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Trade, Growth, and the Environment[1]

BRIAN R. COPELAND *and* M. SCOTT TAYLOR

1. *Introduction*

For the last ten years environmentalists and the trade policy community have engaged in a heated debate over the environmental consequences of liberalized trade. The debate was originally fueled by negotiations over the North American Free Trade Agreement and the Uruguay Round of GATT negotiations, both of which occurred at a time when concerns over global warming, species extinction, and industrial pollution were rising. Recently it has been intensified by the creation of the World Trade Organization (WTO) and proposals for future rounds of trade negotiations.

The debate has often been unproductive because the parties differ greatly in their trust of market forces and typically value the environment differently. It has been hampered by the lack of a common language and also suffered from little recourse to economic theory and empirical evidence. This is perhaps not surprising, because much of the work in this area is still quite new.

The purpose of this essay is to set out what we currently know about the environmental consequences of economic growth and international trade. We critically review both theory and empirical work to answer three basic questions. What do we know about the relationship between international trade, economic growth, and the environment? How can this evidence help us evaluate ongoing policy debates in this area? Where do we go from here?

To answer these questions, we discuss both the empirical and theoretical literature with the aid of a relatively simple general equilibrium model where government policy and private sector behavior interact to determine the equilibrium level of pollution. The model is developed in section 2 of the paper and then employed in various guises throughout. Our use of a model to organize our review reflects an overarching theme of our essay: economic theory needs to play a much larger role in guiding empirical investigation, suggesting alternative hypotheses, and disciplining inferences. The vast majority of empirical work in this field has little connection to explicit theory, and we argue that this has left important policy debates, which hinge on the relative importance of various theoretical magnitudes, badly informed.

The economic literature on these issues came in two waves, with an initial surge of activity in the 1970s and a resurgence of interest stimulated by the policy debates

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of the past decade.[2] Much of the earlier literature was normative, with a focus on issues such as gains from trade and optimal trade or environmental policies.[3] A large component of recent work also focuses on policy analysis, but its most significant feature is its concern with positive issues: generating and attempting to test hypotheses about how trade or growth affects environmental outcomes. We view these latter issues as fundamental to resolving current policy debates, and so most of our essay will focus on this aspect of the literature.[4]

We begin our analysis in section 2 by examining the link between incomes per capita and environmental quality. Interest in this link arose from the pioneering work by Gene Grossman and Alan Krueger (1993) on NAFTA, which subsequently led to a burgeoning literature on what has come to be known as the environmental Kuznets curve (EKC). The environmental Kuznets curve hypothesizes an inverse-U-shaped relationship between a country's per-capita income and its level of environmental quality: increased incomes are associated with an increase in pollution in poor countries, but a decline in pollution in rich countries. This literature is important because many in the trade-policy community have argued that trade and growth may actually be good for the environment. If environmental quality is a normal good, increases in income brought about by trade or growth will both increase the demand for environmental quality and increase the ability of governments to afford costly investments in environmental protection.

[2] See, for example, William Baumol (1971), Ingo Walter (1973), James Markusen (1975), Rudiger Pethig (1976), and Horst Siebert (1977).

[3] Exceptions include Walter's (1973) empirical paper and Pethig (1976) on the pattern of trade.

[4] Other recent surveys that focus more on policy include Michael Rauscher (2001) and Alistair Ulph (1997). Hakan Nordstrom and Scott Vaughan (1999) provide a good comprehensive review of the trade and environment literature.

Our review of both the theoretical and empirical work on the EKC leads us to be skeptical about the existence of a simple and predictable relationship between pollution and per-capita income. To investigate the EKC we employ a simple pollution demand-and-supply system linking pollution levels to national characteristics (incomes, factor endowments, and technologies) and trading opportunities (comparative advantage and current trade restrictions). Much of the work on the EKC reduces this set of possible explanatory factors to essentially just one—incomes per capita—although it is not clear why we would want to impose these restrictions on empirical estimation ex ante. This concern receives some support from empirical work that finds that the shape of the estimated relationship between pollution and income is sometimes sensitive to functional form, the sample of countries or cities used, and the time period chosen.

Despite these concerns, the EKC literature has made two lasting and significant contributions. First, it raised important empirical questions about how trade and growth affect the environment, and launched a significant research agenda. Second, it has provided quite convincing evidence that there is an income effect that raises environmental quality. Moreover, there are strong indications that this income effect works because increases in the stringency of environmental regulation accompany higher per-capita incomes. Therefore an analysis of the effects of trade and growth on the environment cannot proceed without taking into account endogenous policy responses.

Unfortunately, because most of the literature has relied on simple reduced-form estimation, there is very little work that isolates this income effect from other factors, such as the scale effects of growth and capital abundance. Consequently we still know very little about when this income effect is strong enough to offset forces, such as capital accumulation or export-led expansion of polluting industries, that are associated with

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increased demands on the environment. Some evidence on this score exists, but it is limited and specific to certain commonly measured pollutants (SO_2 for example).

While the link between income growth and the environment is important, trade may alter environmental outcomes through a variety of other channels. Trade may encourage a relocation of polluting industries from countries with strict environmental policy to those with less stringent policy. These shifts may in turn increase global pollution or they may have a chilling effect on environmental policy, as countries will be reluctant to tighten environmental regulations because of concerns over international competitiveness.

To examine these additional concerns we evaluate the environmental impact of trade liberalization in section 3, starting in a small open economy setting and then moving to a world with many small economies and world price determination. Our analysis within the small open economy setting links the environmental impact of trade liberalization to the choice of policy instruments, the flexibility of policy and, most importantly, a nation's comparative advantage. At this point we find it crucial to distinguish between two different hypotheses linking pollution regulation to comparative advantage. The first is that a tightening up of pollution regulation will, at the margin, have an effect on plant location decisions and trade flows. We call this a *pollution haven effect*. This hypothesis has strong theoretical support.

The second hypothesis is that a reduction in trade barriers will lead to a shifting of pollution-intensive industry from countries with stringent regulations to countries with weaker regulations. We call this the *pollution haven hypothesis*. The theoretical support for the pollution haven hypothesis is, in contrast, quite weak, because trade theory suggests that many other factors, in addition to pollution regulation, affect trade flows. If these other factors are sufficiently strong, then it is quite possible for there to exist a pollution haven *effect*, but have the pollution haven *hypothesis* fail. This distinction has a large impact on our discussion of policy issues.

Until quite recently, there was a consensus in the empirical literature that differences in the stringency of environmental regulation have little or no effect on trade and investment flows (Adam Jaffe et al. 1995). Recent work suggests this conclusion was premature. Most of the literature prior to 1997 that investigated the stringency of environmental regulation on trade and investment flows used cross sectional data. These studies are unable to control for unobserved heterogeneity across countries or regions and typically treat pollution regulations as exogenous. If pollution policy is endogenous or there are important omitted factors, then the estimated results will be misleading. Several recent studies have addressed these issues and found evidence for the existence of a pollution haven *effect*: the stringency of pollution regulations does affect plant location and trade flows. There remains little convincing evidence, however, to support the pollution haven *hypothesis*. Instead, the available evidence suggests that other factors are more important in determining trade patterns than are differences in pollution regulations.

