

# Trade and Transboundary Pollution

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*This paper examines how national income and trading opportunities interact to determine the level and incidence of world pollution. We find that (i) free trade raises world pollution if incomes differ substantially across countries; (ii) if trade equalizes factor prices, human-capital-abundant countries lose from trade, while human-capital-scarce countries gain; (iii) international trade in pollution permits can lower world pollution even when governments' supply of permits is unrestricted; (iv) international income transfers may not affect world pollution or welfare; and (v) attempts to manipulate the terms of trade with pollution policy leave world pollution unaffected. (JEL F10, H41, Q28)*

There is growing concern over the effects of international trade on the global environment. While traditional opposition to free trade focused on potential job losses and wage reductions, environmentalists have recently turned the pro-free-trade case on its head by arguing that, even if trade liberalization succeeds in raising incomes and consumption, this will only lead to more pollution.

Economists have responded by pointing out that the national income gains brought about by freer trade will increase the demand for environmental quality, make new investment in pollution abatement affordable, and generate much-needed government revenues for enforcement of environmental regulations. In fact, recent empirical work by Gene M. Grossman and Alan B.

Krueger (1993) suggests that income gains can have a significant effect on some types of pollution emissions.

It is clear that both sides may be at least partially right. Trade may tend to increase world pollution by raising the scale of economic activity and by providing added incentives for polluting industries to locate in countries with low environmental standards. Conversely, the income gains created by trade may increase the pressure for tougher environmental regulation and enforcement. In this paper we develop a very simple model to investigate these issues. We assume that global environmental quality is a pure public good whose supply responds endogenously to trade-induced changes in relative prices and incomes, and we use the model to explore how welfare and pollution levels are affected by free trade in goods and pollution permits, by international income transfers, and by international agreements limiting or reducing pollution emissions. Our model is designed to highlight income effects, since these are central to the arguments put forward on both sides of the debate.

The model builds on our earlier work (Copeland and Taylor, 1994), where we studied trade in a world where environmental quality is a *local* public good (pollution damage is confined to the emitting country). In that paper, we developed a static two-country general-equilibrium model with a

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continuum of goods differing in their pollution intensity of production. Countries differed only in their endowment of the one primary factor (human capital); and we studied only the case in which this difference was large. Governments set pollution policy endogenously, and because environmental quality is a normal good, the higher-income country had tougher environmental regulations. We found that free trade shifted pollution-intensive production to the human-capital-scarce country and raised world pollution. Nevertheless, there was no market failure because pollution stayed within the country of origin and governments regulated pollution optimally. Consequently, trade always increased welfare.

In the present paper, global environmental quality is a *pure* public good (or equivalently, pollution is a pure public bad): all countries are equally exposed to a given unit of pollution, regardless of its source. The pollutants we have in mind feature prominently in much of the debate over global warming, depletion of the ozone layer, and biodiversity. The welfare effects of trade in this case are fundamentally different. If pollution is a pure public bad, the relocation of pollution-intensive industries to countries with less stringent environmental protection may increase the exposure of home residents to pollution, and this works against standard gains from trade. Because pollution crosses borders, uncoordinated regulation of pollution at the national level does not eliminate all market failures, and consequently free trade need not raise welfare.

In addition to allowing for transboundary pollution, we depart from our earlier work in several other significant ways. We allow for an arbitrary number of countries, and we consider two cases: one with a large number of countries (where no country perceives a terms-of-trade effect from changes in its environmental policy) and one with a small number of countries (where terms-of-trade motivations for environmental policy cannot be ignored). This allows us to isolate the effects of terms-of-trade motivations for pollution policy from purely environmental motives. Finally, we study equilibria where

factor prices are equalized by trade (FPE equilibria), as well as specialized equilibria. This allows us to examine how inequalities in the international distribution of income influence the effects of trade on the environment.

The bulk of the paper focuses on the case with a large number of countries. Each government sets a national pollution quota and implements it with marketable permits, treating the rest of the world's pollution as given. We find a Nash equilibrium in pollution levels, examine the effects of liberalizing trade in goods, and analyze various proposals for reducing world pollution. Within this context we obtain several interesting results.

First, if human-capital levels differ substantially across countries, then a movement from autarky to free trade raises world pollution. In contrast, if all countries have similar human-capital levels, then world pollution does not rise with trade. When countries are very different, trade does not equalize factor prices, and consequently pollution permit prices are lower in human-capital-scarce countries. "Pollution havens" are created by trade as the most pollution-intensive industries shift to countries with weak environmental regulations. This tends to raise world pollution above autarky levels. On the other hand, if countries are sufficiently similar, then trade equalizes pollution-permit prices, and the pollution-haven effect is eliminated.

Second, we find that the human-capital-abundant countries lose from trade and the human-capital-scarce countries gain from trade when regions have similar (but still different) income levels in autarky. As we show, lower-income countries have a strategic advantage when setting pollution levels in a free-trade regime, and this allows them to increase their income and pollution at the expense of richer countries.

Third, we find that when free trade in goods raises world pollution, allowing for international trade in pollution permits can lower global pollution. This result holds even when countries are not restricted in the number of permits they issue. This is because free trade in permits equalizes

pollution-permit prices and eliminates the pollution-haven effect.

Fourth, we show that untied international transfers of income lower the recipient's pollution but raise the donor's. In an FPE equilibrium, the donor's welfare may be no lower after the transfer than before. This result underscores the potential importance of income effects in analyzing global pollution reform.

Finally, when we move to the case with a small number of countries, we find that the flavor of most of our results carries over; although terms-of-trade motivations for pollution policy reduce the strategic advantage of low-income countries, increase the pollution produced by the high-income North, and render income transfers from North to South welfare-reducing for the donor and welfare-enhancing for the recipient.

While there is an extensive literature on transboundary pollution, there is little work examining the interaction among pollution, income levels, and the pattern of trade in a general equilibrium setting (see Judith M. Dean [1992] for a survey). Optimal unilateral and multilateral approaches to transboundary pollution have been addressed in a number of papers (see in particular James R. Markusen [1975a, b]), but this literature is mainly concerned with how to regulate pollution and not with the interaction among income levels, pollution policy, and trade. Markusen (1975b) also considered a noncooperative Nash equilibrium in pollution levels between governments, but the pattern of trade was exogenous. Rodney D. Ludema and Ian Wooton (1994) have recently extended this work, but confine their attention to strategic trade policy issues. Michael Rauscher's (1991) work is closest in spirit to ours: he uses a two-country general-equilibrium model with no goods trade, but capital is mobile and responds to differences in environmental regulations. He finds that increased capital mobility leads to a pollution reduction in at least one country but has ambiguous welfare effects. In contrast, we adopt a multi-good, many-country trading model. This allows us to analyze linkages between trade patterns and pollution levels, and also to contrast FPE equi-

libria with specialized equilibria and to compare pure goods trade with trade in pollution permits.

The remainder of the paper proceeds as follows. In the first six sections of the paper we assume that the number of countries is large, and hence terms of trade motivations for pollution policy can safely be ignored. Sections I and II detail the model's assumptions and derive the equilibrium conditions. Section III examines autarky, and Section IV considers the effects of trade on welfare and pollution levels. We examine various approaches to pollution policy reform in Section V and study the effects of untied income transfers in Section VI. Section VII reconsiders our earlier results when the number of countries is small, and Section VIII presents our conclusions.

### I. The Model

We consider a world economy consisting of two regions (North and South), each composed of many countries:  $n$  in the North and  $n^*$  in the South. All countries within a region are identical. Countries differ across regions only in their endowments of the one primary factor, effective labor, which is supplied inelastically. Effective labor can be thought of as the product of the number of workers and an efficiency index determined by the level of human capital. Since the number of individuals per country plays no independent role in our analysis, we normalize the population of each country to 1.<sup>1</sup> Consequently, international differences in effective labor endowments reflect differences in human capital. Each Northern country has  $L$  units of effective labor, and each Southern country has  $L^*$  units. We assume  $L > L^*$  so that Northern countries are human-capital-abundant relative to Southern countries.

<sup>1</sup>In section 7 of Copeland and Taylor (1994) we consider an extension of the model in which factors such as country size, population density, and the environment's absorptive capacity allow these two components of effective labor to have different effects. We have not adopted this extension here, given the complications of transboundary pollution.

There is a continuum of private consumption goods, indexed by  $z \in [0, 1]$ . Pollution is produced jointly with consumption goods, but the output ( $y$ ) of a consumption good  $z$  can be written as a function of pollution emissions ( $e$ ) and labor input ( $\ell$ ).<sup>2</sup> To keep the model simple, we adopt the following functional form:

$$(1) \quad y = f(e, \ell; z) = \begin{cases} \ell^{1-\alpha(z)} e^{\alpha(z)} & \text{if } e/\ell \leq \lambda \\ 0 & \text{if } e/\ell > \lambda \end{cases}$$

where  $\lambda > 0$ , and  $\alpha(z) \in (0, 1)$  is a parameter varying across goods. Because pollution is a by-product of production, output must be bounded above for any given labor input. This constraint is most easily captured by the requirement  $e \leq \lambda \ell$  since this ensures that  $y \leq \lambda^\alpha \ell$ .

