alpha I}\right)$. Note that $\kappa > 0$ as both $\frac{1}{K^N} - \frac{1}{\bar{K}+\alpha I} > 0$ and $\frac{1}{K^S} - \frac{1}{\bar{K}-\alpha I} > 0$. Since $dT^N/dI < 0$ and $dT^S dI > 0$, the sign of either F^N or F^S is undetermined *a priori* from (C1) and (C2). However, given $\beta < (1-\alpha)$, we observe from (C1) and (C2) that F^N and F^S are positive if

$$\frac{T^N}{K^N} + \frac{dT^N}{dI} > 0; \tag{C7}$$

$$\frac{T^S}{K^S} - \frac{dT^S}{dI} > 0. \tag{C8}$$

It is easier to prove (C8) first. Adding $-\alpha\kappa\left(\frac{\Phi''}{\Phi' T^N}\right) > 0$ and $\alpha\frac{(1-\beta)}{T^N T^S}\left(\frac{1}{K^N} - \frac{1}{\bar{K}+\alpha I}\right) > 0$ to the numerator in the r.h.s. of (C6), it turns out that

$$\frac{dT^S}{dI}\frac{1}{T^S} < \frac{-\alpha\kappa\frac{\Phi''}{\Phi' T^S} - \alpha\kappa\frac{\Phi''}{\Phi' T^N} + \frac{\alpha(1-\beta)}{T^N T^S}\kappa}{(1-\beta)\left(\frac{1-\beta}{T^N T^S} - \frac{\Phi''}{\Phi'}\left(\frac{1}{T^N} + \frac{1}{T^S}\right)\right)} < \frac{\alpha\kappa}{1-\beta}\left[\frac{-\frac{\Phi''}{\Phi'}\left(\frac{1}{T^N} + \frac{1}{T^S}\right) + \frac{1-\beta}{T^N T^S}}{\frac{1-\beta}{T^N T^S} - \frac{\Phi''}{\Phi'}\left(\frac{1}{T^N} + \frac{1}{T^S}\right)}\right]$$

$$< \frac{\alpha\kappa}{1-\beta} < \kappa, \tag{C9}$$

since $\frac{\alpha}{1-\beta} < 1$. Thus,

$$\frac{1}{K^S} - \frac{1}{T^S}\frac{dT^S}{dI} > \frac{1}{K^S} - \kappa > \frac{(\alpha I)^2 + 2K^N\bar{K} - \bar{K}^2}{K^N(\bar{K}-\alpha I)(\bar{K}+\alpha I)} > 0 \tag{C10}$$

since $K^N > K^S \Leftrightarrow 2K^N\bar{K} > \bar{K}^2$. The chain of inequalities in (C10) implies (C8).

We next turn to (C7). As stated in Proposition 4, a move from autarky to free capital mobility leads to increase in world pollution, $T^W (\equiv T^N + T^S)$. Combining this with regional pollution changes implied in (C5) and (C6) we have

$$\left|\frac{dT^N}{dI}\right| < \left|\frac{dT^S}{dI}\right|. \tag{C11}$$

Moreover, capital market clearing condition (7) yields

$$\frac{K^N}{K^S} = \left(\frac{T^N}{T^S}\right)^{\frac{\beta}{1-\alpha}} < \frac{T^N}{T^S}, \quad \text{since } T^N > T^S \text{ and } \beta/(1-\alpha) < 1. \tag{C12}$$

The relations in (C10), (C11) and (C12) together imply

$$\frac{T^N}{K^N} > \frac{T^S}{K^S} > \left|\frac{dT^S}{dI}\right| > \left|\frac{dT^N}{dI}\right|. \tag{C13}$$

This proves (C7).

Appendix D

In the case of neutral-environment good, the effects of cooperative behavior on regional pollution levels are derived here. This is done in two steps. First, the effect of change in the pollution policies of countries is considered as they move from non-cooperative to cooperative regime, whilst there is no change in FDI. Second, the level of FDI is allowed to change.

Step 1:

Define $m \equiv \alpha I/\bar{K}$. Then eqs. (28)-(29) are expressed as

$$\tau^N(1+m(1-b)) = (1+b)\gamma\Phi'(\bar{T}-T^W) \quad \text{(D1)}$$

$$\tau^S(1-m(1-b)) = (1+b)\gamma\Phi'(\bar{T}-T^W). \quad \text{(D2)}$$

The non-cooperative equilibrium is defined at $b=0$, and cooperative equilibrium at $b=1$. Therefore, an increase in "b" would capture the change of regime from non-cooperative to cooperative equilibrium.