This is an area that still needs much more work, in part because the literature has often blurred the distinction between the pollution haven effect and the pollution haven hypothesis. This distinction is also important to our answers to two key policy questions. In section 4 we first ask whether environmental policy should be constrained by international trade law to prevent countries from using it as a substitute for trade policy. This issue lies behind much of the concern that trade liberalization might lead to a "race to the bottom" in standards as countries weaken their environmental policy in response to the competitive pressures of freer trade. The empirical evidence on the pollution haven effect is relevant to this question, because if pollution policy does affect trade and investment flows, as recent

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evidence indicates, then it is possible that weak pollution policy may be used as a loophole in trade agreements. The second key policy question is whether trade policy should be used to achieve environmental objectives either at home or abroad. The disputes at the WTO arising from the U.S. import bans on tuna from Mexico to protect dolphins and on shrimp from various countries to protect turtles are two prominent examples of this type of issue. On this issue, evidence concerning the pollution haven hypothesis is relevant because much of the concern over trade's environmental effect—either at home or abroad—disappears if the hypothesis is false.

We do not provide unequivocal answers to the questions we pose. Instead we try to report on the current state of affairs and identify the set of important but as yet unanswered questions that we need to resolve to better understand the trade, growth, and environment link.[5]

2. *Growth and the Environment*

We start with the relationship between income and the environment. This is a key aspect of the debate. The main argument for free trade is that it will raise national incomes; but if this is so, then it is important to understand how higher incomes affect environmental quality.

The empirical literature on the relationship between environmental quality and per-capita income has proliferated over the past decade, following the seminal work of Grossman and Krueger (1993). Using a panel of data on air quality from 42 countries, Grossman and Krueger found a hump-shaped relation between some measures of air quality (such as SO2 concentrations) and per-capita income: pollution at first rises and then falls with income per capita.[6] Thomas Selden and Daqing Song (1994) found a similar pattern using data on sulfur dioxide emissions. For some other pollutants (such as contaminated drinking water), Grossman and Krueger (1995) and Nemat Shafik and S. Banyopadhyay (1992) found pollution declines monotonically with income per capita; while for others (such as carbon emissions) pollution tends to rise with income per capita. The hump-shaped relation has captured most of the attention and for this reason, this line of work is known as the environmental Kuznets curve (EKC) literature, since it echoes Simon Kuznets' (1955) finding of a hump-shaped relation between inequality and per-capita income. There are now numerous papers that estimate an EKC for various measures of environmental quality, time periods, countries, etc.[7]

What is perhaps most striking about the EKC literature is the limited role that theory has played in its development. This has created difficulties in interpretation, since the basic finding is consistent with many possible explanations. For this reason, we begin by asking what theory has to say about the relation between income and pollution before moving on to the empirical work.

2.1. *A Model*

We need a model with three key features to help interpret the literature. We need at least two goods that differ in pollution intensity to allow for the possibility of differences in the composition of economic activity over

[5] One large omission from our review is any explicit discussion of renewable or nonrenewable resource use and sustainability. For many in the developing world, the status of fish stocks, aquifers, and forests are key environmental indicators, but an analysis of trade's impact on resource use would take us too far afield. For recent work on these issues, see the survey by Gardner Brown (2000), the series of case studies examining the impact of trade liberalization on resource industries available from the United Nations Environment Programme at http://www.unep.ch/etu/publications/index.htm, and the excellent book-length treatment by Ian Coxhead and Sisira Jayasuriya (2003).

[6] An earlier literature found some evidence to support a hump-shaped relationship between the intensity of metal use (consumption of a given metal per unit of GDP) and per-capita income. See Wilfred Malenbaum (1978). Note, however, that this does not imply a fall in resource use per capita after the hump is passed.

[7] See Therese Cavlovic et al. (2000) and Susmita Dasgupta et al. (2002) for recent reviews of this work.

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time or across countries. We need at least two primary factors of production to provide a simple motive for international trade that is independent of pollution regulation. And finally, we need endogenous pollution policy to examine how pollution may vary across countries with different levels of per-capita income. In what follows, we opt for simplicity rather than generality and do not attempt to be exhaustive in our coverage.[8]

We adopt a static model and focus on production-generated pollution.[9] Pollution from a given firm harms consumers but does not affect the productivity of other producers.[10] There are two goods, X and Y, each produced with a constant returns to scale technology using two primary factors, capital (K) and labor (L). Denote the price of X by p, and treat Y as the numeraire. To capture differences in pollution intensity across sectors, we assume X generates pollution during production, but Y does not pollute at all.

The production function for good Y is simply:

$$Y = H(K_y, L_y). \tag{1}$$

where H is increasing, concave, and linearly homogeneous.

Production of good X generates pollution emissions (Z). If firms do not undertake abatement, we assume each unit of output generates one unit of pollution, and that output of X is given by $F(K_x, L_x)$, where F is increasing, concave, and linearly homogeneous. We can think of F as "potential output." If abatement does occur, then for $z \leq F$, output of X is given by:

$$x = z^{\alpha}[F(K_x, L_x)]^{1-\alpha}, \tag{2}$$

where $0 < \alpha < 1$. Although pollution is a joint output, one can treat pollution (or environmental services) as an input for analytical convenience.[11] A firm can reduce pollution and maintain output constant by using more primary factors and adopting less-polluting techniques.[12]

If governments regulate pollution, we assume that firms face a price τ for each unit of emissions that they release. This price may be implemented with either an emissions tax τ or by a tradable emissions permit system, in which the government sets the total level of pollution Z, and the emissions price τ is determined in the market.

Firms choose the emissions intensity that minimizes their production costs. Let $e = z/x$ denote emissions per unit of output. The Cobb-Douglas form of the production function implies that the share of emission charges in the value of output is $\alpha = \tau z/px$, and hence at an interior solution, we have:[13]

$$e \equiv \frac{z}{x} = \frac{\alpha p}{\tau} \leq 1 \tag{3}$$

The emission intensity falls as pollution taxes rise; and it rises when the price of the polluting good p rises because the opportunity cost of resources used in abatement is higher.

To close the production side of the model, we require nonpositive profits in each industry, and full employment. These conditions can be solved to obtain outputs as functions of endowments, prices and policy:

$$\begin{aligned} x &= x(p, \tau, K, L) \\ y &= y(p, \tau, K, L) \end{aligned} \tag{4}$$

[8] The model is based on Brian Copeland and M. Scott Taylor (2003), which has its roots in Copeland and Taylor (1994). Martin McGuire (1982) and Rauscher (1997) use similar models.