Private firms must obtain permits to emit pollution. Letting  $\tau$  denote the price of a permit, and  $w$  the return to a unit of effective labor, the unit-cost function corresponding to (1) is

$$(2) \quad c(w, \tau; z) = \kappa(z) \tau^{\alpha(z)} w^{1-\alpha(z)}$$

where  $\kappa(z) \equiv \alpha^{-\alpha} (1-\alpha)^{-(1-\alpha)}$  is an industry-specific constant.<sup>3</sup> Since the share of pollution charges in the total cost of producing good  $z$  is  $\alpha(z)$ , we can easily rank goods in terms of pollution intensities so that  $\alpha'(z) > 0$ . High- $z$  goods are more pollution-intensive than low- $z$  goods at all factor prices.

Northern and Southern consumers have identical utility functions defined over consumption goods and aggregate world pollution. Pollution is a pure public bad: consumers in all countries are harmed by the

pollution released from any one country. To simplify matters we assume that pollution affects only the level of utility and plays no role in determining consumer choice among goods. For tractability, we follow Rudiger Dornbusch et al. (1980) and impose constant budget shares; hence,

$$(3) \quad U = \int_0^1 b(z) \ln[x(z)] dz - \beta \left( \sum_{i=1}^{n+n^*} E_i \right)^\gamma / \gamma$$

where  $\beta$  and  $\gamma$  are positive constants,  $E_i$  is the total amount of pollution emitted by country  $i$ ,  $x(z)$  is consumption of good  $z$ , and  $b(z)$  is the budget-share function satisfying  $\int_0^1 b(z) dz = 1$ . We assume that  $\gamma \geq 1$ , to ensure that the marginal willingness to pay for pollution reduction is a nondecreasing function of pollution levels.

### II. Pollution Supply

There are three types of decision-makers: governments, producers, and consumers. We abstract from all income distributional issues and assume that the government chooses policy to maximize the utility of the representative consumer. Governments move first and set national pollution quotas. Next, consumers and producers maximize utility and profits, treating prices and pollution as given. Finally, markets clear.

We consider a noncooperative Nash equilibrium with each government treating the rest of the world's pollution as given when choosing its own pollution quota  $E_i$ . Pollution targets are implemented with a marketable permit system: the government of country  $i$  issues  $E_i$  pollution permits, each of which allows a (local) firm to emit one unit of pollution. The permits are auctioned off to firms, and all revenue is given to consumers via lump-sum transfers.<sup>4</sup>

<sup>2</sup>This requires that the technology satisfy certain regularity conditions. In Copeland and Taylor (1994), we show how (1) can be derived from a joint production technology.

<sup>3</sup>We assume an interior solution, but one always obtains if effective labor endowments are not too small. See Copeland and Taylor (1994) for further details.

<sup>4</sup>This is equivalent to assuming that the aggregate pollution target is implemented with a pollution tax whose revenues are rebated to consumers.

We begin with the production sector. Given goods prices  $p(z)$ , and the government's allotment of pollution permits, profit-maximizing firms maximize national income and, hence, implicitly solve

$$G(p, E_i, L_i) \\ = \max_{\{l(z), e(z)\}} \left\{ \int_0^1 p(z) f[e(z), l(z); z] dz \right\}$$

subject to

$$\int_0^1 e(z) dz = E_i \\ \int_0^1 l(z) dz = L_i.$$

For given  $p(z)$ , the market price of a pollution permit in country  $i$  can be obtained as

$$\tau_i = \partial G / \partial E_i$$

which measures the marginal cost to the economy of reducing pollution.

Consumers maximize utility, given prices and pollution levels. Let  $I_i$  denote national income of country  $i$  [in equilibrium  $I_i = G(p, E_i, L_i)$ ]. Then the indirect utility function corresponding to (3) for the representative consumer in country  $i$  is given by

$$(4) \quad V = \int_0^1 b(z) \ln[b(z)] dz \\ - \int_0^1 b(z) \ln[p(z)] dz + \ln(I_i) \\ - \beta \left( \sum_{j=1}^{n+n^*} E_j \right)^\gamma / \gamma.$$

Each government chooses its pollution target  $E_i$  to maximize the utility of its representative consumer, treating the pollution level of all other countries as fixed. For country  $i$  the first-order condition implies

$$(5) \quad \tau_i = -V_E / V_I + \int_0^1 m_i(z) \frac{dp(z)}{dE_i} dz$$

where  $m_i(z)$  is net imports of good  $z$ . Equation (5) tells us that the pollution target

should be chosen so that the equilibrium permit price (the marginal cost of pollution abatement) is equal to the marginal benefit from lower pollution, measured by marginal damage ( $V_E / V_I$ ) plus an indirect terms-of-trade effect.

When the number of countries is large, no individual government can have a significant effect on its terms of trade. Consequently, the final term in (5) tends to zero as  $n$  and  $n^*$  increase. In contrast, each country retains an incentive to control its pollution even as the number of countries grows large. The intuition for this result is as follows. Start from an existing equilibrium with  $n + n^*$  countries each contributing to global pollution, and add another country. On impact, this extra country adds to the stock of world pollution. Since the marginal damage from pollution is rising in global pollution levels, this extra pollution *increases* the incentive of each existing country to control its own pollution. Hence as  $n$  and  $n^*$  grow large, each country retains an incentive to limit its contribution to global pollution.<sup>5</sup>

Until Section VII, we assume that the number of countries is large enough so that no government will perceive any terms-of-trade benefit from manipulating pollution policy. With this assumption, each government chooses its target so that the equilibrium permit price is equal to marginal damage:

$$(6) \quad \tau_i = -V_E / V_I = \beta \left( \sum_{j=1}^{n+n^*} E_j \right)^{\gamma-1} I_i.$$

<sup>5</sup>For a proof of this assertion see footnote 25 in Section VII. This result, which applies to public bads, is in fact just the mirror image of the typical (voluntary provision) public-goods problem. In the public-goods case, the addition of further agents increases the quantity of the public good on impact and reduces the incentive of each agent to provide the public good. The key difference between public bads and goods is that the impact effect of another agent in the public-bads case is to *lower* the utility of all others, thus raising the marginal benefit of controlling the public bad; whereas in the public-goods case, adding an extra agent *raises* the utility of others, thus reducing the marginal benefit of contributing to the public good.

Permit prices are increasing in income since environmental quality is a normal good,<sup>6</sup> and nondecreasing in the aggregate pollution level since the marginal willingness to pay for pollution reduction is nondecreasing.

To generate a relationship between relative factor prices ( $\tau_i/w_i$ ) and pollution supply, note that national income is the sum of labor income and returns from pollution permits:

$$(7) \quad I_i = w_i L_i + \tau_i E_i.$$

Combining (6) with (7), letting  $E^w \equiv \sum_j E_j$  denote world pollution, yields country  $i$ 's inverse pollution supply curve:

$$(8) \quad \rho_i \equiv \frac{\tau_i}{w_i} = \frac{\beta L_i (E^w)^{\gamma-1}}{1 - \beta E_i (E^w)^{\gamma-1}}.$$

Since all countries within a region are identical, it is clear from (8) that their pollution supply curves are identical. In equilibrium (autarky or free trade), all countries within a region attain the same level of utility and emit the same amount of pollution.

### III. Autarky Equilibrium

The (derived) demand for pollution in autarky arises from the demand for goods whose production creates pollution. Recalling that  $\alpha(z)$  is the share of pollution charges in the cost of production, we have

$$(9) \quad \begin{aligned} \tau_i e_i(z) &= \alpha(z) p_i(z) y_i(z) \\ &= \alpha(z) p_i(z) x_i(z) = \alpha(z) b(z) I_i \end{aligned}$$

where  $e_i(z)$  is the number of pollution per-

mits needed to produce autarky consumption  $x_i(z)$ . Integrating over all goods and using (7) yields the derived demand for pollution:

$$(10) \quad \rho_i \equiv \frac{\tau_i}{w_i} = \frac{\bar{\theta} L_i}{E_i [1 - \bar{\theta}]}$$

where  $\bar{\theta} \equiv \int_0^1 \alpha(z) b(z) dz$  is the share of pollution-permit revenue in national income. Equating country  $i$ 's pollution demand (10) and supply (8) yields its best response to foreign pollution:

$$(11) \quad E_i (E^w)^{\gamma-1} = \bar{\theta} / \beta.$$

Solving the system (11) simultaneously for all  $i$  yields autarky pollution levels:

$$(12) \quad E_i^a = \left( \frac{\bar{\theta}}{\beta (n + n^*)^{\gamma-1}} \right)^{1/\gamma} \equiv E^a.$$

World pollution in autarky is obtained by summing (12) over all countries:

$$(13) \quad E^{aw} = \left( \frac{(n + n^*) \bar{\theta}}{\beta} \right)^{1/\gamma}$$

Autarky pollution is independent of the level of human capital, and hence all countries generate the same amount of pollution. A larger production capacity created by higher human-capital levels increases the demand for pollution permits (a scale effect), but the ensuing higher income reduces the amount of pollution the population is willing to supply, leading to a higher pollution-permit price and cleaner techniques of production. As in Copeland and Taylor (1994), these scale and technique effects exactly offset each other in autarky, leaving pollution independent of the level of human capital.

On the other hand, changes in the number of countries do affect pollution. On impact, an increase in the number of countries raises world pollution. This increases marginal damage and raises the marginal benefit of controlling pollution. In response,

<sup>6</sup>The optimal permit supply problem depends on aggregate income, reflecting our decision to abstract from income distributional issues by assuming a representative agent. If instead pollution permits were given to firms (rather than auctioned), and if the government placed different weights on labor income and pollution-permit rents collected by firms, then the supply of pollution would depend on distributional weights.