It is shown that (a) $\partial T^N/\partial b < 0$; $\partial T^S/\partial b \gtrless 0$, and (b) $\left|\partial T^N/\partial b\right| > \left|\partial T^S/\partial b\right|$ if $\partial T^S/\partial b < 0$.

Totally differentiating (D1) and (D2) with respect to b, at given I, yields the matrix system

$$\begin{pmatrix} \frac{\partial\tau^N}{\partial T^N}(1+m(1-b))+(1+b)\gamma\Phi'' & (1+b)\gamma\Phi'' \\ (1+b)\gamma\Phi'' & \frac{\partial\tau^S}{\partial T^S}(1-m(1-b))+(1+b)\gamma\Phi'' \end{pmatrix} \begin{bmatrix} \frac{\partial T^N}{\partial b} \\ \frac{\partial T^S}{\partial b} \end{bmatrix} = \begin{bmatrix} m\tau^N+\gamma\Phi' \\ -m\tau^S+\gamma\Phi' \end{bmatrix}$$

Let Y denote the coefficient matrix in the l.h.s.. Since $\partial\tau^j/\partial T^j < 0$, $\Phi'' < 0$, and $(1+m(1-b))$ and $(1-m(1-b)) > 0$, it follows that $|Y| > 0$. Using Cramer's rule

$$|Y|\frac{\partial T^N}{\partial b} = \underbrace{m(\tau^N+\tau^S)}_{(+)}(1+b)\gamma\underset{(-)}{\Phi''} + \underbrace{(m\tau^N+\gamma\Phi')}_{(+)}\left(\underset{(-)}{\frac{\partial\tau^S}{\partial T^S}}(1-m(1-b))\right); \quad \text{(D3)}$$

$$|Y|\frac{\partial T^S}{\partial b} = \underbrace{-m(\tau^N+\tau^S)}_{(-)}(1+b)\gamma\underset{(-)}{\Phi''} + \underbrace{(\gamma\Phi'-m\tau^S)}_{(+)}\left(\underset{(-)}{\frac{\partial\tau^N}{\partial T^N}}(1+m(1-b))\right). \quad \text{(D4)}$$

Given $|Y| > 0$, $\partial\tau^j/\partial T^j < 0$ and $\Phi'' < 0 < \Phi'$, it follows that $\partial T^N/\partial b < 0$ whilst $\partial T^N/\partial b \gtrless 0$. The ambiguity in the sign of $\partial T^S/\partial b$ arises because the first term in the r.h.s. of (D4) is positive (in view of $\Phi'' < 0$) whilst the sign of the second terms is ambiguous as $\gamma\Phi' - m\tau^S \gtrless 0$. Now, observe that from (D2)

$$\tau^S = \frac{(1+b)\gamma\Phi'}{1-m(1-b)} \Leftrightarrow \gamma\Phi' - m\tau^S = \gamma\Phi'\frac{(1-2m)}{1-m(1-b)}.$$

From $I < \left(\bar{K}^N - \bar{K}^S\right)/2$, we have

$$m < \frac{I}{\bar{K}} < \frac{(\bar{K}^N-\bar{K}^S)}{2\bar{K}} < \frac{1}{2} \Leftrightarrow 1-2m > 0 \Rightarrow \gamma\Phi' - m\tau^S > 0.. \quad \text{(D5)}$$

Given the sign of $\gamma\Phi' - m\tau^S$ in (D5), it follows that the second term of (D4) is negative. Hence, $\partial T^S/\partial b \gtrless 0$, and this together with $\partial T^N/\partial b < 0$ proves (a).

We now prove (b). As discussed in the text, this is used in explaining the increase in the level of FDI in moving from non-cooperation to cooperation. When $\partial T^S/\partial b < 0$, substituting for $\partial\tau^j/\partial T^j$, $j = N, S$ in (D3) and (D4), the absolute difference

$$\begin{aligned}\left|\frac{\partial T^N}{\partial b}\right| - \left|\frac{\partial T^S}{\partial b}\right| &= \frac{1}{|Y|}(1-\beta)(1+b)\gamma\frac{\Phi'}{T^N T^S}\left[m\tau^N T^N + m\tau^S T^S + \gamma\Phi'(T^N - T^S)\right] \\ &\quad + \frac{2}{|Y|}\left|(1+b)m(\tau^N+\tau^S)\gamma\Phi''\right| > 0,\end{aligned}$$

in view of $T^N > T^S$ and $\Phi'' < 0 < \Phi'$. Hence, (b) is proved.

