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Trade and the Environment: A Partial Synthesis

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There is an emerging consensus in the environmentalist community opposing free trade. While some economists view this as simply another outlet for protectionism, recent work has begun to move beyond the rhetoric to probe more deeply into the theoretical and empirical relationships between international trade and environmental quality.

The purpose of the present paper is twofold. We first integrate some of the existing literature by using the simple concepts of general equilibrium pollution supply and demand. Our survey of the trade and environment literature is more analytical, but admittedly less comprehensive, than those of Dean; and Beghin, Roland-Holst, and van der Mensbrugghe. In conducting the survey we find that under a wide variety of assumptions about the institutional response to pollution, the theoretical models predict that (all else equal), pollution-intensive industries tend to migrate to countries with weaker pollution regulations.

Because the empirical work on this point is at best inconclusive, in the second section of the paper we develop a simple new model to examine whether the dirty industry migration hypothesis holds in a world in which pollution is a by-product of consumption. Most existing theoretical work has focused on production-generated pollution despite the empirical importance of consumption-generated pollution. Examining consumption-generated pollution is especially important in a trading context because although pollution-intensive production can migrate to countries with weaker environmental standards, rich countries cannot so easily escape the environmental consequences of their own consumption. Nevertheless, in our model of consumption-generated pollution we find that trade shifts pollution-intensive consumption to the low-income, low-regulation country. Consequently, the dirty industry migration hypothesis (broadly defined) appears to be robust to generalizations that include consumption-generated pollution.

Production-Generated Pollution: A Survey

We construct a simple model to illustrate how different assumptions about tastes, technologies, or institutions are reflected in either the general equilibrium demand or supply for pollution. As a result, we are able to map differences in assumptions across the existing literature into differences in demand or supply functions and hence differences in the results obtained. To keep things simple, we limit ourselves to a class of models in which all pollution is generated by production, pollution harms consumers but does not affect production possibilities, and pollution has only localized effects. Even within this limited class of models, trade may have very different effects on the environment depending upon our other assumptions.

The supply of pollution is the amount of pollution a country is willing to allow. As we will show, the amount of pollution authorities are willing to allow depends not only on individual preferences, but also on the political process that transforms preferences into policies, and on the institutional framework that determines the types of policies adopted. We begin with an ideal world, in which government policy

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costlessly reflects the preferences of a representative agent. For concreteness, let our agent's indirect utility be given by $V(\mathbf{p}, I, Z) = \ln[I/h(\mathbf{p})] - \beta Z$, where Z is pollution, β is a positive constant, $\mathbf{p}$ is a goods price vector, I is income, and $h(\mathbf{p})$ is a price index.

Income is determined by a GNP function $G(\mathbf{p}, \mathbf{v}, Z)$, where $\mathbf{v}$ is the endowment vector of primary factors and Z is the economy's supply of the "input" pollution (for more details, see Copeland and Taylor 1994). Suppose for simplicity that the regulator perceives no market power, so that the effect of pollution on the terms of trade is ignored. Then to maximize the representative agent's utility, the regulator chooses a pollution level so that its shadow price τ (the optimal pollution tax) is equal to its marginal damage. Thus

$$(1) \qquad \tau = -V_z/V_I = \beta I.$$

To construct the pollution supply curve, note that if labor is the only primary factor of production then income is simply $I = wL + \tau Z$. Substituting for I in equation (1) yields

$$(2) \qquad \rho = \frac{\beta L}{1 - \beta Z}$$

where $\rho \equiv \tau/w$. The inverse supply curve for pollution is upward sloping because consumers are willing to tolerate increased pollution if they are compensated with the income derived from higher pollution charges. With our very simple utility function, supply can be written simply as a monotonic increasing function of ρ. More generally though, the supply curve for pollution shares many of the properties of a general equilibrium labor supply curve, and hence may be backward bending if the income elasticity of the demand for environmental quality is sufficiently strong.