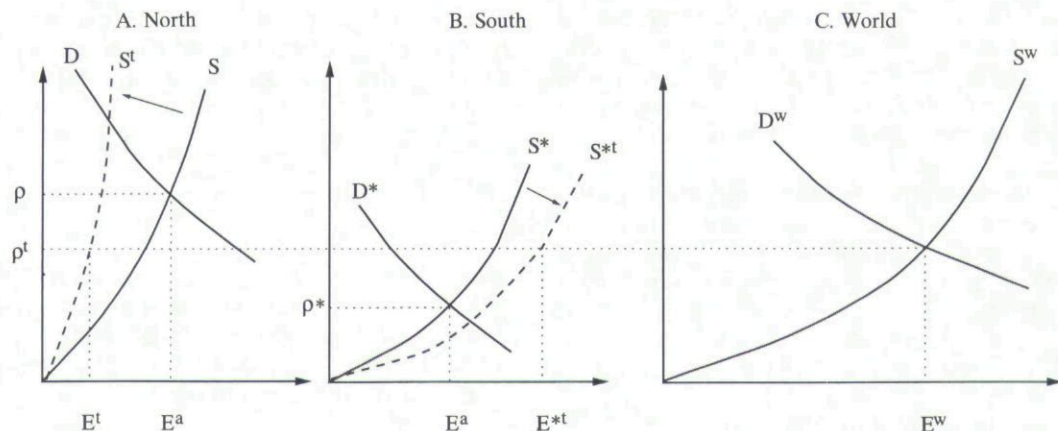


FIGURE 1. POLLUTION DEMAND AND SUPPLY

each country cuts back its pollution [from (12), an individual country's pollution is declining in  $n + n^*$ ], but not by enough to prevent global pollution from rising [from (13), world pollution is increasing in  $n + n^*$ ].

While pollution levels are the same across countries, the relative price of pollution permits differs: since  $L > L^*$ , we have  $E^a/L < E^a/L^*$ , and hence pollution permits are relatively scarce (and expensive) in the North. This is illustrated in Figure 1, which plots a Northern and a Southern country's pollution demand ( $D$ ) and supply ( $S$ ) [using equations (8) and (10)], parameterized by the equilibrium autarky pollution level of the rest of the world. Because of its higher income, Northern demand for pollution is higher, and its supply lower, than in the South. Consequently,  $\rho^a > \rho^{a*}$ , and this provides the basis for trade.

#### IV. Trading Equilibrium

If countries have sufficiently similar effective labor endowments, factor prices will be equalized by trade; conversely, if endowments are sufficiently different, trade will not equalize factor prices.<sup>7</sup> Since these two

types of equilibria have very different implications, we consider both cases.

##### A. Factor Prices Equalized

First consider the FPE case. With equal factor prices the exact pattern of commodity trade is indeterminate,<sup>8</sup> but we can obtain results on the pattern of trade in factor services. Moreover, because supply curves of countries within a region are identical, all countries within a region will produce the same amount of pollution and attain the same income level in free trade. Consequently, we omit individual country subscripts, except in cases where there may be some ambiguity. Thus, for example,  $E$  is the amount of pollution produced by a typical Northern country. Asterisks denote corresponding Southern-country variables.

Since  $\tau = \tau^*$  in a FPE equilibrium, we conclude from (6) that  $I = I^*$ , and hence  $wL + \tau E = wL^* + \tau E^*$ . Rearranging yields

$$(14) \quad L - L^* = \rho(E^* - E)$$

where  $\rho \equiv \tau/w$ . By definition we have  $L >$

<sup>7</sup>The conditions which generate each type of equilibrium are discussed in the Appendix.

<sup>8</sup>This is a standard feature of trade models in which the number of goods exceeds the number of factors. See, for example, Dornbusch et al. (1980).

$L^*$ , and hence  $E^* > E$ ; more pollution is generated by Southern countries. Moreover, since  $I = I^*$  and preferences over goods are homothetic, each country consumes a fraction  $1/(n + n^*)$  of the world's (embodied) pollution and effective labor services. Hence each Northern country is a net exporter of  $n^*(L - L^*)/(n + n^*)$  units of effective labor services, and each Southern country is a net exporter of  $n(E^* - E)/(n + n^*)$  units of pollution services.

Equilibrium pollution levels can be obtained by equating world demand and supply for pollution services.<sup>9</sup> Denote world magnitudes with a superscript "w", and use the same argument that led to (10) to obtain the world demand for pollution:

$$(15) \quad \rho = \frac{\bar{\theta}L^w}{(1 - \bar{\theta})E^w}.$$

Next, invert (8), sum, and rearrange to obtain world supply:

$$(16) \quad \rho = \frac{\beta L^w (E^w)^{\gamma-1}}{n + n^* - \beta (E^w)^\gamma}.$$

Equating demand and supply yields world pollution in the FPE equilibrium:

$$(17) \quad E^w = \left( \frac{(n + n^*)\bar{\theta}}{\beta} \right)^{1/\gamma}.$$

Comparing (17) with (13), and using (12) and (14), we have shown the following.

**PROPOSITION 1:** *In an FPE equilibrium, trade raises the level of pollution generated by each Southern country, lowers the pollution level generated by each Northern country, and leaves world pollution unaffected.*

Figure 1 illustrates the effects of trade on pollution. In Figure 1A and 1B, we depict

the autarky ("a") and trading ("t") equilibria for typical Northern and Southern countries. Figure 1C illustrates the trading equilibrium with aggregate world demand and supply. Trade eliminates the gap between Northern and Southern pollution permit prices. Northern countries move down their supply curves as the relative price of a pollution permit drops, while Southern countries move up their supply curves. In addition, each Northern country's supply curve shifts inward in response to the net increase in foreign pollution,<sup>10</sup> while each Southern supply curve shifts outward in response to the net decrease in pollution from the rest of the world. Consequently, pollution must fall in the North and rise in the South. As is apparent from the diagram, the elastic supply of pollution and the pollution spillovers tend to reinforce the production shifts that trade creates in a standard Heckscher-Ohlin model.

Aggregate world pollution is unaffected by trade for essentially the same reason that pollution is independent of the level of human capital in autarky. Trade leads to real income changes which generate offsetting scale and technique effects. In addition, trade generates a composition effect, as the relatively pollution-intensive industries on average shift to the South from the North. Nevertheless, when factor prices are equalized by trade, the techniques of production are identical across countries, and hence shifting production across regions has no effect on pollution emissions.

Although trade does not affect the level of global pollution, it nevertheless has interesting welfare effects. These can be investigated with the aid of Figure 2. Since the world pollution level is unaffected by trade, we can draw an Edgeworth box with dimensions equal to the world supply of pollution

<sup>9</sup>This aggregation is possible because factor prices are equalized by trade and tastes are homothetic over private consumption goods.

<sup>10</sup>The net result of Southern pollution increases and other Northern reductions leaves a typical Northern country facing more foreign pollution. The shift in the supply curve can be obtained from (8): we have  $\partial \rho_i / \partial E_j > 0$  for  $j \neq i$  since an increase in foreign pollution raises the marginal damage from domestic pollution.



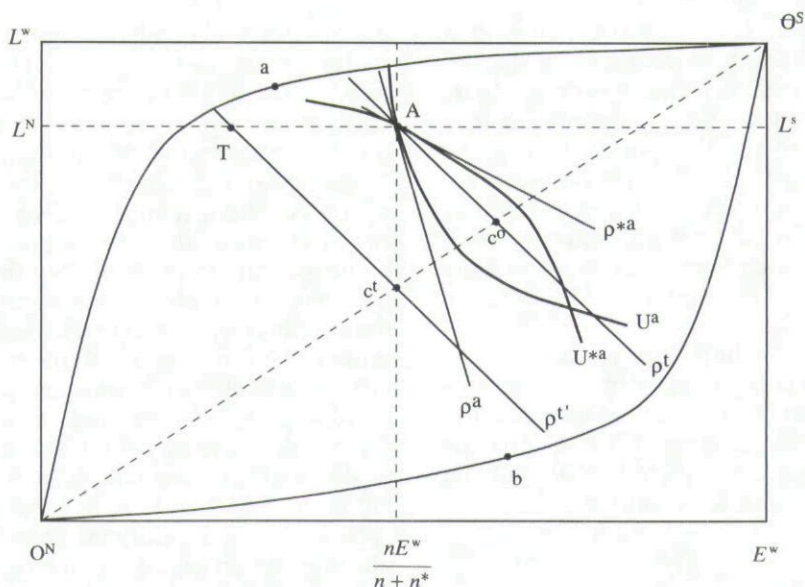


FIGURE 2. GAINS AND LOSSES FROM TRADE

$E^w$  and effective labor  $L^w$ . Let  $L^N$  denote North's aggregate endowment of effective labor. Then the autarky factor supply point is at  $A$ , since North produces a share  $n/(n+n^*)$  of pollution in autarky (recall that autarky pollution levels are identical across countries). Now consider an *integrated equilibrium* where factor supplies are fixed but freely mobile across countries. This yields some equilibrium  $\rho = \tau/w$ , and a production locus  $y(z)$ . If we now divide the world factor supplies between the two regions and allow free trade in goods but not in factors, then, as in Avinash Dixit and Victor Norman (1980), we can find the set of factor allocations where trade in goods alone can replicate the integrated equilibrium. This set is the interior and boundary of the area  $O^N a O^S b O^N$ . Outside of this area, the full-employment conditions for countries in at least one of the regions cannot be satisfied at the factor price and output vector of the integrated equilibrium.<sup>11</sup>

<sup>11</sup>In Dixit and Norman's analysis, the boundaries of the integrated equilibrium region are piecewise linear, with the slope of each piece being the factor-input ratio of each good. With a continuum of goods, the boundary is smooth, and the slope at each point is the factor-input ratio for some good  $z$ .