[9] Models with consumption-generated pollution have been somewhat neglected in the trade literature. For one example, see parts of Copeland and Taylor (1995b) and Rauscher (1997).

[10] Production externalities are discussed in Copeland and Taylor (1999) and Michael Bennaroch and Henry Thille (2001).

[11] One can alternatively start with a joint production technology and then (under some regularity conditions) invert it to obtain a production function that treats pollution as an input. See Siebert et al. (1980) and Copeland and Taylor (2003).

[12] Our functional form implicitly assumes that abatement has the same factor intensity as production or potential output. This assumption is made for simplicity.

[13] If the pollution tax is sufficiently low, firms will not abate at all, and a corner solution will result. At this point z = x, and so e = 1. Referring to (3), this no-abatement solution occurs if $\tau \leq \alpha p$.

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For a given pollution tax, it can be verified that this model behaves much like the production side of the standard Heckscher-Ohlin model of international trade. In particular, an increase in the supply of capital will increase the output of the capital-intensive industry X, and reduce the output of Y. An increase in the supply of labor stimulates Y and contracts X.

We can summarize the production side of the model with a national income function. Because markets are competitive, the private sector maximizes the value of national income for any given pollution level z. This allows us to write national income G as the solution to an optimization problem:

$$G(p,K,L,z) = \max_{\{x,y\}} \{px + y: (x,y) \in T(K,L,z)\} \tag{5}$$

where T is the feasible technology set. As is well known, the national income function satisfies a number of useful properties.[14] Most useful to us is the following:

$$\tau = \frac{\partial G}{\partial z}. \tag{6}$$

The equilibrium price of a pollution permit is equal to the effect on national income of an increase in allowable pollution; that is, if more pollution is allowed, national income rises by the value of the marginal product of emissions. If we instead think of the effects of a *reduction* in emissions z, then the cost to the economy is also $\partial G/\partial z$. This is the general equilibrium marginal abatement cost. Hence another interpretation of (6) is that the price of a unit of emissions is equal to the marginal abatement cost, which is a standard result in environmental economics.

We assume there are N identical consumers in the economy. Each consumer maximizes utility, treating pollution as given. For simplicity, we assume preferences over consumption goods are homothetic and the utility function is strongly separable with respect to consumption goods and environmental quality.[15] The indirect utility function for a typical consumer is

$$V(p,I,z) = v(I/\beta(p)) - h(z) \tag{7}$$

where h is increasing and convex, I is per capita income (so $I = G/N$), β is a price index, and v is increasing and concave. Pollution is harmful to consumers and is treated as a pure public bad (all consumers experience the same level of pollution).

The Demand for Pollution. In our approach, we treat pollution as an endogenously supplied factor of production. This suggests a natural way to think about the determinants of pollution is in terms of its demand and supply. Notice (6) can be interpreted as the inverse demand for pollution. We illustrate this demand curve in figure 1. It slopes down because G is concave in z. More intuitively, we can exploit the structure we imposed on technology to write pollution demand as

$$z = e(p/\tau)x(p,\tau,K,L) \tag{8}$$

This is the same relation we would obtain by inverting (6) and using our assumptions on technology. From (8), we can see that the demand for pollution slopes down for two reasons: as τ falls, firms pollute more both because the emissions intensity e rises, and because the lower tax on pollution makes production of the dirty good more attractive (so that output of X expands while Y contracts).

The Supply of Pollution. Pollution supply depends on the policy regime. If there is no

[14] It is concave in (K, L, and z) and convex in prices. Moreover, outputs and factor prices can be recovered with simple differentiation: $x = \partial G/\partial p$; $r = \partial G/\partial K$; $w = \partial G/\partial L$. See Alan Woodland (1982) and Avinash Dixit and Victor Norman (1980) for the standard treatment of national income functions, and Copeland (1994) for an application to environmental problems.

[15] Homotheticity allows us to write the indirect utility function as an increasing function of real income. It also ensures that the relative demand for goods is unaffected by income levels. This is a standard assumption in the international trade literature and it allows us to focus on the role of environmental policy and factor supplies in explaining trade patterns.

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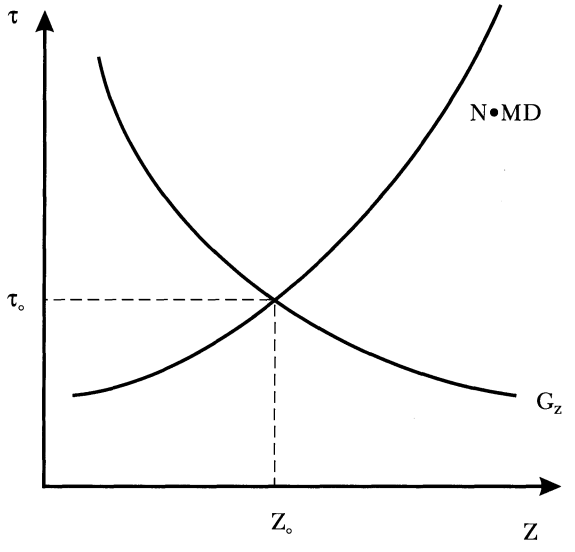

Figure 1. Pollution Demand and Supply

regulation, then pollution supply is perfectly elastic at $\tau = 0$. Pollution in this case is entirely demand driven. If there is an exogenous pollution tax τ_o, then supply is a horizontal line. Shifts up or down in pollution demand raise or lower emissions. Alternatively, if there is a fixed overall pollution quota in place (as in a tradable emission permit system), then the pollution supply curve is vertical. Shifts in pollution demand raise or lower the price of emissions, but have no effect on overall pollution.

In general, we expect pollution policy to be endogenous; and in particular, we expect that changes in per-capita income will lead to an increase in the demand for environmental quality, and (if governments are responsive) a tightening up of pollution regulations. The endogeneity of pollution policy plays a key role in both the theory and empirical literature.

There are two approaches to modeling the policy process. One is to simply assume a benevolent government chooses policy. Another is to adopt a political economy framework where the interaction of competing interest groups determines policy.[16] We follow the bulk of the literature on endogenous policy and adopt a representative agent framework in which the government provides efficient policy.[17]

To determine the optimal pollution policy, the government chooses the pollution level to maximize the utility of a representative consumer subject to production possibilities and private sector behavior. The government's problem is:

$$\underset{z}{Max}\{V(I/\beta(p),z) \quad s.t. I = G(p,K,L,z)/N\} \tag{9}$$

Because we assume the economy is small in world markets, the government treats the goods price p as given. Hence $dp/dz = 0$ and the first order condition from (9) becomes:

[16] The use of political economy models in the trade and environment literature is still in the early stages. Examples include Arye Hillman and Heinrich Ursprung (1994), Per Fredriksson (1997, 1999), Sumeet Gulati (2001), Carol McAusland (2003), Raucher (1997, ch. 5), and Joachim Schleich (1999).