The demand for pollution is derived from producer behavior. Suppose that goods vary in pollution intensity and that firms have access to abatement technologies so that the pollution intensity of a given good is variable. Although pollution is a joint output, it is useful to think of it as an intermediate input into goods production (see Copeland and Taylor 1994). Then an increase in the pollution tax tends to reduce pollution demand via two channels: firms substitute toward cleaner techniques of production and consumers substitute away from pollution-intensive goods as their price rises relative to that for cleaner goods. Consequently, the demand for pollution is decreasing in the level of the pollution tax. Under suitable restrictions on technology, pollution demand can be written as a decreasing function of ρ. The equilibrium level of pollution is then simply determined by the intersection of demand and supply (see figure 1).

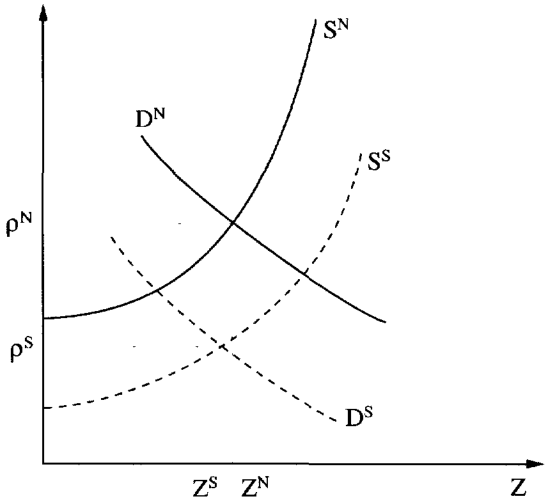

Figure 1. Pollution supply and demand

Let us extend this simple framework to two countries (North and South) that differ only in their endowment of human capital. Under these assumptions we have a simplified version of Copeland and Taylor (1994). If North has a greater level of human capital, then the (derived) demand for pollution in North is greater than in South, since North has a greater income. As well, since North's income is higher, its willingness to supply pollution is less than South's. Consequently, North's supply curve must lie to the left of South's, and in autarky we can conclude that $\rho^N > \rho^S$.

The autarky level of pollution in North could be more than, less than, or equal to that in South depending on the assumptions made concerning substitution possibilities in both production and consumption. With the elasticity of substitution in both consumption and production equal to one, Copeland and Taylor (1994) show that pollution levels are independent of scalar increases in human capital or growth in factor endowments. Cronshaw and Requate employ a similar model and show that pollution may rise or fall with growth, depending on the structure of preferences and technology. As well, Lopez shows that if preferences over goods and environmental quality are homothetic, then pollution rises with growth. When preferences with respect to pollution are not homothetic, he finds that pollution may fall with growth if the elasticity of substitution between pollution and nonpollution inputs and the income elasticity of the demand for environmental quality are both large. In this last case, pollution supply shifts in by more than demand rises.

Regardless of how growth affects autarky pollution levels, it is clear that pollution regulations are tougher in the higher income North, and this creates an incentive to trade. South's weaker pollution regulations give it a comparative advantage in pollution-intensive goods. With trade, North begins to import pollution-intensive goods from South, and the demand for pollution in South rises, pushing up ρ^S. Conversely, as South begins to import cleaner goods from North, pollution demand falls in North, and ρ^N falls. Hence, in our trading equilibrium, this model predicts that South should export relatively dirty goods and import relatively clean goods.

With our simple framework in hand, we can now consider various modifications that have been adopted in the literature. While the assumptions required for treating pollution as an input to production are quite general, the assumptions adopted to generate our pollution supply curve are quite specific. Not surprisingly, much of the literature can be categorized according to assumptions regarding pollution supply.

First, however, one interesting alternative interpretation of the demand side of our model should be noted. The model described above is similar to that of Rauscher (1991a). Rauscher allows for only one consumption good (and hence no trade), but capital is mobile and responds to international differences in environmental regulation. (He also allows for transboundary pollution, which we shall ignore for simplicity.) The supply of pollution is essentially the same as in equation (1), where now the primary factor L is interpreted as capital. Because it is richly endowed with capital, North has a high demand for pollution and a relatively high pollution tax in autarky. Whereas differences across countries in Copeland and Taylor (1994) provided a basis for trade, the differences in Rauscher's model create incentives for capital mobility. When capital flows from North to South, the derived demand for pollution falls in North and increases in South. The incidence of world pollution changes in the same way as predicted above.