Because of constant returns to scale, we can think of each consumer as buying a bundle of factor services and using the bundle to produce consumption goods.<sup>12</sup> Hence we can draw indifference curves with re-

<sup>12</sup>If consumers have a factor service bundle of  $(E, L)$ , utility is given by

$$\bar{U}(E, L) = \max \left\{ \int_0^1 b(z) \ln(f[e(z), l(z); z]) dz - \beta(E^w)^\gamma / \gamma \right\}$$

subject to

$$\int_0^1 e(z) dz = E$$

$$\int_0^1 l(z) dz = L$$

where consumers treat world pollution  $E^w$  as fixed. Solving, we obtain

$$\bar{U}(E, L) = K + \bar{\theta} \ln E + (1 - \bar{\theta}) \ln L - \beta(E^w)^\gamma / \gamma$$

where  $K$  is a constant. This analysis (i.e., the equivalence of buying goods and factor services) is valid as long as all goods are produced by firms facing the same factor prices.

spect to factor services. Moreover, we can aggregate preferences because all individuals within a region have identical incomes and homothetic preferences over goods. This allows us to draw an indifference curve in Figure 2 which represents "Northern utility." In autarky, Northern consumers collectively face the budget constraint labeled  $\rho^a$ , and their indifference curve is tangent to this line at point A. Southern consumers face the budget constraint  $\rho^{*a}$  and must also be at point A. Potential gains from trade lie within the lens-shaped area bounded by the two indifference curves. If pollution were unaffected by trade, the equilibrium free-trade factor-price ratio would generate a budget constraint through point A (labeled  $\rho^t$ ), and because preferences over goods are identical and homothetic, the equilibrium consumption point would be at  $c^0$ . In this hypothetical case, all countries necessarily gain from trade.

Although global pollution is not affected by trade, pollution levels within each country do respond to trade. Southern countries increase their pollution, and Northern countries reduce their pollution. This corresponds to a leftward movement along the line  $L^N L^S$  to point T. Because pollution permits generate income, this change in the distribution of pollution-generating activities has the same effect on the North as a transfer of some of its earning potential to the South. The free-trade budget constraint is thus  $\rho^{t'}$ , and the free-trade consumption point is at  $c^t$ .<sup>13</sup>

Several results are immediately apparent from this analysis. First, Southern countries must always gain from trade. World pollution is not affected by trade, and so welfare is affected only by the change in real income. If factor supplies stayed constant before and after trade, then the standard gains-from-trade results would apply. Since the South also generates a greater share of

the world's pollution after trade, it realizes additional income gains from its expanded supply of pollution permits.

**PROPOSITION 2:** *In the FPE equilibrium, Southern countries always gain from trade.*

Whether or not the North gains from trade depends on how much the South increases its pollution as a result of trade. If pollution supplies did not change, the North would gain from access to the South's relatively cheaper (in autarky) pollution-intensive production. However, the North is harmed by South's increase in pollution. As Northern countries cut back on their pollution in response to increased pollution from the South, their collective budget constraint shifts down. In fact, as shown, the North's free-trade budget constraint,  $\rho^{t'}$ , must lie outside the lens-shaped area, and hence Northern countries lose from trade.

**PROPOSITION 3:** *Each Northern country is worse off in free trade than in autarky.*

(See Appendix A for the proof.)

The North loses from trade because without any global agreements, Southern countries have a strategic advantage: their lower income allows them to commit to higher pollution levels with the opening of trade. Northern countries can respond either by accepting more global pollution or by cutting back on their own pollution and allowing their incomes to fall. In our model, the reduction in pollution by Northern countries is exactly enough to maintain global pollution at its autarky level. In a more general model, Northern countries may choose a different income/pollution trade-off. But the central point remains: the increased pollution emanating from the South reduces the gains from trade for the North, and this effect can be strong enough to make the North lose from trade.

This suggests that there are strong incentives for the North to link environmental agreements to free-trade agreements. As noted above, if the South were prevented from increasing its pollution, then the North would always gain from trade. Thus, the North has an incentive to link a free-trade

<sup>13</sup>The slopes of  $\rho^{t'}$  and  $\rho^t$  are equal because A and T are both within the FPE region. The equilibrium consumption point must be at  $c^t$  because with identical homothetic preferences and identical incomes, the North consumes a fraction  $n/(n+n^*)$  of the world's factor services.

agreement with an agreement that freezes pollution at its pre-trade levels, whereas the South has an incentive to oppose this.

**PROPOSITION 4:** *As compared with unconstrained free trade, each Northern country would gain from an agreement that freezes pollution in each country at its pre-trade levels, and each Southern country would lose from such an agreement.*

Note that global pollution levels are unaffected by such an agreement—the issue here is a conflict over who generates the pollution. For a given level of global pollution, the right to pollute is a valuable asset, and each country can gain if it obtains a greater share of this asset. Since free trade allows the South to exploit its strategic advantage, the North has an incentive to place restrictions on its ability to do so, either by opposing free trade or by insisting that a trade agreement be linked to an environmental agreement.

#### B. Factor Prices Not Equalized

If factor prices are not equalized by trade, Northern countries specialize in human-capital-intensive goods, and Southern countries specialize in pollution-intensive goods. Given our ordering on  $\alpha(z)$  there will exist some  $\bar{z}$  such that goods on the interval  $[0, \bar{z})$  are produced in the North, and goods on the interval  $[\bar{z}, 1]$  are produced in the South. To determine the equilibrium, we follow Dornbusch et al. (1980), and solve for the marginal good. As in the FPE case, all countries within a region will attain the same outcome, and we omit country subscripts. Aggregate Northern and Southern variables are denoted with superscripts N and S; hence, for example,  $L^N = nL$ .

Since the marginal good is produced at equal cost in both regions; we have  $c(w, \tau; h, \bar{z}) = c(w^*, \tau^*; \bar{z})$ , or equivalently, using (2),

$$(18) \quad \omega \equiv \frac{w}{w^*} = \left( \frac{\tau^*}{\tau} \right)^{\alpha(\bar{z})/[1-\alpha(\bar{z})]}$$

To eliminate  $\tau^*/\tau$  from the above, note that North's share of world income equals the share of world spending on Northern goods:

$$(19) \quad I^N = \varphi(\bar{z})(I^N + I^S)$$

where  $\varphi(\bar{z}) \equiv \int_0^{\bar{z}} b(z) dz$  is the North's share of world income. Using (6) and (19), we have  $\tau^*/\tau = n\varphi^*(\bar{z})/n^*\varphi(\bar{z})$  where  $\varphi^*(\bar{z})$  is the South's share of world income. Substituting into (18) yields the following:<sup>14</sup>

$$(20) \quad \omega = \left( \frac{n\varphi^*(\bar{z})}{n^*\varphi(\bar{z})} \right)^{\alpha(\bar{z})/[1-\alpha(\bar{z})]} \\ \equiv T(\bar{z}).$$

To obtain another equation linking  $\omega$  and  $\bar{z}$ , note that income is the sum of wages and pollution-permit revenue, and pollution-permit revenue is the sum of fees paid by all producers. In the North, we have

$$(21) \quad \tau E^N = \int_0^{\bar{z}} \alpha(z)b(z)I^w dz \\ = \frac{I^N \theta(\bar{z})}{\varphi(\bar{z})}$$

where the last step uses (19) and where  $\theta(\bar{z}) \equiv \int_0^{\bar{z}} \alpha(z)b(z) dz$  is the share of Northern pollution charges in world income. Now use (21) to eliminate pollution charges in (7), do the same for the South, substitute into (19), and simplify to obtain:

$$(22) \quad \omega = \frac{n^*L^*}{nL} \left[ \frac{\int_0^{\bar{z}} b(z)[1-\alpha(z)] dz}{\int_{\bar{z}}^1 b(z)[1-\alpha(z)] dz} \right] \\ \equiv B(\bar{z}).$$

Jointly solving (22) and (20) determines the equilibrium.

<sup>14</sup>This analysis is valid only if  $\tau > \tau^*$ , since otherwise we are in the FPE case. Thus we must have  $n\varphi^*(\bar{z}) < n^*\varphi(\bar{z})$ ; or letting  $\varphi(\hat{z}) \equiv n/(n+n^*)$ , we require  $z > \hat{z}$ .

**PROPOSITION 5:** *If trade does not equalize factor prices, then (i) global pollution is higher in free trade than in autarky; (ii) pollution in the North falls with trade; and (iii) pollution in the South rises with trade.*

(See Appendix A for the proof.)