[17] See, however, our discussion of political economy elements in section 3 on policy implications.

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$$\frac{V_I G_z}{N} + V_z = 0.$$

To simplify, recall that $G_z = \tau$, which is the private sector's marginal valuation for a unit of pollution. As well, define $R = I/\beta(p)$ as real income of the representative consumer. We can then rewrite the first order condition as:

$$\tau = N \bullet [-V_z / V_I] = N \bullet MD(p,R,z) \qquad (10)$$

where $MD(p,R,z)$ is a representative consumer's marginal damage from pollution (the marginal rate of substitution between pollution and income). The optimal tax simply implements the standard Samuelson rule: the pollution tax is the sum of marginal damages across all individuals.

If pollution policy is implemented efficiently, then (10) can be interpreted as the supply of pollution. As shown in figure 1, the supply curve slopes upwards because increases in pollution tend to make environmental quality scarce relative to consumption. That is, a diminishing marginal rate of substitution between consumption and environmental quality yields an upward sloping supply curve. As well, exogenous increases in endowments or technology that increase real income will shift the supply curve in: because environmental quality is a normal good, marginal damage is increasing in real income ($MD_R > 0$).[18]

Market Equilibrium with Efficient Policy. The equilibrium level of pollution is determined by the interaction between the derived demand for pollution and the aggregate marginal damage as captured in pollution supply. Combining (6) and (10) yields:

$$G_z(p,K,L,z) = N \bullet MD(p,R(p,K,L,z),z). \qquad (11)$$

Equation (11) determines the efficient level of pollution z_o, as illustrated in figure 1. To implement z_o, the government can either introduce a pollution tax τ_o, or issue z_o marketable permits which would yield the equilibrium permit price τ_o.

Scale, Technique, and Composition Effects. It is useful to have a simple way to link changes in the economy to environmental outcomes. An understanding of these links is critical for empirical work because we have to distinguish between the effects of growth, trade, and other factors if we are to measure their importance. Grossman and Krueger (1993) used the concepts of scale, composition and technique effects as the basis of their discussion, and we proposed formal model-based definitions in Copeland and Taylor (1994). Here we employ these definitions to provide a simple decomposition.

Trade and growth both increase real income, and therefore both increase the economy's scale. To be more precise, we need a measure of the scale of the economy; that is, we need an index of output. There are many ways to create such a quantity index, but for simplicity, we will use the value of output at a given level of world prices as our measure of the economy's scale. Our measure of scale, S, is defined as

$$S = p_x^o x + p_y^o y \qquad (12)$$

where p_x^o *and* p_y^o denote the level of world prices prior to any shocks we analyze. If world prices change, we continue to construct S using the old (base-period) world prices. This is so that scale will not change simply because of a change in valuation.

Given this definition of scale, and setting base-period prices to unity, we now use (12) to write pollution as

$$z = ex = e\varphi_x S \qquad (13)$$

where $\varphi_x = p_x{}^o x/S = x/S$ is the value share of the dirty good X in total output evaluated at base-period prices. Hence pollution emissions, z, depend on the emissions intensity of production, e, the importance of the dirty good industry in the economy, φ, and the scale of the economy, S.

[18] R also varies endogenously with z; this is taken into account when drawing the supply curve.

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Taking logs and totally differentiating yields our decomposition:

$$\hat{z} = \hat{S} + \hat{\varphi} + \hat{e} \tag{14}$$

where $\hat{z} = dz/z$, etc.

The first term is the *scale effect*. It measures the increase in pollution that would be generated if the economy were simply scaled up, holding constant the mix of goods produced and production techniques. As an example, if there were constant returns to scale and all of the endowments of the economy grew by 10 percent, and if there were no change in relative prices or emission intensities, then we should expect to see a 10 percent increase in pollution.

The second term is the *composition effect* as captured by the change in the share of the dirty good in national income. If we hold the scale of the economy and emissions intensities constant, then an economy that devotes more of its resources to producing the polluting good will pollute more.

Finally, we have the *technique effect*, captured by the last term in (14). Holding all else constant, a reduction in the emissions intensity will reduce pollution.

Understanding the interaction between these effects will play an important role in determining how trade and growth affect the environment.

2.2 *The Environmental Kuznets Curve*

With our model and definitions in hand we now consider the literature on the Environmental Kuznets Curve. From the vantage point of our demand and supply system, a key difficulty immediately arises. The EKC literature seeks to estimate a simple relationship between per-capita income and pollution. But income and pollution are each endogenous variables that are functions of more primitive determinants. Since different types of economic activity have different pollution intensities, it would be surprising to find a simple relationship between all possible realizations of income and pollution. Our simple theory predicts instead that the shape of the relationship between income and pollution should vary with the source of income growth.

To illustrate, we demonstrate how physical and human capital accumulation yield different income-pollution paths. For simplicity, normalize the population so that $N = 1$, and suppose there is no pollution regulation. In this case, the emission intensity is $e = 1$ and we can specialize (8) to write pollution as

$$z = x(p, \tau, K, L) \tag{15}$$

where $\tau = 0$. Income is given by

$$I = G(p, K, L, z) \tag{16}$$

Suppose growth occurs via capital accumulation alone. Then differentiating (15) and (16), holding $\tau = 0$ and L constant, yields[19]

$$\hat{z} = \varepsilon_{xK}\hat{K} \tag{17}$$

and

$$\hat{I} = s_r\hat{K}. \tag{18}$$

where $\varepsilon_{xK} > 0$ is the elasticity of X output with respect to the endowment of capital, $s_r > 0$ is the share of capital in national income, and $\hat{z} = dz / z$, etc. Equations (17) and (18) tell us that capital accumulation raises both income and pollution.

Combining them we obtain a reduced form relationship between pollution and income:

$$\hat{z} = \underset{(+)}{\frac{\varepsilon_{xK}}{s_r}}\hat{I} \tag{19}$$

With no pollution policy, there is a positive, monotonic relationship between pollution and income if growth occurs via the factor used intensively in the dirty industry.

Alternatively, suppose growth occurs via human capital accumulation. Then we have:

$$\hat{z} = \underset{(-)}{\frac{\varepsilon_{xL}}{s_w}}\hat{I} \tag{20}$$

[19] Note that $G_z = 0$ since $\tau = 0$.

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where $\varepsilon_{xL} < 0$ is the elasticity of X output with respect to the endowment of human capital and $s_w > 0$ is the share of human capital in national income. Note $\varepsilon_{xL} < 0$, follows from the Rybczinski theorem of international trade: human capital accumulation stimulates the clean industry Y, which draws resources out of the dirty industry X and lowers pollution. Hence when growth occurs via accumulation of the factor used intensively in the clean industry, there is a *negative* monotonic relationship between pollution and income.