Turning to the supply side, it is important to note that here we have assumed an efficient political mechanism that translates the demand for improved environmental quality into new regulations that reduce the supply of pollution. If pollution supply does not respond to reflect the interests of the community, then the consequences of trade liberalization may be significantly different. This issue is quite important given that recent empirical work confirms the importance of political variables in determining pollution levels (Grossman and Krueger, Congleton).

Several authors have considered the effects of a pollution supply process that does not reflect community preferences. Chichilnisky assumes that North and South are identical, except that North has the institutions to optimally control externalities, while South has no such institutions. (She studies common property resources, but her analysis can also apply to pollution.) In terms of figure 1, we can think of North as having a supply curve S^N, with an autarky relative pollution tax of ρ^N, while South's pollution supply curve is perfectly elastic at $\rho^S = 0$. South's institutional failure generates a comparative advantage in pollution-intensive goods and, as before, trade creates a pollution haven in South as pollution-intensive industries relocate there. North's gains from trade are higher than before, as North obtains free access to South's environmental services via trade. South's gains from trade are less, and indeed the utility loss from increased pollution may more than offset the increased consumption due to trade.

In other work, authors do not assume the absence of regulatory institutions but merely assume that they are inflexible. For example, Pethig considers two identical countries with different exogenous pollution taxes. In terms of figure 1, we might think of North and South as having perfectly elastic pollution supply curves at ρ^N and ρ^S, respectively. Once again, trade creates a pollution haven as pollution-intensive industry migrates to South. As shown by Siebert, the welfare effects of trade liberalization in this case depend on whether pollution taxes were initially set too high or too low. If they are too low, trade can benefit North by encouraging dirty firms to leave the country. But at the same time, South can lose from the increased pollution.

Moreover, when institutions are inflexible, the type of inflexibility matters. Copeland has pointed out that if pollution regulations are exogenous, then the welfare effects of trade liberalization are sensitive to the type of instrument used to control pollution. To illustrate, suppose that pollution regulations are exogenous as in Pethig, but suppose that each country uses an aggregate pollution quota (this type of model was analyzed by Rauscher 1991b). In this case, each country's pollution supply curve is vertical. Suppose now that two countries have identical primary factor endowments and hence have identical pollution demands. If country A's quota is more restrictive than B's, then we have $\rho^A > \rho^B$ (where now τ is the price of a pollution permit). As before, differences in pollution policies generate an incentive to trade, and pollution-intensive industries move to the country with weaker regulations. In this case, however, trade must be welfare-improving for both countries because aggregate pollution levels in each country are unchanged by assumption. In fact, in this case, as Rauscher (1991b) points out, the model is simply a two-factor Heckscher-Ohlin model with labor and pollution permits as the exogenous factors. Trade serves to lessen or eliminate the disparity between factor prices and increases economic efficiency.

In summary, under a wide variety of assumptions about the institutional response to pollution, these models predict that (all else equal) pollution-intensive industries tend to migrate to countries with weaker pollution regulations. Weaker regulations in turn can follow from differences across countries in tastes or income levels that affect the derived demand for pollution, or can instead be due to supply-side differences in institutions, in the flexibility of institutions, or in the instrument chosen by institutions to control pollution. Moreover, even if we take as given the migration of dirty industries, the welfare effects of this migration are very sensitive to the institutional response. Welfare rises with trade if externalities are fully internalized or if pollution levels are constrained by quotas. If instead pollution regulations are nonexistent or rigid, and if they do not fully constrain the aggregate level of pollution, then welfare can fall with trade. Also, once transboundary pollution and strategic issues are introduced, there is no presumption that trade increases welfare (Copeland and Taylor, forthcoming), even when governments are efficient in the sense of maximizing the welfare of a representative consumer.