In contrast to the FPE case, free trade increases global pollution in a specialized equilibrium.<sup>15</sup> As before, the supply response to the factor-price movements created by trade leads to reduced pollution in the North and increased pollution in the South. However, since the gap between factor prices is not fully eliminated, the South has relatively lower pollution-permit prices than the North. Consequently, the marginal good is produced with more pollution-intensive techniques in the South than in the North. Since the most pollution-intensive industries shift to the country with the lowest pollution-permit price, the increase in pollution generated by the South is less than the fall in the North.<sup>16</sup>

### C. Trade in Pollution Permits

As in the Heckscher-Ohlin model, trade in goods in our model is an indirect way of allowing countries to trade factor services. We now consider the effects of allowing direct trade in pollution services when governments agree that a permit issued by one country can be used by a firm that wants to emit pollution in any country.

In the FPE equilibrium, trade in goods and trade in factors are perfect substitutes: allowing trade in pollution permits has no

effect on production, incomes, pollution, or welfare. This is a standard result in factor-proportions models—the only difference is that, in our case, the supply of the tradable factor is endogenous. Despite the fact that pollution permits are potential revenue-generators for governments, opening up international trade in pollution permits does not create an incentive to increase their supply beyond the levels of the pure goods-trading equilibrium. This is because pollution is a pure public bad. Since the harm suffered from pollution by the permit-issuing country is independent of the location of production, the income/pollution trade-off is not affected by making permits tradable when factor prices are equalized by goods trade alone.

In the specialized production equilibrium, trade in goods and trade in permits are no longer perfect substitutes. Consider an equilibrium with free trade in goods and then allow pollution permits to be freely traded internationally. Arbitrage equalizes the price of pollution permits across countries, and the zero-profit conditions ensure that  $\tau/w$  is equalized. Consequently, the FPE equilibrium conditions apply. Since opening up the pollution permit market to international trade induces an FPE equilibrium, pollution must fall.

**PROPOSITION 6:** *Suppose factor prices are not equalized by goods trade. Then if countries allow pollution permits to be tradable internationally (without any global agreement to restrict their supply), global pollution will fall (relative to the pure goods trade level).*

When pollution-permit prices differ across countries and goods are freely tradable, there is an incentive to shift the most pollution-intensive production to countries with the lowest pollution-permit prices. This composition effect tends to increase world pollution because production techniques are dirtier in countries with low permit prices. Allowing trade in permits equalizes permit prices, ensures that production techniques are identical across countries, and thus eliminates the “pollution haven” effect.

<sup>15</sup>The intuition is similar to that for proposition 2 of Copeland and Taylor (1994), where we provide a detailed explanation based on the scale, technique, and composition effects.

<sup>16</sup>A general welfare result for the non-FPE case corresponding to Propositions 2 and 3 has thus far eluded us. It is, however, possible to derive some limited results. For example, at the borderline between FPE and non-FPE, Propositions 2 and 3 hold; as well, if  $n^* = 1$ , the South must always gain in the non-FPE case.

## V. Reform of Pollution Policy

In autarky, there are two distortions: relative goods prices differ across countries, and the international externality leads to excessive global pollution. Thus far, we have considered the effects of eliminating the trade distortion, while leaving the pollution distortion unresolved. We now consider the effects of various proposals to control world pollution.

### A. Global Reform

We begin by briefly discussing the first best. Since environmental quality is an international public good, it is clear that global pollution levels are Pareto inefficient in a Nash equilibrium. The Samuelson condition for efficient public-goods provision requires that permit prices (the marginal pollution-control cost) be equalized across countries, and set equal to the global sum of marginal damages; that is, for any country  $j$ ,

$$(23) \quad \tau_j = \tau \equiv - \sum_{i=1}^{n+n^*} (V_{E_i}^i / V_{I_i}^i) \\ = \beta (E^w)^{\gamma-1} I^w.$$

Combining (23) with (15) yields the optimal global pollution level:<sup>17</sup>

$$(24) \quad \bar{E}^w = \left( \frac{\bar{\theta}}{\beta} \right)^{1/\gamma}$$

which is less than autarky and free-trade global pollution levels, as one would expect.

Implementation of the first best is straightforward in theory, but difficult in practice. For example, governments could agree to issue a fixed number of interna-

tionally tradable pollution permits. Moreover, since permits generate income, negotiations to divide the initial allocation of permits across countries can take the place of explicit international side payments. Alternatively, the permits need not be tradable, but since efficiency requires that their price be equalized, they must be allocated across countries in a manner that is consistent with factor-price equalization. In this case, explicit international transfer payments may be required to support some points on the Pareto frontier.

In practice, large changes in pollution may not be politically feasible. Instead, international agreements often require only small reductions in the target variable. In our model, it is easy to show that equiproportionate reductions in pollution by all countries will be Pareto-improving as long as global pollution exceeds the optimum, and that repeated application of the equiproportionate reduction rule will eventually implement a point on the Pareto frontier. In a more general model, the path to the Pareto frontier may not be so simple. But the main point remains: application of standard results from public finance implies that either radical or gradual multilateral reductions in pollution, perhaps combined with international transfers of income, can achieve a first-best allocation.

### B. Regional Reforms

In reality, any multilateral agreement requiring pollution reductions by *all* countries may be difficult to achieve. Some pollution agreements, such as the Montreal protocol, require pollution reductions by only the major polluting countries. To examine the effect of these limited agreements, suppose all countries in the North agree to reduce their pollution by the same small amount while the South commits to freezing its pollution at current levels. For simplicity, we focus on the FPE case.

First consider the effect on the welfare of a typical Northern country whose indirect utility is given by (4). Using the zero-profit conditions and (2) we have  $p(z) = c(z) = \kappa(z)\rho^{\alpha(z)w}$ , and using (7) we have an ex-

<sup>17</sup>Note that the optimal level of global pollution is independent of any distributional weights on country utilities. This follows from our assumption that pollution is strongly separable from consumption in the (homothetic over goods) utility function.

pression for income. Substituting these into (4) and rearranging, we obtain the following expression for Northern country  $i$ 's indirect utility:

$$(25) \quad V^i = K + \ln(L + \rho E) - \bar{\theta} \ln(\rho) - \beta(E^w)^\gamma / \gamma$$

where  $K$  is a constant. Totally differentiating, and noting that each individual country  $i$  has chosen its pollution level so that  $dV^i / dE_i = 0$ , yields

$$(26) \quad dV^i = \left[ \frac{\rho E}{L + \rho E} - \bar{\theta} \right] \hat{\rho} - \beta(E^w)^{\gamma-1} \sum_{j \neq i} dE_j.$$

To simplify, let  $M = E^w / (n + n^*) - E$  denote a Northern country's net imports of embodied pollution services in the FPE equilibrium. Then, after some manipulation, we obtain:<sup>18</sup>

$$(27) \quad dV^i = \frac{\rho E}{L + \rho E} \left[ \frac{nM}{E^w} - (n-1) \right] \hat{E}.$$

As (27) illustrates, a cut in pollution by the North has two effects on Northern welfare. First, since world pollution is reduced, the relative price of pollution permits rises ( $\hat{\rho} > 0$ ). Since each Northern country is a net importer of pollution services ( $M > 0$ ), this worsens Northern countries' terms of trade. Although no individual country perceives a terms-of-trade effect from cutting

its own pollution, when the coalition of all Northern countries cuts pollution, the terms-of-trade effect is multiplied  $n$ -fold and is therefore significant.

If there were only one Northern country ( $n = 1$ ), then the terms-of-trade deterioration would be the only effect of a unilateral pollution cut,<sup>19</sup> and that country would have an incentive to *increase* its level of pollution in order to improve its terms of trade. With  $n$  countries, however, each country benefits from the reduction in pollution by the other pollution-cutting countries. This is the second term in (27), and it provides a counterbalance to the terms-of-trade effect. To determine the net effect, substitute for  $M$  in (27). Northern countries gain from a cut in Northern pollution provided that

$$\left[ \frac{n}{n + n^*} - (n-1) \right] E^w < nE$$

which is true for  $n \geq 2$ . Once there are at least two Northern countries, the benefits of partially correcting the international pollution externality more than offset the terms-of-trade deterioration, and the North has a collective incentive to cut its pollution.

Let us now consider the effects of the North's cut in pollution on the South. Since Southern countries are net exporters of pollution services, they stand to reap a terms-of-trade gain as the relative price of pollution-intensive goods rises. Moreover, the South benefits from a cleaner environment. Hence, the South must gain from a cut in pollution by the North.

For similar reasons, a small cut in pollution by a coalition of all the Southern countries must also benefit the South: their terms of trade improve, and each Southern country benefits from the pollution cuts carried out by the other Southern countries. The North also gains from a pollution reduction by the South, despite a terms-of-trade deterioration. Totally differentiating (25), and

<sup>18</sup>Since  $I = I^*$  in the FPE equilibrium, we have  $(L^w + \rho E^w) = (n + n^*)(L + \rho E)$ . Combining this with (15) yields  $\bar{\theta} = \rho E^w / [(n + n^*)(L + \rho E)]$ . Substituting this into (26), using (17) to eliminate  $E^w$ , and noting that  $dE_j = dE$  for all Northern  $j$ , and  $dE_j = 0$  for Southern  $j$ , yields

$$dV^i = \frac{\rho}{L + \rho E} [-M\hat{\rho} - (n-1)dE].$$

Finally, noting from (15) that  $\hat{\rho} = -\hat{E}^w = -(nE/E^w)\hat{E}$ , we obtain (27).