Step 2:

Next, we differentiate eqs. (D1) and (D2) with respect to I at given b, $b \in (0,1)$. This yields

$$\begin{pmatrix} \frac{\partial\tau^N}{\partial T^N}\left(1+m(1-b)\right)\gamma\Phi'' & (1+b)\gamma\Phi'' \\ (1+b)\gamma\Phi'' & \frac{\partial\tau^S}{\partial T^S}\left(1-m(1-b)\right) + (1+b)\gamma\Phi'' \end{pmatrix} \begin{bmatrix} \frac{dT^N}{dI} \\ \frac{dT^S}{dI} \end{bmatrix} = \begin{bmatrix} -\frac{\partial\tau^N}{\partial I}(1+m(1-b)) - \frac{\alpha}{\bar K}\tau^N(1-b) \\ -\frac{\partial\tau^S}{\partial I}(1-m(1-b)) + \frac{\alpha}{\bar K}\tau^S(1-b) \end{bmatrix}.$$

The matrix system is solved to obtain

$$\begin{aligned}|Y|\frac{\partial T^N}{\partial I} &= (1+b)\underset{(-)}{\gamma\Phi''}\left\{\left[\frac{\alpha\tau^N}{K^N}\left(\underbrace{\frac{\bar K - (K^N-\alpha I)(1-b)}{\bar K}}_{(+)}\right)\right] + \left[\frac{\alpha\tau^S}{K^S}\left(\underbrace{\frac{\bar K - (K^S+\alpha I)(1-b)}{\bar K}}_{(+)}\right)\right]\right\} \\ &\quad + \underset{(-)}{\frac{\partial\tau^S}{\partial T^S}}(1-m(1-b))\left\{\left[\frac{\alpha\tau^N}{K^N}\left(\underbrace{\frac{\bar K - (K^N-\alpha I)(1-b)}{\bar K}}_{(+)}\right)\right]\right\}; \qquad \text{(D6)}\end{aligned}$$

$$\begin{aligned}|Y|\frac{\partial T^S}{\partial I} &= (1+b)\underset{(-)}{\gamma\Phi''}\left\{\left[-\frac{\alpha\tau^S}{K^S}\left(\underbrace{\frac{\bar K - (K^S+\alpha I)(1-b)}{\bar K}}_{(+)}\right)\right]\left[-\frac{\alpha\tau^N}{K^N}\left(\underbrace{\frac{\bar K - (K^N-\alpha I)(1-b)}{\bar K}}_{(+)}\right)\right]\right\} \\ &\quad + \underset{(-)}{\frac{\partial\tau^N}{\partial T^N}}(1+m(1-b))\left\{-\left[\frac{\alpha\tau^S}{K^S}\left(\underbrace{\frac{\bar K - (K^S+\alpha I)(1-b)}{\bar K}}_{(+)}\right)\right] - \underbrace{(m\tau^N - \gamma\Phi'')}_{(-)}\right\}. \qquad \text{(D7)}\end{aligned}$$

It is now shown that $\partial T^N/\partial I < 0$, whilst $\partial T^S/\partial I > 0$. Let $b_1(b) \equiv [\bar K - (K^N - \alpha I)(1-b)]/\bar K$, and $b_2(b) \equiv [\bar K - (K^S + \alpha I)(1-b)]/\bar K$. Since $b_1(\cdot)$ and $b_2(\cdot)$ are increasing in b, both attain their minimum at $b = 0$. Therefore, it follows that $b_1(b) > (K^S + \alpha I)/\bar K$, which is positive. Moreover, $b_2(b) > (K^N - \alpha I)/\bar K$, which is also positive in view of $I^o < (K^N - K^S)/2$ (see (18)). These, together with $\partial\tau^j/\partial T^j < 0$, $\Phi'' < 0$, and $1 - m(1-b) > 0$ and $1 + m(1-b) > 0$, imply that for any given b, $\partial T^N/\partial I < 0$ and $\partial T^S/\partial I > 0$.

Combining results of Steps 1 and 2, and the fact that $dI/db > 0$, it is straightforward that $dT^N/db < 0$, whilst $dT^S/db \gtrless 0$.

Appendix E

In case of the neutral-environment good model, the implications of cooperation on world pollution are derived. We need to prove that Ω, as defined in (32) is less than Λ as defined in (20). This implies that $T^{W^c} < T^{W^a}$. To prove $\Omega < \Lambda$ is equivalent to proving

$$2^{-\frac{\alpha+\beta}{1-\beta}}\bar{K}^{\frac{\alpha}{1-\beta}} \quad < \quad \bar{K^N}^{\frac{\alpha}{1-\beta}} + \bar{K^S}^{\frac{\alpha}{1-\beta}}. \tag{E1}$$

Note that we have earlier defined the r.h.s. as $q^a(\bar{K}^N)$, and, further, $dq^a/d\bar{K}^N < 0$ (see Appendix B). This implies that $q^a(\bar{K}^N) > q^a(\bar{K}) = \bar{K}^{\frac{\alpha}{1-\beta}} > 2^{-\frac{\alpha+\beta}{1-\beta}}\bar{K}^{\frac{\alpha}{1-\beta}}$, which proves that $\Omega < \Lambda$.