The empirical evidence concerning "dirty industry migration" is inconclusive. Lucas, Wheeler, and Hettige found that although many high-income countries are experiencing a fall in the pollution intensity of national product, this appears to be due to a change in the composition of output rather than to a movement toward cleaner production methods. Low and Yeats found that the export share of pollution-intensive goods has been increasing for many low-income countries. And Lee and Roland-Holst found that Indonesia exports pollution-intensive goods to Japan in exchange for relatively clean goods. On the other hand, because attempts to measure the cost of complying with environmental standards have yielded low estimates (less than 3% of total production cost), Tobey found that the stringency of environmental regulations was not a significant factor in explaining the pattern of trade.

There clearly is a need for much better data on pollution intensities and for more empirical research in this area. Moreover, there is much scope for generalizing the theoretical work. Perhaps the least appealing abstraction made in much of this literature is that pollution is only created as a by-product of production. In the next section we remedy this imbalance by developing a simple model in which all pollution is generated by consumption. As well as providing a simple framework that could be extended in various ways, we are able to examine whether the dirty industry migration hypothesis (broadly defined) continues to hold in models in which pollution arises only from consumption.

Consumption-Generated Pollution: A Model

Suppose there are two goods, X and Y; two countries, North and South; and two primary factors of production, capital and labor. Good X is a dirty good that generates α units of pollution per unit consumed. Good Y is clean. Pollution generated by the consumption of X stays within the country of consumption. South's endowment is $\mathbf{v} = (K, L)$. North's endowment is just a scalar multiple of South's; that is, $\lambda^N \mathbf{v}$, where $\lambda^N > 1$. (It is useful to write South's endowment as $\lambda^s \mathbf{v}$, with $\lambda^s = 1$.) Both goods are produced with constant returns to scale and technologies are identical across countries.

Let $G(p, 1, \lambda^i \mathbf{v})$ be the GNP function of country i. The relative producer price of good Y is p, and by making good X the *numéraire*, the producer price of good X is 1 (i.e., $p = p_y/p_x$ and $p_x = 1$). To economize on notation, we suppress the "1" in the GNP function throughout and when there is no ambiguity we suppress all the arguments. Since the GNP function is homogenous of degree 1 in factor endowments, North's GNP is $\lambda^N G(p, \mathbf{v})$ and South's is just $G(p, \mathbf{v})$.

Suppose both countries use taxes to regulate pollution optimally. Since X is the *numéraire*, the producer price of X is $p_x = 1$, but consumers pay $p_x^c = 1 + \alpha\tau$, where τ is the tax per unit of pollution generated during consumption.

The equilibrium level of pollution in autarky can again be determined by supply and demand. The government's first-order condition again requires that equation (1) hold, but now income is GNP plus pollution tax revenue: $I = G + \tau Z$. Pollution supply becomes

$$(3) \quad \frac{\tau}{G} = \frac{\beta}{1 - \beta Z}.$$

For simplicity, assume preferences are Cobb-Douglas and let the share of spending on good X be denoted by b. The demand for pollution is then just $Z = \alpha X$. By substituting for the demand for X and rearranging, we obtain the inverse demand for pollution as

$$(4) \quad \frac{\tau}{G} = \frac{b}{(1 - b)Z} - \frac{1}{\alpha(1 - b)G}.$$

Equating equations (3) and (4) implicitly solves for the level of pollution $Z = Z[G(p, \lambda'\mathbf{v})]$, with $Z'(G) > 0$. (See figure 3). Finally, using $Z(G)$ in equation (3) yields the equilibrium consumption tax function $\tau = \tau(p; \lambda)$. It is straightforward to show that the pollution tax is increasing in p and λ because GNP is increasing in p and in the scale of factor endowments.