<sup>19</sup>Since we are starting at a Nash equilibrium, where each country sets its pollution level optimally, there is no first-order benefit to a country from its own pollution reduction.

noting from (16) that  $\hat{p} = -\hat{E}^w$  (where  $\hat{E}^w$  is the change in world pollution due to the South's cut), the effect on a typical Northern consumer in country  $i$  is

$$dV^i = \left[ -\frac{\rho E}{L + \rho E} + \bar{\theta} - \beta(E^w)^\gamma \right] \hat{E}^w.$$

As long as world pollution is above the global optimum (i.e., as long as  $E^w > [\bar{\theta}/\beta]^{1/\gamma} = \bar{E}^w$ ), Northerners must gain from a fall in Southern pollution.

These results have several interesting implications for policy. First, since one region's reduction in pollution always benefits the other, each region has an incentive to offer a cash payment to the other in return for a reduction in pollution; however, net exporters of pollution services have a stronger incentive to do this. Second, a net exporter of pollution services stands to gain from its own region's cut in pollution. This means that selfish interests of pollution-intensive countries need not necessarily be in conflict with global environmental quality. Finally, the use of pollution policy by a coalition of countries to improve its terms of trade can be Pareto improving in some cases. If the pollution-intensive countries tighten their pollution regulations, they benefit through improved terms of trade, and their trading partners benefit from improved environmental quality.

It is, however, important to keep in mind that these results require that those countries not cutting pollution must commit to freezing pollution at its current level. Moreover, each country would prefer to be in the group subject to the freeze rather than in the group actually reducing emissions. Hence while the cuts are "unilateral," a multilateral treaty must be in force to restrict opportunistic behavior.

## VI. Transfers

Because global pollution levels are inefficient at the Nash equilibrium, coalitions of countries have incentives to pay their trading partners to reduce pollution. Therefore a transfer tied to pollution reduction can

lead to a Pareto improvement. In this section, we consider the effects of *untied* transfers. If there is no externality, then in a standard two-country trade model with identical homothetic tastes, a transfer leaves world prices unaffected and must harm the donor country. This result requires that, on impact, the transfer not directly affect the supply side of the model. In our case, however, the supply side of the model is affected, since pollution supplies respond to income changes. Despite this complication, we will show that a transfer has no real effects even if tastes are neither identical nor homothetic.

We consider only the FPE case. Let labor be the numeraire, and suppose a Northern country gives a transfer  $T$  to a Southern country.<sup>20</sup> Each country chooses its pollution level based on (6), where income is interpreted as being net of the transfer. Using a derivation similar to that which led to (8), the pollution supply of country  $i$  is given by

$$(28) \quad E_i = \frac{\rho - \beta(E^w)^{\gamma-1}(L_i + T_i)}{\rho\beta(E^w)^{\gamma-1}}$$

where  $T_i = -T$  for the donor,  $T_i = T$  for the recipient, and  $T_i = 0$  for other countries.

Summing over all countries, we find that world pollution supply is unaffected by the transfer.<sup>21</sup> With FPE, both countries face the same income/pollution trade-off at the margin. Consequently, one country's marginal increase in pollution exactly offsets the other's reduction.

Perhaps more surprisingly, incomes are also unaffected by the transfer. The donor issues enough new pollution permits to bring its income back to where it was prior to the transfer. Similarly, the recipient's cut in pollution reduces its net income back to

<sup>20</sup>The same analysis applies if a coalition of Northern countries gives transfers to a group of Southern countries.

<sup>21</sup>In contrast, when factor prices are not equalized by trade, one can show that a transfer from Northern to Southern countries lowers world pollution.

its pre-transfer level. From (28), we have  $\Delta E_i = -\Delta T_i / \rho$ , and since  $I_i = L_i + \rho E_i + T_i$ , we have  $\Delta I_i = 0$ .

Since global pollution and each country's income are unaffected by the transfer, goods prices are also unaffected, and there is no effect on welfare in either country. The only effect of a transfer is to change the location of pollution emissions: the donor becomes more pollution-intensive, and the recipient becomes less pollution-intensive. To summarize, we have shown the following.

**PROPOSITION 7:** *In an FPE equilibrium, an income transfer between countries (i) raises pollution in the donor country, (ii) lowers pollution in the recipient country, (iii) has no effect on global pollution, and (iv) has no effect on welfare in either country.*

These surprising results are more general than might be thought, and they are quite closely related to Warr's theorem in public finance (Peter G. Warr, 1983). Warr shows that the private provision of a public good, and the welfare levels of the providers, are unaffected by income transfers among agents. Warr's result and ours do not rely on identical or even homothetic tastes;<sup>22</sup> they do, however, require that each individual face the same trade-off between private-goods consumption and public-goods

consumption at the margin. In our context, agents (nations) contribute to a pure public bad (pollution), and each makes a positive contribution; but more importantly, each faces the same trade-off between private goods and pollution abatement in any FPE equilibrium. Consequently, income transfers have no effect on any agent's welfare.

## VII. Terms-of-Trade Effects

Up until now, we have assumed that no individual country has an incentive to use its pollution policy to improve its terms of trade. In this section, we relax this assumption and allow each country to account explicitly for terms-of-trade effects when choosing its pollution quota.

We consider only the FPE case. Each country  $i$  chooses its own pollution  $E_i$  to maximize (25), treating foreign pollution ( $E_{-i}^w \equiv E^w - E_i$ ) as given, subject to the market-clearing condition (15), which can be rewritten as

$$(29) \quad \rho \equiv \frac{\bar{\theta} L^w}{(1 - \bar{\theta})(E_{-i}^w + E_i)}$$

The first-order condition for country  $i$ 's optimal choice is

$$(30) \quad \rho + V_E^i / V_I^i - M_i(\partial \rho / \partial E_i) = 0$$

where  $M_i$  is net imports of embodied pollution services. Using (29) to solve for  $\partial \rho / \partial E_i$ , and rearranging, we can write (30) as

$$(31) \quad \rho - \beta(E^w)^{\gamma-1} I_i - \frac{\theta_i - \bar{\theta}}{E^w} I_i = 0$$

where  $I_i \equiv L_i + \rho E_i$  is national income of country  $i$ , and  $\theta_i \equiv \rho E_i / I_i$  is the share of pollution-permit income in country  $i$ 's national income (recall that  $\bar{\theta}$  is the share of pollution charges in world income). Equation (31) differs from (6) only by the presence of the final term, which represents the terms-of-trade effect. Taking account of terms-of-trade effects tends to increase the marginal benefit of polluting for the North

<sup>22</sup>The following argument demonstrates that we do not require homotheticity or identical preferences. See also the proof of Warr's result in Theodore C. Bergstrom et al. (1986). With FPE and constant returns to scale, consumers can be thought of as purchasing embodied factor services (see footnote 11), and therefore the utility of a donor can be written as  $V(\rho, I_0 + \rho E^w, E^w)$ , where  $I_0 = L - T - \rho E_{-i}$ ,  $E_{-i}$  denotes foreign pollution, and where we can think of the government as choosing  $E^w$ , subject to  $E^w \geq E_{-i}$ . The first-order condition is  $\rho = -V_E / V_I \equiv \phi(\rho, I_0, E^w)$ . If the South adjusts its pollution to fully offset the transfer (i.e., if  $\Delta E^* = -\Delta T / \rho$ ), then  $\Delta I_0 = 0$ . Moreover,  $\phi(\rho, I_0, E^w)$  is unchanged. Consequently, North's optimal choice of  $E^w$  (and hence  $E_i$ ) is unchanged. Thus, if all other countries adjust their pollution to fully offset the transfer, the remaining country's optimal response is to do the same. Finally, since all real incomes and trade-offs are unaffected, the aggregate demand for pollution services is unaffected, and hence the equilibrium price  $\rho$  is also the same as before.



(a net importer of pollution services with  $\theta < \bar{\theta}$ ) and tends to reduce it for the South (a net exporter with  $\theta^* > \bar{\theta}$ ).

To find the new global pollution level, sum (31) over all countries, rearrange, and obtain (17): the level of world pollution is unaffected by the recognition of terms-of-trade effects! Moreover, using (15), we conclude that the equilibrium level of  $\rho$  is also unaffected. These two results might appear to be artifacts of our Cobb-Douglas specification, but they are not. In fact, they require only that aggregate demand and supply for pollution services be independent of the world distribution of income.

**PROPOSITION 8:** *Assume FPE, constant-returns-to-scale technologies which are identical across countries, and identical preferences which are homothetic over goods for any given level of world pollution. Consider two regimes: one where countries ignore terms-of-trade effects when choosing pollution levels, and the other where countries do take into account terms-of-trade effects. Then the equilibrium level of world pollution is the same in the two regimes.*

(See Appendix A for the proof.)

The intuition for this result is as follows. Notice from (30) that the introduction of terms-of-trade effects means that the net marginal benefit of polluting shifts up by  $M \partial \rho / \partial E$  for a pollution importer, and down by  $M^* \partial \rho / \partial E^*$  for a pollution exporter. But since these terms represent pure transfers of income, they must always sum to zero. Hence, on impact, the aggregate net marginal benefit of polluting (i.e., the aggregate "supply" of pollution) is unaffected by the introduction of terms-of-trade effects. If preferences are identical and homothetic over goods for given levels of global pollution, the ensuing income redistribution will also have no effect on the aggregate demand for pollution. Consequently, with both demand and supply unaffected, so too is world pollution.