Appendix F

When there are positive-income effects on the demand for environment, the effect on global and regional pollution in moving from autarky to capital mobility (non-cooperative Nash) equilibrium is worked out. We first look at the impact on global pollution. It is derived that global pollution at the free FDI equilibrium is higher than under at the autarky equilibrium.

Consider the Nash first-order conditions (41)-(42). Multiplying (41) by T^N, (42) by T^S and adding them up give rise to

$$\left(\frac{1+\frac{\alpha I}{K}}{1+\frac{\alpha I}{K^N}}\right) + \left(\frac{1-\frac{\alpha I}{K}}{1-\frac{\alpha I}{K^S}}\right) = \frac{\gamma T^W}{\beta(\bar{T}-T^W)} \equiv \widetilde{g}(T^W). \tag{F1}$$

Next turn to the autarky first-order condition (38), which could be similarly manipulated to yield

$$2 = \widetilde{g}(T^W). \tag{F2}$$

Since $\widetilde{g}(\cdot)$ is increasing in T^W, the Nash equilibrium global pollution (T^{W^o}) will be higher (lower) as compared to autarky pollution, T^{W^a}, according as

$$\left(\frac{1+\frac{\alpha I}{K}}{1+\frac{\alpha I}{K^N}}\right) + \left(\frac{1-\frac{\alpha I}{K}}{1-\frac{\alpha I}{K^S}}\right) > (<)2. \tag{F3}$$

Utilizing $K^N = \eta\bar{K}$, $K^S = (1-\eta)\bar{K}$ and $\alpha I/\bar{K} \equiv m$, this is equivalent to $\frac{1+m}{1+\frac{m}{\eta}} + \frac{1-m}{1-\frac{m}{1-\eta}} > (<)2 \Leftrightarrow (1-2\eta-m) > (<)2(1-2\eta-m)$. Therefore, global pollution would fall (rise) as compared to autarky if

$$1 - 2\eta - m \left(\equiv \frac{\bar{K}^S - \bar{K}^N + (2-\alpha)I}{\bar{K}} \right) \quad > (<) \quad 0 \tag{F4}$$

$$\Leftrightarrow I^o \quad > (<) \quad \frac{\bar{K}^N - \bar{K}^S}{2-\alpha}. \tag{F5}$$

We have $I^o < (\bar{K}^N - \bar{K}^S)/(2-\alpha)$, which entails $T^{W^o} > T^{W^a}$.

We now consider the effect on regional pollution levels, T^N and T^S.

The impacts on regional pollution levels depend on the effects on marginal benefits and marginal costs of pollution as countries move from autarky to free capital mobility. It is already shown in section 4.2 that compared to autarky, the marginal benefit of pollution is affected by an additional effect – the income adjusted factor terms-of-trade effect. This is captured by the term $p^N(\cdot) < 1$ and $p^S(\cdot) > 1$ for the North and South. *Ceteris paribus*, this implies that the marginal benefits are lowered (raised) for North (South). At the same time, it is derived above that aggregate global pollution increases, implying an increase in the marginal costs of pollution. Combining the effects on the marginal benefits and costs, it is clear that North's pollution will fall in moving from autarky to free FDI equilibrium. That the pollution in South will rise follows from the fact that North's pollution level has gone down whilst global pollution has increased. Hence, $T^{N^o} < T^{N^a}$ and $T^{S^o} > T^{S^a}$.

Appendix G

When environment is a normal good, the effect of capital mobility on the regional and global welfare levels is analyzed here. It is derived that the change in welfare at both the regional and global levels remains ambiguous in general. However, at sufficiently small levels of FDI, the implications are similar to that for the earlier model, i.e., South has a welfare gain, North incurs a welfare loss and global welfare is reduced. Observe that the pair of expressions: $\widetilde{U}^N = \ln\left[Y^N(\bar{K}^N - I, T^N) + r^N(\bar{K}^N - I, T^N)I\right] + \gamma\ln(\bar{T} - T^W)$ and $\widetilde{U}^S = \ln\left[Y^S(\bar{K}^S + I, T^S) - r^S(\bar{K}^S + I, T^S)I\right] + \gamma\ln(\bar{T} - T^W)$, represent North's and South's welfare in "generic" form, that is, they hold true for any value of I. As $I \to 0$, welfare levels approach their counterparts in autarky and when $I > 0$, they express welfare under non-cooperation.[24] Using I as