Thus far we have solved for the level of pollution, Z, and the pollution tax, τ, as functions of the producer price p and the scale of factor endowments λ. The next step is to close the model by equating the relative demand and supply for Y/X to solve for p in autarky. By constant returns to scale, the relative supply of Y to X is increasing in their producer price ratio p. Moreover, since factor endowment ratios are identical across countries, the relative supply curve $S_{Y/X}(p)$ of Y to X is also identical across countries.

The relative demand curve follows quite simply when we are careful to distinguish between the producer price of X, $p_x = 1$, and the consumer price of X, $p_x^c = 1 + \alpha\tau$. Hence the relative demand curve for Y/X can be written as

$$(5) \quad D_{Y/X}(p, \tau) = \frac{(1 - b)I/p_y}{bI/(p_x + \tau\alpha)} = \left(\frac{1 - b}{b}\right)\left(\frac{1 + \tau\alpha}{p}\right).$$

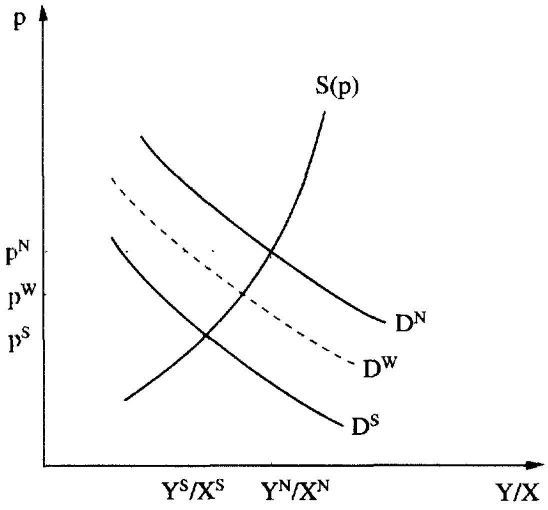

Figure 2. Relative supply and demand for goods

Goods market clearing requires the relative producer price satisfy $S_{Y/X}(p) = D_{Y/X}(p, \tau)$.

In a standard model with no pollution, $\alpha = 0$ and relative demand in equation (5) is necessarily downward sloping and identical across countries. The downward sloping relative demand intersects the upwardly sloping relative supply only once and we have a unique equilibrium. In our formulation, $\alpha > 0$ and this has two important implications. First, the slope of the relative demand curve $D_{Y/X}$ need not be negative. Second, two countries that differ only in scale will have different relative demand curves, different autarky relative producer prices, and will now have incentives to trade.

Consider first the slope of the relative demand curve. Holding τ constant, an increase in the producer price of Y leads to an increase in the consumer price of Y, which lowers the optimal ratio of Y to X consumed. All else equal, this makes our relative demand negatively sloped. However, since τ is increasing in p, the consumer price of X rises with p, and hence the consumer price ratio of Y to X rises by less than the producer price ratio. This dampens substitution away from Y, and makes the demand curve steeper than in the absence of pollution. Provided α and β are not too large, the relative demand curve will have a negative slope. We assume this is the case throughout. Next, recall that τ is also increasing in λ, the scale of factor endowments. Hence for any given p, the larger is λ, the greater is the desired ratio of Y/X in consumption and the further to the right is a country's relative demand curve. Consequently, North has a higher relative demand for Y, and with identical relative supplies we have $p^N > p^S$, as shown in figure 2. This creates an incentive to trade even though factor endowment ratios and preferences are identical.

The key point is that once the consumption externality is accounted for, preferences are nonhomothetic and income differences across countries are translated into differences in producer prices. Because environmental quality is a normal good, the pollution tax is higher in North. The higher pollution tax in turn increases the relative consumer price of the dirty good and discourages its consumption. This shifts demand toward Y in North and, with a concave production frontier, equilibrium in the market for Y requires a higher relative producer price of Y prior to trade. In addition to having different producer prices prior to trade, North and South also have different pollution levels. In figure 3, we plot equations (3) and (4) for North and South, treating p as parametric and equal to their autarky levels. Both countries share the same pollution supply curve, and North's demand for pollution lies everywhere above South's because North's GNP is larger. Consequently, prior to trade, North has a greater pollution level than South.