This simple example highlights how different sources of growth will in general trace out different income and pollution paths.[20] Theory suggests there may well be a stable relation between pollution and various primitives such as technology and primary factors of production, and between income and these same variables. But unless all countries grow in exactly the same way, there is little reason to expect that there will be a simple relationship between pollution and income.[21] Accordingly, all theories that generate an inverse-U-shaped environmental Kuznets curve must proceed by imposing more structure than even our simple pollution demand and supply model contains.

There are four main explanations for the EKC. Each explanation places restrictions on preferences and technology to make equilibrium pollution a function of per capita income, and to generate the desired shape of the income-pollution relation. We classify these explanations by the key mechanism driving their results. These are: (1) sources of growth; (2) income effects; (3) threshold effects; and (4) increasing returns to abatement. Although all of these explanations describe forces that could interact, we will isolate the key features of each in our presentation.

Sources of Growth. To obtain the rising and then falling portions of an EKC, even in the absence of any environmental policy, we could place restrictions on the growth process across all countries. This yields one of the commonly mentioned explanations for the EKC, although it seems to lack a formal development in the theoretical literature.[22] Very simply, suppose policy is not very responsive to income (i.e. a restriction on pollution supply), but countries grow primarily via capital accumulation in the early stages of development and by human capital acquisition in later stages (i.e. restrictions on the time profile of demand shifters). Then pollution will rise and then fall with growth in per-capita income, as composition effects driven by the factor growth drive the profile for pollution. Composition effects are key here, because we have assumed a zero policy response eliminating technique effects, and the composition effects of factor accumulation dominate scale effects in this model. Given these assumptions, changes in the sources of growth are reflected in the pattern of pollution.[23]

[20] In an interesting paper, Erwin Bulte and Daan van Soest (2001) make a related point in the context of renewable resource exploitation. Using a model of optimal resource use, they consider the relation between the steady state resource stock and income, and point out that the shape of the relation depends on whether income rises via an increase in the resource price or an exogenous increase in non-resource-based income.

[21] Some empirical support for this view can be found in William Harbaugh, Arik Levinson, and David Wilson (2002) and other papers, as we discuss later.

[22] Grossman and Krueger (1995) and others cite Moshe Syrquin's (1989) discussion of the structural transformation in an economy during the development process (for example, for agriculture to manufacturing to services) as motivation for the view that predictable changes in the sources of growth during the development process could affect the pollution-income relationship.

[23] This approach has been relatively neglected in the empirical literature until recently. Lewis Gale and Jose Mendez (1998) include relative capital abundance in their estimation of an EKC for sulfur dioxide, and Theodore Panayotou, Alix Peterson, and Jeffrey Sachs (2000) use a measure of the capital stock in their study of CO_2 emissions. Hermamala Hettige, Muthukumara Mani, and David Wheeler (2000) decompose industrial water pollution into scale, composition and pollution intensity effects, and find that the manufacturing's share of output follows a hump-shaped pattern, but that it is not strong enough to yield an EKC pattern for water pollution.

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The source of growth explanation for the EKC is important to our discussion for two reasons. First, it demonstrates how the pollution consequences of growth depend on the source of growth. Therefore, the analogy drawn by some in the environmental community between the damaging effects of economic development and those of liberalized trade is, at best, incomplete. Second, the sources of growth explanation demonstrates that a strong policy response to income gains is not necessary for pollution to fall with growth. Hence the shape of the EKC need not be driven by income gains making pollution policy more stringent.

Income Effects. An alternative widely cited explanation for the EKC is that its shape reflects changes in the demand for environmental quality as income rises.[24] To illustrate this theory, suppose governments set policy efficiently, and consider the effects of neutral technical progress. Let λ be a shift parameter representing technology, and again normalize the population so that $N=1$. With neutral technical change, we can write our GNP function as $\lambda G(p,K,L,Z)$.

Pollution is determined by:

$$\lambda G_z(p,K,L,z) = MD(p,\lambda G(p,K,L,z)/\beta(p),z) \tag{21}$$

and differentiating with respect to λ and rearranging yields:

$$\frac{dz}{d\lambda} = \frac{1-\varepsilon_{MD,R}}{\Delta} \tag{22}$$

where $\Delta > 0$, and $\varepsilon_{MD,R}$ is the income elasticity of marginal damage. Neutral technological progress shifts both the demand and supply of pollution. Demand shifts because the marginal product of pollution rises; supply shifts because real income has grown.

Whether pollution rises or falls with real income changes depends on the income elasticity of marginal damage.[25] If the elasticity is less than one, then the supply shift is swamped by the demand shift and pollution rises; if it is greater than one, the opposite occurs.[26]

Because the EKC has both an increasing and decreasing segment, this pure income-driven explanation requires a variable income elasticity of marginal damage to generate the required shape. As an example, suppose indirect utility is given by:

$$V(p,I,z) = c_1 - c_2\exp(-R/\xi) - h(z) \tag{23}$$

where $\xi > 0$ (and R is real income). The key characteristic of (23) is that the income elasticity of marginal damage is simply R/ξ. Using (22), we obtain an inverse-U relation between real income and pollution: pollution rises with neutral growth if $R > \xi$ and falls with neutral growth if $R < \xi$. Environmental quality is a normal good throughout, but at low incomes, pollution rises with growth because increased consumption is valued highly relative to environmental quality. As income rises, the willingness to pay for environmental quality

[24] Ramon Lopez (1994) provides an early treatment of this approach, as he shows how non-homotheticity in preferences between consumption and environmental quality can lead to an EKC. Kishore Gawande, Robert Berrens, and Alok Bohara (2001) provide an interesting variation on the income effect approach—in their model, agents are freely mobile and so income effects induce a sorting equilibrium in which higher income agents avoid polluted areas.

[25] Similar results are obtained by considering the effects of neutral factor accumulation on pollution. Lopez (1994) shows how the effects of factor accumulation on the environment depend on interaction between the elasticity of substitution between pollution and nonpollution inputs and the income elasticity of marginal damage. Copeland and Taylor (2003, ch.3) explore these issues in greater detail.

[26] While the income effect theory is illustrated here in terms of a benevolent government in a representative agent economy, it can be modified to allow for political economy motives. For example, Lopez and Siddhartha Mitra (2001) show how the presence of corruption will move the turning point of the EKC to the right. Some empirical studies, such as Scott Barrett and Kathryn Graddy (2000) include measures of political freedom as an extra shift variable in their EKC regressions; and find that all else equal, increased freedom is associated with a cleaner environment. However, the theory outlined above would imply that the political freedom variables should be interacted with income variables since one would expect political freedom to influence the strength of the policy-induced technique effect.

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rises and increasingly large sacrifices in consumption are made to provide greater environmental benefits.