[24] Recall that although I is an endogenous variable, it is valid to use it as a parameter here to characterize the move from autarky to non-cooperation.

the parameter, the total change in regional welfare levels can be expressed as:

$$\frac{d\widetilde{U}^N}{dI} = \frac{1}{Y^N + r^N I}\underbrace{\left((1-\alpha)\frac{r^N}{K^N}I + \beta\frac{r^N}{T^N}I\underset{(-)}{\frac{dT^N}{dI}}\right)}_{(+)/(-)} + \underbrace{\underset{(-)}{\left(\frac{\tau^N}{Y^N + r^N I} - \frac{\gamma}{\bar{T} - T^W}\right)}\underset{(-)}{\frac{dT^N}{dI}}}_{(+)} - \underbrace{\frac{\gamma}{\bar{T} - T^W}\underset{(+)}{\frac{dT^S}{dI}}}_{(+)} \gtrless 0, \quad \text{(G1)}$$

$$\frac{d\widetilde{U}^S}{dI} = \frac{1}{Y^S - r^S I}\underbrace{\left((1-\alpha)\frac{r^S}{K^S}I - \beta\frac{r^S}{T^S}I\underset{(+)}{\frac{dT^S}{dI}}\right)}_{(+)/(-)} + \underbrace{\underset{(+)}{\left(\frac{\tau^S}{Y^S - r^S I} - \frac{\gamma}{\bar{T} - T^W}\right)}\underset{(+)}{\frac{dT^S}{dI}}}_{(+)} - \underbrace{\frac{\gamma}{\bar{T} - T^W}\underset{(-)}{\frac{dT^N}{dI}}}_{(-)} \gtrless 0. \quad \text{(G2)}$$

The first bracketed term in the r.h.s. of (G1) and (G2) is the sum of the *direct and indirect factor terms-of-trade* effects, that is, the sum of gains from pure rate of return change and change in the return due to country's *own* pollution policy change. (The only difference is that this is now adjusted for the marginal utility of income.) From Proposition 10, we have $dT^N/dI < 0$ and $dT^S/dI > 0$, and hence *a priori* the sign of this effect remain unclear for either country. Unlike the neutral-environment good model, analytically it could not be proved whether the regional welfare change on account of net factor terms-of-trade effect would be positive or negative. The second terms in the r.h.s. of (G1) and (G2) respectively represent the change in welfare due to optimal adjustment of countries' *own* pollution policies. The first-order conditions (39) and (40) imply that $\tau^N/(Y^N + r^N I) - \gamma/(\bar{T} - T^W) < 0$ and $\tau^S/(Y^S - r^S I) - \gamma/(\bar{T} - T^W) > 0$.[25] Together with $dT^N/dI < 0$ and $dT^S/dI > 0$, the second term is positive. Thus, the change in welfare of both the countries on account of this effect is positive. The third effect refers to the change in welfare on account of change in the pollution policy of the *other*/partner country; this effect is negative (positive) for the North (South) as South (North) increases (reduces) its pollution. Note that the directions of change of both – own and spillover pollution – effects on welfare are qualitatively the same as in the neutral-good model. In the aggregate, the welfare implications for either country remain ambiguous. As expected, the effect on global welfare is also ambiguous. The aggregate

[25]This is so since from (39) and (40) we have

$$\frac{\tau^N}{Y^N + r^N I} < \frac{\tau^N\left(1 + \frac{\alpha I}{K}\right)}{Y^N + r^N I} = \frac{\gamma}{\bar{T} - T^W}; \quad \text{(G3)}$$

$$\frac{\tau^S}{Y^S - r^S I} > \frac{\tau^S\left(1 - \frac{\alpha I}{K}\right)}{Y^S - r^S I} = \frac{\gamma}{\bar{T} - T^W}. \quad \text{(G4)}$$

welfare change is expressed as

$$\frac{d\widetilde{U}^W}{dI} \equiv \frac{d\widetilde{U}^N}{dI}+\frac{d\widetilde{U}^S}{dI}=\frac{1}{Y^N+r^NI}\underbrace{\left((1-\alpha)\frac{r^N}{K^N}I+\beta\frac{r^N}{T^N}I\underset{(-)}{\frac{dT^N}{dI}}\right)}_{(+)/(-)}+\frac{1}{Y^S-r^SI}\underbrace{\left((1-\alpha)\frac{r^S}{K^S}I-\beta\frac{r^S}{T^S}I\underset{(+)}{\frac{dT^S}{dI}}\right)}_{(+)/(-)}$$