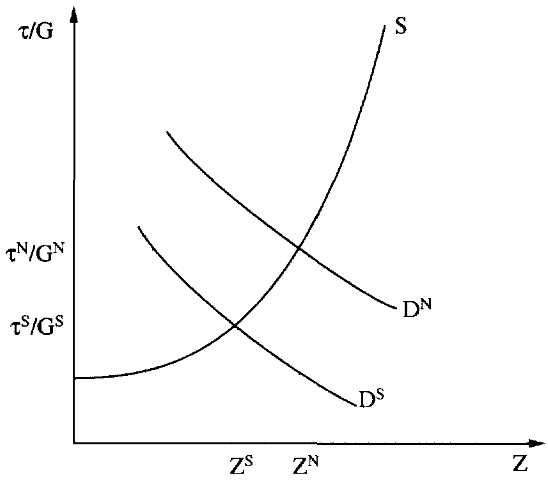

Figure 3. Consumption-generated pollution supply and demand

Now consider the effects of trade. The world's relative goods supply curve is just the (identical) relative goods supply curve of each country. World relative demand lies between the two autarky demand curves. In figure 2 we plot the relative supply and demand curves. Since $p^N > p^S$ in autarky, North imports good Y in free trade and exports good X. Moreover, we must also have $p^N > p^W > p^S$, where p^W is the equilibrium-free trade relative producer price of Y. Consequently, the producer price of Y falls in North, as consumers gain access to South's cheaper imports, and the producer price of Y rises in South. Free trade equalizes the producer price of both goods, but consumer prices still differ because pollution taxes differ across countries.

Since North has a relatively higher income, its higher pollution tax gives it a stronger demand for the relatively clean good. Free trade provides a mechanism through which supplies of the clean good are transferred to North. Conversely, South's lower pollution tax gives it a relatively stronger demand for the dirty good and it imports X from North. Not surprisingly, given these consumption shifts, it is straightforward to show that pollution in North falls with trade, while pollution in South rises with trade. South's demand for pollution rises, since the producer price of Y [and hence $G(p, \mathbf{v})$] rises with free trade. In figure 3, South's demand curve would shift to the right and the equilibrium level of pollution would also rise. At the same time, North's demand for pollution falls as the producer price of Y falls from its autarky level. Consequently, North's pollution falls. However, North still pollutes more than South because, while both face the same producer price, North's endowment is greater. This ensures that North's demand for pollution in figure 3 is to the right of South's demand.

In summary, our model predicts that in autarky, the richer North will have a greater pollution level, a relatively low producer price of the dirty good, a relatively high consumer price of the dirty good, and a relatively stiff pollution tax. Most importantly, because producer prices differ across countries, there is an incentive for these very similar economies to trade. With the advent of trade, the model predicts that the incidence of world pollution will shift away from North, even when all pollution is generated by consumption. That is, in a general sense, it confirms the dirty industry migration hypothesis. Another appealing feature of this model is that it predicts that pollution is higher in the rich country both before and after trade. This contrasts with earlier work based on production-generated pollution where pollution was higher in South than in North after trade. Trade is welfare-increasing in this model because the supply of pollution was managed by a perfectly costless and well-intentioned institutional structure. It should be apparent though that extensions to less "ideal settings" could well overturn these rather sanguine welfare results.

Conclusion

The theoretical and empirical literature on trade and the environment is still in its infancy. While some of the issues regarding trade's effect on the environment have been resolved, many other issues remain unsettled. While the dirty industry migration hypothesis appears to be supported theoretically, the empirical work is not definitive. Clearly there is a need for both more empirical work and more general theoretical models. In particular, there is still much to be done before we fully understand the interaction between trade and the environment when pollution is created as a by-product of consumption, when pollution creates stock effects that harm production possibilities in the long run, and when pollution spills across national boundaries. These and other topics are likely to keep researchers busy for many years to come.

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