This is quite a striking result because it tells us that global pollution levels will be unaffected if nations manipulate pollution policy to gain a terms-of-trade advantage. While this is quite surprising, it does rely

heavily on our assumption that global pollution affects all countries equally. If instead we were to assume that creating emissions within a country also leads to additional local effects, then the result would not hold. That is, like Warr's theorem, Proposition 8 relies on the purity of the public bad or good.

Even though terms-of-trade effects have no aggregate effect on pollution, country-specific levels are affected. Using  $I_i = L_i + \rho E_i$  in (31), we find

$$(32) \quad E_i = \frac{\rho E^w - L_i [\beta (E^w)^\gamma - \bar{\theta}]}{\rho [1 + \beta (E^w)^\gamma - \bar{\theta}]}$$

Using (32) and (17), the difference between Northern and Southern pollution is

$$(33) \quad E^* - E = \frac{L - L^*}{\rho} \left[ \frac{(n + n^* - 1) \bar{\theta}}{1 + (n + n^* - 1) \bar{\theta}} \right] > 0.$$

As before, Southern countries produce more pollution than Northern countries in free trade. Moreover, Propositions 2 and 3 continue to hold: the South must always gain from trade, and the North must always lose (see the Appendix). Despite these similarities, it is straightforward to show that the gap between Northern and Southern pollution is smaller in (33) than in (14). Consequently, the North does not cut its pollution with the opening of trade by as much as before, and the South increases its pollution by less. As a result, the North's free-trade income is higher, and the South's is lower, when terms-of-trade effects are not ignored.

We previously noted that South's low income gives it a strategic advantage in the pollution game since it can credibly commit to polluting more with the opening of trade. Our analysis here reveals that being a net importer of pollution services gives the North a strategic advantage in the interaction over terms-of-trade effects: the North's incentive to improve its terms of trade allows it to commit credibly to pollute more,

and this makes the South less aggressive in increasing its pollution. In terms of the graph shown in Figure 2, when terms-of-trade effects were ignored, the free-trade equilibrium was at point T; once countries actively manipulate the terms of trade, the new equilibrium point must be to the right of point T.

It is apparent that the relative strengths of these two strategic effects determine the division of the gains from trade. As mentioned earlier, the strategic advantage of a low income always dominates in our formulation, to leave the North worse off in trade. Since this result is likely to be model-specific, it is useful to examine how the strengths of the two opposing effects are determined. Since market size is an obvious determinant of the strength of terms-of-trade effects, let us consider the effects of increasing the number of countries, holding the ratio of Northern to Southern countries ( $n/n^*$ ) fixed:

**PROPOSITION 9:** *Let  $n^* = kn$ , where  $k$  is a constant. Let  $V^T$  and  $V^A$  denote Northern utility in free trade and autarky. Then  $d(V^T - V^A)/dn < 0$ , and  $d(V^{*T} - V^{*A})/dn > 0$ , when terms-of-trade effects are not ignored by countries when choosing pollution policy; when terms-of-trade effects are ignored,  $d(V^T - V^A)/dn = d(V^{*T} - V^{*A})/dn = 0$ .*

(See Appendix A for the proof.) Proposition 9 follows because the North, as a pollution importer, gains a strategic benefit as terms-of-trade effects become stronger. Terms-of-trade effects strengthen as the number of countries shrinks, and consequently, Northern losses from trade decrease. Conversely, Southern gains from trade rise with the number of countries because terms-of-trade motivations diminish in importance, and hence the strategic advantage of low income is enhanced.

A further implication of this analysis is the following.

**PROPOSITION 10:** *The North prefers a regime that allows pollution policy to be used as an instrument of trade policy, whereas the South prefers that such actions be banned.*

This proposition suggests that GATT Article XX outlawing environmental policy as disguised trade policy works in favor of lower-income nations. A regime that removes the ability of net importers of pollution services to manipulate their terms of trade via pollution policy puts them at a strategic disadvantage relative to net exporters. Such a rule strengthens the South's commitment to pollute more in free trade, and this shifts the ownership of the world's pollution services to the advantage of the South. Again, what is at issue here is the division of the right to pollute across countries, since global pollution is unaffected.

A final interesting change created by terms-of-trade effects is that the normative part of the neutrality result on transfers (Proposition 7) now fails.<sup>23</sup> Consider the effect of a transfer  $T$  from a Northern country to a Southern country. It is straightforward to show that, as before, the transfer does not affect the level of world pollution. The welfare effects, however, are different. In the large-country case, we had  $dE/dT = 1/\rho$ , and hence the North's real income was unaffected by the transfer (since  $dI/dT = \rho dE/dT - 1 = 0$ ). In the present case, we have [differentiating (31), and noting that  $\rho$  and  $E^w$  stay constant]:

$$\frac{dE}{dT} = \frac{1}{\rho} - \left[ \frac{I}{\rho(n+n^*-1)\bar{\theta} + \theta} \right] \frac{d(\theta - \bar{\theta})}{dT}$$

$$< \frac{1}{\rho}.$$

Once again, North's pollution response is dampened by its recognition of terms-of-trade effects. Moreover, since  $dE < dT/\rho$ , the North must lose from a transfer to the South. The intuition for this result is evi-

<sup>23</sup> Many other authors have noted that Warr's result relies on each agent valuing his or her contribution to the public good only so far as it contributes to the aggregate quantity of the public good. Once terms-of-trade effects are allowed, this requirement is no longer met.

dent once we recall that the incentive to exploit terms-of-trade effects increases in the relative difference between countries. Since income is the only fundamental difference between countries, an income-disparity-reducing transfer from the North to the South tends to reduce the motive to use pollution to manipulate the terms of trade. [In terms of equation (31), the absolute value of  $\theta - \bar{\theta}$  falls with the transfer.] This reduces the North's incentive to raise its pollution level to compensate for the income-reducing effects of the transfer, and similarly dampens the South's pollution reduction.

In summary, the analysis of strategic trade-policy motives for pollution policy has allowed us to generate several new and interesting results. In particular it has highlighted the strategic advantage gained by a net importer of pollution services and has shown that the key qualitative implications of our model are not sensitive to the recognition of terms-of-trade effects.<sup>24</sup> Moreover, substituting (17) into (31), we see that, as  $n + n^*$  gets large, the terms-of-trade effect,  $[\theta_i - \bar{\theta}]/E^w$ , approaches zero, while the marginal disutility of increased pollution,  $\beta(E^w)^{\gamma-1}$ , gets large.<sup>25</sup> Thus, as  $n + n^*$  gets large, the model of this section converges to our earlier specification.

<sup>24</sup> Moreover, as before, the North would prefer to commit to autarky pollution levels prior to trade, whereas the South would not (Proposition 4). The effects of pollution reform in Section V are only slightly different since each country has internalized its own terms-of-trade effect. If  $n = n^* = 1$ , no country has an incentive to make a unilateral reduction, since countries are initially at a Nash equilibrium. However, when there is more than one country of each type, the effects of pollution reduction by a coalition of countries are essentially the same: there is no first-order benefit or cost from the terms-of-trade effects of one's own reduction, but as before, each country in the coalition is affected by the terms-of-trade consequences of pollution reduction by all other members of the coalition, and also by the environmental benefits.

<sup>25</sup> The terms-of-trade effect  $[\theta_i - \bar{\theta}]/E^w$  approaches zero as  $n$  approaches infinity because  $E^w$  is increasing in  $n + n^*$ , and  $0 \leq \theta_i \leq 1$ . Using (17) in (31), the marginal disutility of increased pollution is then  $\beta[(n + n^*)\bar{\theta}/\beta]^{\gamma-1}/\gamma$ . This increases with  $n + n^*$  since  $\gamma \geq 1$ .

## VIII. Conclusion

This paper has examined the effects of trade and environmental policy on trade flows, pollution levels, and welfare. To focus on income effects, we have eliminated all motives for trade except those arising from income-induced differences in attitudes toward the environment. In addition we have modeled global pollution as a pure public bad where a country's physical size, population density, or weather pattern has no bearing on its exposure to global pollution. A resolution of the debate over the effects of trade on the environment must of course examine the interaction among all of the many motives for trade and must consider how local and global pollution interact with each country's physical environment to generate the true impact of pollution. Nevertheless, while our model is very simple and stylized, we think it raises several interesting issues worthy of future examination.

First, we find that the pre-trade world distribution of income determines how trade will affect the environment. If the world distribution of income is highly skewed, then free trade harms the global environment; but if countries have relatively similar incomes, then free trade has no adverse effect on the environment. Second, we find that, because lower-income countries have a strategic advantage in setting pollution levels in a free-trade regime, they have an incentive to delay international pollution negotiations until after multilateral trade liberalization has been achieved. Third, we find that reductions in pollution by a coalition of countries may be Pareto improving, and that income transfers tied directly to pollution reduction can be welfare-enhancing. Untied transfers, however, may have no effect on global pollution levels, on prices, and most surprisingly, on either country's welfare. Finally, we find that many of these results continue to hold when countries use pollution policy to manipulate their terms of trade. However, terms-of-trade motivations for pollution policy do lessen the strategic advantage of lower-income countries.