$$+\underbrace{\left(\underset{(-)}{\frac{\tau^N}{Y^N+r^NI}}-\frac{\gamma}{\bar{T}-T^W}\right)\underset{(-)}{\frac{dT^N}{dI}}}_{(+)}+\underbrace{\left(\underset{(+)}{\frac{\tau^S}{Y^S-r^SI}}-\frac{\gamma}{\bar{T}-T^W}\right)\underset{(+)}{\frac{dT^S}{dI}}}_{(+)}-\underbrace{\frac{\gamma}{\bar{T}-T^W}\underset{(+)}{\frac{dT^W}{dI}}}_{(+)}\gtrless 0. \quad \text{(G5)}$$

The signs of the first two terms are ambiguous, the second and third terms are positive on account of optimal adjustment of own pollution levels by countries, and the last term is negative as global pollution rises with FDI, that is $dT^W/dI > 0$ (this is derived in Appendix F).

However, in the special case of capital endowment differences between the North and the South being sufficiently small, and hence the magnitude of FDI being small enough, welfare predictions similar to the neutral-good model emerge. That is,

$$\lim_{I\to 0}\frac{d\widetilde{U}^N}{dI}=-\frac{\gamma}{\bar{T}-T^W}\frac{dT^S}{dI}<0; \qquad \lim_{I\to 0}\frac{d\widetilde{U}^S}{dI}=-\frac{\gamma}{\bar{T}-T^W}\frac{dT^N}{dI}>0; \quad \text{(G6)}$$

$$\lim_{I\to 0}\frac{d\widetilde{U}^W}{dI} = -\frac{\gamma}{\bar{T}-T^W}\frac{dT^W}{dI}<0. \quad \text{(G7)}$$

Appendix H

It is shown that, when environment is a normal good, at the cooperative equilibrium North's contribution to pollution is lower than South's.

Define $k^{N^c} \equiv \frac{\bar{K}+\alpha I}{K^N+\alpha I}-\frac{\alpha I}{K^S-\alpha I}$ and $k^{S^c} \equiv \frac{\bar{K}-\alpha I}{K^S-\alpha I}+\frac{\alpha I}{K^N+\alpha I}$. Now, the first-order conditions (47)-(48) in the text could be combined to yield

$$\frac{k^{N^c}}{k^{S^c}}=\left(\frac{T^{N^c}}{T^{S^c}}\right)^{1-\theta}<1 \Leftrightarrow T^{N^c}<T^{S^c}. \quad \text{(H1)}$$

This is proved by contradiction. Suppose (H1) is not true, then

$$\frac{T^{N^c}}{T^{S^c}}>1 \quad\Rightarrow\quad k^{N^c}>k^{S^c}. \quad \text{(H2)}$$

$$\Rightarrow \frac{\bar{K}+\alpha I}{K^N+\alpha I}-\frac{\alpha I}{K^S-\alpha I} > \frac{\bar{K}-\alpha I}{K^S-\alpha I}+\frac{\alpha I}{K^N+\alpha I}$$

$$\Rightarrow \frac{\bar{K}}{K^N+\alpha I} > \frac{\bar{K}}{K^S-\alpha I} \Rightarrow K^S-\alpha I > K^N+\alpha I$$

$$\Rightarrow K^S > K^N. \quad \text{(H3)}$$

Utilizing the last inequality in the capital market clearing condition (7) yields $T^{S^c}>T^{N^c}$, which contradicts (H2). Thus, under cooperation, $T^{N^c}<T^{S^c}$, which implies that $K^{N^c}<K^{S^c}$.

Appendix I

In case of environment being a normal good, the effect of cooperation (in respect of environment policies) on the magnitude of FDI, and regional and global pollution is analyzed here. Recalling the definitions of $p^N(\cdot)$ and $p^S(\cdot)$ in subsection (4.2), and denoting $\left(\frac{\alpha I}{K}\right) / \left(1 - \frac{\alpha I}{K^S}\right) \equiv q^N(I)$ and $\left(\frac{\alpha I}{K}\right) / \left(1 + \frac{\alpha I}{K^N}\right) \equiv q^S(I)$, equilibrium conditions (45) and (46) in the text could be expressed as

$$\tilde{f^N}^c \equiv \frac{\beta}{T^N}\left(p^N(\cdot) - \frac{Y^N}{Y^S}q^N(\cdot)\right) = \frac{2\gamma}{\bar{T} - T^W} \tag{I1}$$

$$\tilde{f^S}^c \equiv \frac{\beta}{T^S}\left(p^S(\cdot) + \frac{Y^S}{Y^N}q^S(\cdot)\right) = \frac{2\gamma}{\bar{T} - T^W} \tag{I2}$$