The income-effect explanation of the EKC follows from two assumptions: neutral growth and a particular assumption on preferences. Neutral growth restricts the magnitude of shifts in pollution demand as growth proceeds; while the rising income elasticity of marginal damage ensures ever-stronger technique effects. Composition effects play little or no role.

This explanation suggests that the relationship between pollution and income should vary across pollutants according to their perceived damage. For example, we might expect a very low ξ for directly life-threatening pollutants such as contaminated drinking water. In this case, the EKC would be (almost) monotonically declining throughout, as was found by Shafik (1994) and Grossman and Krueger (1995). Alternatively, ξ might be very high for pollutants whose harm is uncertain or delayed. Carbon emissions may fit this category, and indeed most studies have found that carbon emissions per capita tend to increase monotonically with per-capita income.[27]

Threshold Effects. An alternative explanation for the EKC is based on threshold effects. Threshold effects can arise in either the political process as in Larry Jones and Rudolfo Manuelli (1995), or in abatement opportunities as in Andrew John and Rowena Pecchino (1994), Selden and Song (1995), and Nancy Stokey (1998). Threshold effects lead to a very different relationship between income and pollution in early versus later stages of development. At low levels of economic activity, pollution may be unregulated entirely or regulation may have little impact on the profitability of abatement. Pollution therefore at first rises with growth. But after some threshold has been breached, and policy is either implemented or starts to bind, these models predict pollution declines with income—provided appropriate assumptions are imposed on tastes and technology.

There are at least two possible ways to ensure regulation is ineffective in checking pollution at low levels of income. The first is to assume an abatement production function where the marginal product of abatement is bounded. In this case, there will exist a set of relatively low pollution taxes for which firms choose the zero abatement option; consequently, even though taxes may rise with growth over some range, this has no affect on abatement, and pollution rises with economic activity. An abatement function of this type was used in Copeland and Taylor (1994) and is implicit in Stokey (1998). The model we presented in section 1 contains this attribute because we note from (3) that if $\tau < \alpha p$, no abatement occurs. This means that there is no technique effect to offset the scale effect of growth when incomes are low. In models with only one good, this ensures that pollution must rise with growth at low levels of income. In multi-good models, the pollution tax can still play a role by altering the composition of output at low levels of income, but it becomes much more effective once the abatement threshold is breached.

Alternatively we can assume a fixed cost to either abatement or policy. Suppose there is a fixed cost C_R of setting up a pollution regulation system. When national income is low, the aggregate willingness to pay to reduce pollution to its first best level may be less than the fixed regulatory cost C_R, in which case it is not worth setting up a regulatory system. With no system in place, pollution rises lock-step with output.

Both threshold theories need two further assumptions to generate an EKC. First we need an assumption on the growth process to restrict composition effects. This is typically done by adopting a one good framework or by limiting substitution possibilities by functional form assumptions. We will

[27] See Shafik (1994) and Douglas Holz-Eakin and Selden (1995). However, Richard Schmalensee, Thomas Stoker, and Ruth Judson (1998) do find a within-sample peak for carbon emissions per capita.

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consider neutral growth. Second, we need an assumption on preferences to ensure that once abatement occurs, the response of pollution taxes is sufficiently income elastic. In our framework, this requires an income elasticity of marginal damage in excess of one.

With these two assumptions in hand, consider the impact of growth via neutral technological progress. In the policy threshold model, the demand for pollution shifts out as technology improves and income rises. The net benefits of reducing pollution increase with income because we have assumed the elasticity of marginal damage with respect to income is greater than one, and hence there will be a critical income level at which it is worth setting up a regulatory system. Further income gains then lower pollution. This simple model predicts a discrete improvement in environmental quality at the critical point; however, by introducing adjustment costs, we could obtain a smooth response.[28]

In the abatement threshold model, pollution taxes rise with growth and eventually firms move off their corner solution. Abatement occurs and further increases in income drive pollution downward. Hence we obtain an inverse-U relation between pollution and income that is kinked at its peak.

Since threshold explanations also rely on income effects, they bear a close family resemblance to the income-effects explanation. Both explanations rely on a strong policy response to income gains as development proceeds, but they differ in their explanations for the initial rising segment. Threshold effect explanations predict a period of inactivity in pollution policy and/or private sector responses to policy whereas the income effect explanations predict small but increasingly tougher policies and higher pollution abatement costs over time.

Increasing Returns to Abatement. A final explanation for the EKC is increasing returns in abatement. The argument is simply that as the scale of abatement rises its efficiency may increase. These efficiencies make abatement more profitable and hence even if pollution policy is stagnant and unchanging pollution can fall as more abatement is undertaken. James Andreoni and Arik Levinson (2000) develop this idea within a one-good endowment model and demonstrate how this process can lead to an EKC. This explanation carries with it an interesting twist on scale and technique effects because as the scale of output rises, even with constant pollution taxes, firms switch to cleaner techniques of production. The scale effect creates its own technique effect even with no pollution policy response to higher incomes. As such, this theory shares a common feature with the sources of growth explanation in that an EKC pollution profile is compatible with no change in pollution policy over the development path.

In Andreoni and Levinson's endowment model, issues of market structure arising from the increasing returns technology do not arise, but one can relatively easily extend their increasing returns to abatement explanation to allow for perfectly competitive firms by using either industry-wide learning by abating[29] or by employing the methods of Markusen (1989) and introducing intermediate goods.

The Role of International Markets. Each of the theories we discussed above could generate an EKC with no international trade, but without trade it becomes more difficult for higher income countries to shed dirty production. Hence, it is useful to consider more explicitly how trade affects the EKC.

One key role for international trade is to offer an alternative abatement mechanism. Access to world markets offers an easy abatement alternative—import the good from abroad when higher pollution taxes make it more expensive at home. Consequently, trade makes pollution

[28] See Copeland and Taylor (2003) for an explicit development of this model.

[29] See Copeland and Taylor (2003) for such a model.

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demand more elastic and pollution becomes more responsive to changes in policy.

As well, international markets create links between country pollution levels, and this has important implications for the interpretation of the EKC. In the income effects explanation for the EKC, rich countries can reduce their pollution either by abating more or by using policy to encourage dirty industry to migrate to poorer countries. If the former process is the main driving force, then all countries could follow a similar path. But if it is the latter, then even if an EKC exists for rich countries, the newly industrialized countries may not replicate the experience of the current rich.[30]

A natural concern is whether country-specific explanations are consistent with the overall cross-country evidence. One relatively uncharted branch of theoretical research is investigating whether one-country (or small open-economy) explanations given for the EKC add up. That is, is there a fallacy of composition lurking in the background? At present, we know of no research addressing these concerns head on, but existing results in the literature suggest further work may be needed. For example, the Copeland and Taylor (1994) pollution-haven model predicts a very different relation between growth and pollution in autarky than in free trade. If the income elasticity of marginal damage is one, the scale and technique effects of growth exactly offset each other in autarky, so growth has no effect on pollution. In contrast, in free trade, with the same preferences and technology, growth in the North raises both Northern and Southern pollution; and growth in the South lowers both Northern and Southern pollution. These results follow from composition effects created by differences in pollution regulations across countries. Further work along these lines would be useful and indeed a multicountry perspective would seem to be a necessity if the pollutant in question has strong transboundary or global effects.