Overall, our results underline the importance of endogenizing pollution policy within

a general-equilibrium framework. While a complete resolution of the debate over the effects of trade on the environment must await further study and more general models, we have shown that income effects created by income transfers or by trade in goods or pollution permits have important and often surprising effects on pollution, trade flows, and welfare levels. Competitive trade theory is replete with examples of surprising results created by general-equilibrium income effects. Our contribution has been to show that these same income effects may also play a large role in determining how international trade affects the global environment.

APPENDIX A: PROOFS OF PROPOSITIONS

PROOF OF PROPOSITION 3:

Denote free trade variables with T and autarky variables with A. Then using (4), and the fact that  $E^w$  is not affected by trade, we have

$$(A1) \quad V^T - V^A = \int_0^1 b(z) \ln \left[ \frac{I^T / p^T(z)}{I^A / p^A(z)} \right] dz$$

$$= \ln \left( \frac{L + \rho^T E^T}{L + \rho^A E^A} \right) \left( \frac{\rho^A}{\rho^T} \right)^{\bar{\theta}}$$

Derivation of (A1) also uses (7) and the fact that  $p(z) = c(z) = \kappa(z) \rho^{\alpha(z)} w$ , where  $\kappa(z)$  is an industry-specific constant. Let  $s \equiv \bar{\theta} / (1 - \bar{\theta})$ . Then from (10) and (16), we have

$$(A2) \quad \rho^A E^A = sL$$

$$\rho^T E^w = sL^w.$$

Dividing these expressions and noting that  $E^w = (n + n^*)E^A$  [from (17) and (12)], we obtain

$$(A3) \quad \frac{\rho^A}{\rho^T} = \frac{(n + n^*)L}{L^w}.$$

Inverting (8), evaluating at free trade, and

rearranging yields

$$(A4) \quad E^T = \frac{E^w}{\beta(E^w)^\gamma} - \frac{L}{\rho^T}.$$

Hence using (17), (A2), and (A4), we have

$$(A5) \quad \rho^T E^T + L = sL^w / (n + n^*) \bar{\theta}.$$

Now substitute (A5), (A2), and (A3) into (A1), and noting that  $\bar{\theta}(1 + s) = s$ , simplify to obtain

$$(A6) \quad V^T - V^A = \ln \left( \frac{L^w}{(n + n^*)L} \right)^{1 - \bar{\theta}} < 0$$

since  $L^w = n^*L^* + nL < (n + n^*)L$ . Similarly,  $V^{T^*} - V^{A^*} > 0$  since  $(n + n^*)L^* < L^w$ .

PROOF OF PROPOSITION 5:

Use (6) to eliminate permit prices from (23) and (24), to obtain:

$$(A7) \quad E^N (E^N + E^S)^{\gamma - 1} = \frac{n\theta(\bar{z})}{\beta\varphi(\bar{z})}$$

$$E^S (E^N + E^S)^{\gamma - 1} = \frac{n^*\theta^*(\bar{z})}{\beta\varphi^*(\bar{z})}.$$

Dividing yields  $E^* = E^S / n^* > E^N / n = E$  in trade, that is,<sup>26</sup>

$$(A8) \quad \frac{E^*}{E} = \frac{\theta^*(\bar{z}) / \varphi^*(\bar{z})}{\theta(\bar{z}) / \varphi(\bar{z})} > 1.$$

<sup>26</sup>To confirm the inequality, note that because  $\alpha$  is increasing in  $z$ , we have

$$\theta^*(\bar{z}) > \int_{\bar{z}}^1 \alpha(\bar{z})b(z) dz = \alpha(\bar{z})\varphi^*(\bar{z})$$

$$\theta(\bar{z}) < \int_0^{\bar{z}} \alpha(\bar{z})b(z) dz = \alpha(\bar{z})\varphi(\bar{z}).$$

Using these inequalities in (A8) yields the result.

World pollution is determined by added the expressions in (A7) and solving

$$(A9) \quad E^N + E^S = \left( \frac{n^*\theta^*(\bar{z})/\varphi^*(\bar{z}) + n\theta(\bar{z})/\varphi(\bar{z})}{\beta} \right)^{1/\gamma}$$

Subtract (13) from (A9) to obtain

$$E^N + E^S - E^{aw} = \left( \frac{n^*\theta^*(\bar{z})/\varphi^*(\bar{z}) + n\theta(\bar{z})/\varphi(\bar{z})}{\beta} \right)^{1/\gamma} - \left( \frac{(n+n^*)\bar{\theta}}{\beta} \right)^{1/\gamma} > 0.$$

The result follows since the first term is increasing in  $z$  and equals the second term for  $\varphi = n/(n+n^*)$ ; but  $\varphi > n/(n+n^*)$  since  $I > I^*$  in the non-FPE equilibrium.

#### PROOF OF PROPOSITION 8:

By constant returns to scale and FPE, the utility function can be written as  $V(\rho, I^i, E^w)$ , using an argument similar to that in footnote 12. By homotheticity,  $V^i = \psi(\rho, E^w)I^i$ , for some function  $\psi$ . Using Roy's identity, the aggregate demand for pollution services is

$$(A10) \quad E^w = - \sum_i (\psi_\rho / \psi) I^i = -I^w (\psi_\rho / \psi) = -(L^w + \rho E^w) (\psi_\rho / \psi).$$

The first-order condition for country  $i$ 's supply of pollution is

$$(A11) \quad -M^i (\partial \rho / \partial E^i) + \rho + (\psi_E / \psi) I^i = 0$$

where  $M^i$  is  $i$ 's net imports of pollution services. Summing over  $i$  (noting that  $\sum_i M^i = 0$  and that, with FPE,  $\partial \rho / \partial E^i = \partial \rho / \partial E^j \forall i, j$ ) yields:

$$(A12) \quad (n+n^*)\rho + (\psi_E / \psi)(L^w + \rho E^w) = 0.$$

The level of  $\rho$  and  $E^w$  are determined by (A10) and (A12). If terms-of-trade effects are ignored, the term  $-M^i(\partial \rho / \partial E^i)$  drops out of (A11), but this has no effect on (A12) or (A10). Hence the same equations (A10) and (A12) determine  $E^w$  in each regime.

#### PROOF OF PROPOSITION 9:

From the proof of Proposition 3, we have  $V^T - V^A = \ln(H)$ , where

$$H \equiv \left( \frac{L + \rho^T E^T}{L + \rho^A E^A} \right) \left( \frac{\rho^A}{\rho^T} \right)^{\bar{\theta}} = \left[ \frac{L + s(nL + n^*L^*)}{L + s(n + n^*)L} \right] \left[ \frac{(n + n^*)L}{nL + n^*L^*} \right]^{s/(1+s)}$$

using an argument similar to that in the proof of Proposition 3, but using (32) instead of (A4). Hence, letting  $n^* = kn$ , we now have  $d(V^T - V^A)/dn = d(\ln H)/dn = k_1(L^* - L) < 0$ , where  $k_1 > 0$ . For the South, the roles of  $L^*$  and  $L$  are reversed, and we have  $d(V^{*T} - V^{*A})/dn > 0$ . For the case in which terms-of-trade effects are ignored, the result follows from (A6), which is independent of  $n$ , once  $n/n^*$  is held constant.

**PROPOSITION A1:** *The South gains from trade, and the North loses from trade, under the assumptions of Section VII (i.e., FPE and that countries take into account terms-of-trade effects when setting pollution quotas).*

#### PROOF:

For the South, the argument behind Proposition 2 still works. For the North, referring to the proof of Proposition 9, note that  $H = 1$  for  $L = L^*$ , and  $H$  is increasing in  $L^*$ . Hence  $H < 1$  for  $L^* < L$ , and therefore  $V^T - V^A = \ln(H) < 0$  for  $L^* < L$ .

#### APPENDIX B: CONDITIONS FOR FACTOR-PRICE EQUALIZATION

To determine the boundary between the FPE and non-FPE cases, start in an equilibrium where factor prices differ, and consider the effects of increasing  $L^*/L$ . This

increases  $B(z)$  for all  $z$ , but does not affect  $T(z)$ . As  $L^*/L$  rises, there is a point at which  $B(z)$  and  $T(z)$  intersect at  $z = \hat{z}$ . At this point,  $\omega = 1$ , and factor prices just equalize. Define

$$\delta \equiv \frac{\int_0^{\hat{z}} b(z)[1 - \alpha(z)] dz}{\int_{\hat{z}}^1 b(z)[1 - \alpha(z)] dz}.$$

Using (22) and (20), we have  $B(\hat{z}) = T(\hat{z})$  when  $n^*L^*\delta/nL = 1$ , since by definition,  $n^*\varphi(\hat{z}) = n\varphi^*(\hat{z})$ . Thus we have a non-FPE equilibrium for  $nL/n^*L^* > \delta$ . By symmetry, if we reverse the roles of North and South, we will also have a non-FPE equilibrium if  $n^*L^*/nL > \delta$ , or if  $nL/n^*L^* < 1/\delta$ . For intermediate values of  $nL/n^*L^*$ , factor prices are equalized.

**PROPOSITION B1:** *Factor prices are equalized if and only if  $1/\delta \leq nL/n^*L^* \leq \delta$ . If  $nL/n^*L^* > \delta$ , then  $\tau > \tau^*$ , and the North specializes in relatively clean goods, while the South specializes in pollution-intensive goods. If  $nL/n^*L^* < 1/\delta$ , then  $\tau < \tau^*$ , and the North specializes in pollution-intensive goods, while the South specializes in clean goods.*

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