We first derive the change in the magnitude of FDI in moving from the non-cooperative (Nash) equilibrium to the cooperative equilibrium. This is done by introducing the parameter $\tilde{b}$, $\tilde{b} \in [0,1]$ into the above conditions such that the pair of equations:

$$\frac{\beta}{T^N}\left(p^N(\cdot) - \tilde{b}\frac{Y^N}{Y^S}q^N(\cdot)\right) = \frac{(1+\tilde{b})\gamma}{\bar{T} - T^W}; \tag{I3}$$

$$\frac{\beta}{T^S}\left(p^S(\cdot) - \tilde{b}\frac{Y^S}{Y^N}q^N(\cdot)\right) = \frac{(1+\tilde{b})\gamma}{\bar{T} - T^W} \tag{I4}$$

represents the non-cooperative equilibrium at $\tilde{b} = 0$ and the cooperative equilibrium at $\tilde{b} = 1$.

Let $\rho \equiv K^N/K^S$ and $\Pi \equiv T^N/T^S$. Equating the l.h.s. of (I3) and (I4) the two equations could be collapsed into

$$p^N(\cdot) - b\rho^\alpha \Pi^\beta q^N(\cdot) = \Pi\left(p^S(\cdot) + bK^{-\alpha}\Pi^\beta q^S(\cdot)\right). \tag{I5}$$

Holding I constant at the non-cooperative equilibrium level, comparative statics with respect to $\tilde{b}$ yield

$$\frac{d\left(T^N/T^S\right)}{d\tilde{b}} \equiv \frac{d\Pi}{d\tilde{b}} = -\frac{\rho^\alpha \Pi^\beta q^N(\cdot) + \frac{\Pi}{\rho^\alpha \Pi^\beta}q^S(\cdot)}{p^S(\cdot) + \frac{\beta\tilde{b}}{\rho^\alpha \Pi^{1-\beta}}q^N(\cdot) + \frac{(1-\beta)\tilde{b}}{\rho^\alpha \Pi^\beta}q^S(\cdot)} < 0. \tag{I6}$$

This implies that pollution in the North relative to the South falls as countries move from non-cooperative to cooperative regime. Moreover, with $I = \bar{K}^N - \eta\bar{K} = \bar{K}^N - \frac{(\Pi)^\theta}{\left(1+(\Pi)^\theta\right)}\bar{K}$ it is easy to check that

$$\frac{dI}{d\Pi} = -\frac{\theta\Pi^\theta}{\Pi(1+\Pi^\theta)^2} < 0 \tag{I7}$$

The signs of the derivatives in (I6) and (I7) together yield

$$\frac{dI}{d\tilde{b}} = \frac{dI}{d\Pi}\frac{d\Pi}{d\tilde{b}} > 0 \tag{I8}$$

Thus, FDI rises in moving from a non-cooperative to a cooperative equilibrium.

We now turn to the implications for regional pollution levels. In comparison with the Nash first-order conditions (39)-(40), with cooperation (characterized by (43)-(44)) three additional effects are observed:

1. From (I8) the level of FDI is higher than under non-cooperation.
2. In both the first-order conditions, (43) and (44), there is now an additional term in the benefit side, which is $\left(-\frac{I\frac{\partial r}{\partial T^N}}{Y^S - rI}\right)$ for the North and $\left(\frac{I\frac{\partial r}{\partial T^S}}{Y^N + rI}\right)$ for the South. This represents the internalization of the income-adjusted factor terms-of-trade effects of the *partner* country from a change in *own* pollution policy of the country – an implication of joint welfare maximization.

   Unlike in the neutral-environment good model, where these effects exactly offset each other, in the presence of income effects on the demand for environmental good, as the sizes of the national income/output vary between the countries, the factor terms-of-trade effects do not net out between the North and South. Further, T and K being complementary factor inputs, an increased use of one raises the marginal product of the other, that is, $\partial \tau^j / T^j > 0$. It is, therefore, intuitive that being a net capital exporter (importer) this effect is negative (positive) for the North (South).
3. On the cost side, international coordination of pollution policy implies that each country now takes into account the global costs of pollution, which are twice of those borne by the individual country (given that both the countries are identical in terms of population and preferences). This represents full internalization of the pure public good (or bad) nature of pollution. At the same time cooperation involves a change in global pollution, T^W.