The Empirical Evidence. As noted above, there has been a flurry of recent empirical work linking economic growth to environmental outcomes. Much of this work has focused on either confirming or denying the existence of similar relationships across different pollutants, considering additional explanatory variables, such as income inequality or political freedom, or investigating the robustness of previous studies.[31]

A growing body of work has found that the estimated EKC is sensitive to the sample used. Harbaugh, Levinson, and Wilson (2002) examine the robustness of estimates of the EKC for SO_2. This was the focus of the original work of Grossman and Krueger (1993) and is one of the most widely cited examples of the existence of an environmental Kuznets curve. They find that the shape of the curve is sensitive to changes in the time period chosen and the set of countries included in the study. This is suggestive of a misspecification of the model, which is what the theory developed above suggests—different sources of growth across countries should yield different reduced-form relations between pollution and income. David Stern and Michael Common (2001) use data on sulfur emissions in 73 countries over 31 years, and by comparing OECD and non-OECD subsamples conclude that the evidence does not support a common EKC across countries. Similarly, John List and Craig Gallet (1999) study sulfur dioxide and nitrogen dioxide emissions in U.S. states over 65 years and conclude that there is not a common EKC across states.[32]

[30] See Kenneth Arrow et al. (1995)

[31] See the surveys cited previously, as well as David Stern (1998).

[32] See also Gary Koop and Lise Tole (1999) who find no evidence for any empirical relationship between deforestation and per capita income. Recent work by William Brock and M. Scott Taylor (2003) shows that while all countries will exhibit an EKC type relationship, countries will differ in their turning points and rates of environmental improvement whenever they differ in initial conditions, their rate of natural regeneration, etc.

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Despite the proliferation of papers in this area, very little work has gone into evaluating the various hypotheses offered for the EKC, or more generally in examining how the interaction between different sources of growth interact with income and other effects to determine the relation between growth and pollution. Unless we can clarify the causal mechanisms involved, the work will be of little use in helping us understand how growth or trade affect the environment.

A few recent studies are useful steps in this direction. Hank Hilton and Arik Levinson (1988) examine the link between lead emissions and income per capita using a panel of 48 countries over the twenty-year period 1972–92. This study is important because it finds strong evidence of an inverted U-shaped relationship between lead emissions and per-capita income, and then factors the changes in pollution into two different components. The first is a technique effect that produces an almost monotonic negative relationship between lead content per gallon of gasoline and income per capita. The second is a scale effect linking greater gasoline use to greater income.[33] This study is the first to provide direct evidence on two distinct processes (scale and technique effects) that together result in an EKC.

To interpret the empirical evidence as reflecting scale and technique effects, one needs to rule out other possibilities. Although the authors do not couch their analysis in this context, their analysis implicitly presents the necessary evidence. First, they document a significant negative relationship between the lead content of gasoline and income per capita (post 1983). This relationship shows up quite strongly in just a simple cross-country scatter plot of lead content against income per capita. We have depicted this in figure 2 below.

Since lead content is arguably pollution per unit output, it is difficult to attribute the negative relationship in this figure to much other than income-driven policy differences.[34] Our interpretation is simply that regulation is tighter in higher-income countries and this is driving down lead content (or e, emissions per unit output, in our framework).

Second, the authors find a hump-shaped EKC using data from the post-1983 period, but in earlier periods they find a monotonically rising relationship between lead emissions and income. The declining portion of the EKC only appears in the data once the negative health effects of lead become well known. The emergence of the declining portion in the income–pollution relationship is very suggestive of a strong policy response to the new information about lead. The fact that this appears late in the sample makes it difficult to attribute the decline in lead to other factors that could be shifting the demand for pollution. For example, if the declining portion of the EKC was due to increasing returns to scale in abatement, then it should appear in both the pre and post-1983 data. If it was due to shifts in the composition of output arising naturally along the development path, why would it only appear in the post-1983 data? While it is possible to think of examples where these other factors are at play, the scope for mistaking a strong policy response for something else is drastically reduced in this study. We are therefore led to conclude that the declining portion of the EKC post-1983 reflects a strong induced policy response that more than offsets the scale effect.

[33] Lurking in the background of this study is a composition effect operating through changes in the fleet of cars. This composition effect is not investigated in the paper, although it may be responsible for the jump in lead per gallon of gasoline use at low income levels shown in figure 2 of the paper.

[34] To be precise we should note that since lead content per gallon is an average, and cars differ in their use of leaded versus unleaded gas, the composition of the car fleet is likely to be changing as well. Therefore, the fall in average lead content may reflect an income-induced change in the average age of the fleet (which would lower average lead content) plus a pure technique effect.

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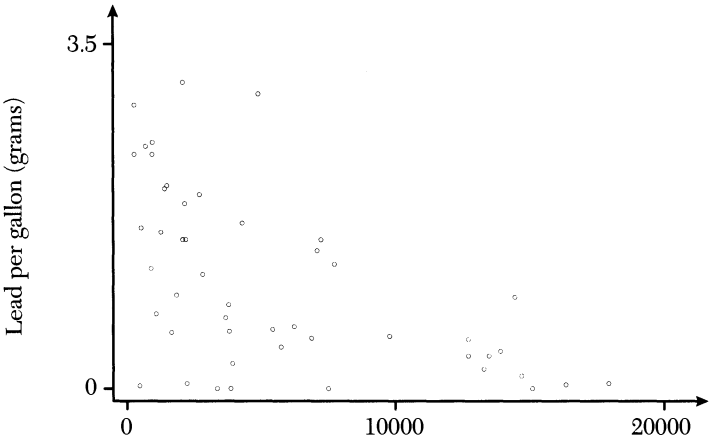

Figure 2. Real GDP Per Capita, 1992

Another paper that attempts to determine whether an income effect is responsible for the downward turn of an EKC is Kishore Gawande et al. (2000). They estimate an EKC for hazardous waste sites in the United States, and find that it is hump-shaped, although only a small percentage of counties are on the downward-sloping portion. Because it is very expensive to clean up hazardous waste sites, they argue that the income effect would be reflected in net out-migration rates. They find evidence that the number of hazardous waste sites in a region increases the net out-migration rate but only after a threshold of income is reached, which is consistent with an income effect driving the downward portion of the EKC. Moreover, the income threshold they estimate is indistinguishable from the peak of their estimated EKC.