All of these effects have implications for marginal benefits and marginal costs of pollution of both countries. *Ceteris paribus*, on account of the first, i.e. a higher magnitude of FDI the marginal benefit schedule of the North shifts down whilst that of the South may shift up or down. Mathematically, this can be seen from $\frac{d}{dI}\left(\frac{1+\frac{\alpha I}{\bar{K}}}{1+\frac{\alpha I}{K^N}}\right) = \frac{\alpha}{K^N \bar{K}}\left((K^N + \alpha I) - \frac{\bar{K}^N}{K^N}(\bar{K} + \alpha I)\right) < 0$ since $\bar{K}^N / \bar{K}^S > 1$, and $\frac{d}{dI}\left(\frac{1-\frac{\alpha I}{\bar{K}}}{1-\frac{\alpha I}{K^S}}\right) = \frac{\alpha}{K^S \bar{K}}\left(\frac{\bar{K}^S}{K^S}(\bar{K} - \alpha I) - (K^S - \alpha I)\right) \gtrless 0$. For small enough $\bar{K}^S$ this may be negative, entailing shifting down of South's marginal benefits.

The second effect (representing the inclusion of the factor terms-of-trade change of the partner country induced by a change in a country's own environment policy) leads to a loss (gain) for the North (South) through a downward (upward) shift in the benefit schedule.

The third manifests in an upward shift in the marginal cost schedule of both countries, which, by itself, would have a negative effect on pollution. But, depending upon the change in the level of aggregate global pollution, there would also be a movement along the marginal cost curve.

Depending upon the strength of these individual effects *a priori* the implication of environment policy coordination on regional pollution levels is not clear. (Although, we shall find below that global pollution falls in moving from non-cooperative to cooperative equilibrium).

The first-order conditions (45) and (46) could be expressed as:

$$\frac{1}{2}\left(\frac{1+\frac{\alpha I^c}{\bar{K}}}{1+\frac{\alpha I^c}{K^{N^c}}} - \frac{Y^N}{Y^S}\left(\frac{\frac{\alpha I^c}{\bar{K}}}{1-\frac{\alpha I^c}{K^{S^c}}}\right)\right) = \frac{\gamma T^N}{\beta(\bar{T}-T^W)}$$
$$\frac{1}{2}\left(\frac{1-\frac{\alpha I^c}{\bar{K}}}{1-\frac{\alpha I^c}{K^{S^c}}} + \frac{Y^S}{Y^N}\left(\frac{\frac{\alpha I^c}{\bar{K}}}{1+\frac{\alpha I^c}{K^{N^c}}}\right)\right) = \frac{\gamma T^S}{\beta(\bar{T}-T^W)}$$

Adding up the two eqs. and utilizing the relationship $Y^N/Y^S = K^N/K^S = \eta/1-\eta$ (that holds for any capital mobility equilibrium), the above pair collapses to:

$$\frac{1}{2}\left(\frac{1+\frac{\alpha I^c}{\bar{K}}}{1+\frac{\alpha I}{K^{N^c}}} - \frac{\eta}{1-\eta}\left(\frac{\frac{\alpha I^c}{\bar{K}}}{1-\frac{\alpha I^c}{K^{S^c}}}\right) + \frac{1-\frac{\alpha I^c}{\bar{K}}}{1-\frac{\alpha I^c}{K^{S^c}}} + \frac{1-\eta}{\eta}\left(\frac{\frac{\alpha I^c}{\bar{K}}}{1+\frac{\alpha I^c}{K^{N^c}}}\right)\right) = \frac{\gamma T^W}{\beta(\bar{T}-T^W)} \equiv g(T^W). \tag{I9}$$

The r.h.s. of (I9) is the same function $g(T^W)$ as in eqs. (F2) and (F1) in Appendix F, which pertain to the autarky and non-cooperation equilibria respectively. Since $g(\cdot)$ is increasing in T^W, if the l.h.s. of eq. (I9) is less than the l.h.s. of eq. (F2), it is sufficient for T^W to fall below the autarky level. (This also implies global pollution at the cooperative equilibrium being lower than at the non-cooperative equilibrium, as the latter is higher than the autarky global pollution). Focussing on the l.h.s. of (I9), indeed it turns out that

$$\frac{1}{2}\left(\frac{\eta(\bar{K}+\alpha I^c)}{\eta\bar{K}+\alpha I^c} - \frac{\eta\alpha I^c}{(1-\eta)\bar{K}-\alpha I^c} + \frac{(1-\eta)(\bar{K}-\alpha I^c)}{(1-\eta)\bar{K}-\alpha I^c} + \frac{(1-\eta)\alpha I^c}{\eta\bar{K}+\alpha I^c}\right) = \frac{1}{2}(1+1) = 1 < 2,$$

which is the l.h.s. of (F2). Hence the result that $T^{W^c} < T^{W^a} < T^{W^o}$.

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