Gale and Mendez (1998) attempted to assess the importance of composition effects in predicting cross-country differences in pollution levels. They re-examine one year of sulfur dioxide data drawn from Grossman and Krueger's (1993) study. They regress pollution concentrations on factor endowment data from a cross-section of countries together with income-based measures designed to capture scale and technique effects. Their results suggest a strong link between capital abundance and pollution concentrations even after controlling for incomes per capita. Their purely cross-sectional analysis cannot differentiate, however, between location-specific attributes and scale effects. Nevertheless, their work is important because the strong link between factor endowments and pollution suggests a role for factor composition to affect pollution demand. That is, even after accounting for cross-country differences in income levels that may determine pollution supply, other national characteristics matter to pollution outcomes.

Finally, two recent studies attempt to assess the relative importance of scale, technique and composition effects in accounting for changes in pollution. Selden, Anne Forest, and James Lockhart (1999) compare emissions of six air pollutants in the United States in 1970 and 1990 and decompose the observed changes in pollution into changes in scale, composition of economic activity

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(due to changes in sectoral output shares), and changes in emissions per unit of output.[35] Although this is simply a measurement exercise based on aggregate data for a single country at two points in time, the study is nevertheless important because it takes seriously the need to investigate the relative strength of the three effects. They find that technique effects were an important factor in explaining the fall in emissions. Although composition effects were present, they were not strong enough to account for the downturn in aggregate emissions during this period.

Hettige, Mani, and Wheeler (2000) use panel data on industrial water pollution from twelve countries and try to isolate composition and technique effects, and explain how they vary with income. They decompose pollution into the manufacturing pollution intensity, the share of manufacturing in the economy, and total output, and then separately regress firm level pollution intensities, the average pollution intensity in manufacturing, and the manufacturing share on per capita income.[36] They find a hump-shaped relation between the share of manufactures and per capita income; however, they find this composition effect is small in magnitude relative to the impact of scale effects. Conversely, they find a strong technique effect: the income elasticity of the pollution intensity is about –1. Overall, they find that industrial water pollution tends to initially rise with income and then flatten out, with the strong technique effect being responsible for offsetting the scale effect of growth.

[35] They actually consider more than one technique effect. They measure changes in energy intensity and a compositional effect reflecting changes in sources of energy as well as an "other technique effect."

[36] They also investigate compositional effects within the manufacturing sector by regressing per capita income on the average pollution intensity in manufacturing, holding the pollution intensity in manufacturing subsectors constant. They find that the average pollution intensity first falls with income, and then levels out.

Summary. The EKC literature is important in several respects: it brought the empirical study of aggregate pollution levels into the realm of economic analysis; it debunked the commonly held view that environmental quality must necessarily decrease with economic growth; and it provided highly suggestive evidence of a strong policy response to pollution at higher income levels. The literature expanded rapidly because of the ease of estimation and the potential relevance of its findings. Studies replicating or extending the methods of early contributors have played a useful role in providing a check on the original work, but further work along these lines has limited usefulness. Investigators must now move beyond the methods that sparked the literature to develop methods useful in revealing the causal mechanisms underlying the relationship.

To proceed further more guidance from theory is surely needed. We would expect that scale, technique and composition effects all play a role in determining the relationship between growth and the environment. This suggests the focus on reduced forms linking only per capita income to pollution is unlikely to be fruitful. If we are to ask more detailed questions of the pollution data, we will need different methods. We suggest a step back from the EKC methods to consider theories determining the equilibrium level of pollution as a function of a relatively few factors. An approach that tries to disentangle the scale, technique and composition effects, and which allows these to vary across countries has much more support from theory and is more likely to generate an increased understanding of what drives the relationship between growth and the environment.

3. *Trade Liberalization and the Environment*

We now turn to the impact of international trade on the environment. We draw

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the usual distinction between trade and growth: trade liberalization changes relative goods prices by opening up the economy to increased foreign competition, while growth increases endowments or improves technology at given external prices.

While this distinction is clear, it may not always be accurate. There is empirical evidence that trade liberalization also stimulates economic growth, and at a theoretical level, trade can alter the rate of growth if it spurs innovation or factor accumulation.[37] In addition, trade may also pave the way for labor and capital mobility and technology transfer. Hence, trade can set in motion forces that shift the production frontier as well. For clarity however we will maintain the distinction drawn above.[38]

We first examine the effects of trade on the environment in a small open economy facing fixed world prices to emphasize three major points. First, the effect of trade liberalization on the environment depends on a country's comparative advantage, which in turn depends on country characteristics. There is no reason to expect trade to have the same effect on all countries. Second, the effects of trade on the environment depend on whether environmental policy is rigid or instead responsive to changes brought about by trade. When policy is rigid we will show that outcomes depend on the type of environmental policy instruments used by regulators. Finally, the welfare effects of trade liberalization are sensitive to both a country's comparative advantage and the flexibility of its policy regime.

We then examine a two-region model to evaluate two of the major hypotheses in the literature linking relative country characteristics to environmental outcomes: the pollution haven hypothesis, and the factor endowments hypothesis. This then sets the stage for our review of the empirical work.

Trade Frictions. For modeling purposes, we need to be specific about the trade barriers that are being reduced. Some trade barriers (such as tariffs) generate revenue; others, such as distance, generate productive activities such as transportation to overcome them; and yet others, such as bureaucratic delays and regulations simply create trading costs. We don't want to focus on the details of trade policy, but simply capture the effects of increased opportunities to trade. To do so we assume there are some trade frictions between countries, which we capture by adopting an "iceberg" model of trade costs.[39]

With iceberg costs, an importer who wants to receive one unit of X from the foreign country has to ship $1+\delta$ units because δ is lost in transport. Trade therefore consumes real resources, and the magnitude of trade frictions increase as δ rises.[40]

Trading costs drive a wedge between the domestic and foreign price of a good. As before let p denote the world price of X, then the domestic price of X for an importing country is:

$$p_m^d = p(1+\delta) \tag{24}$$

Conversely, if Home exports X, then to deliver a unit of X to a foreign market (where the price is p), a home exporter must send $1+\delta$ units, which are acquired locally at the domestic price p_e^d. Hence the domestic price is lower than the foreign price:

[37] See, for example, Gene Grossman and Elhanan Helpman's (1991) book.

[38] We have followed the literature here in examining separately the effects of growth on the environment and the effects of trade on the environment. More generally, we expect that growth, trade, and environmental quality will all interact with each other in interesting ways. However, there is currently little work available exploring these interactions in growth models where comparative advantage is determined by both environmental policy and factor endowments.

[39] This approach has been frequently used in the trade literature. See, for example, Paul Samuelson (1954), and Rudiger Dornbusch, Stanley Fischer, and Samuelson (1977).

[40] For simplicity, we assume there are no trade barriers for the numeraire good. This does not affect the qualitative results.

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$$p_e^d = \frac{p}{1+\delta} \tag{25}$$

It is convenient for us to use "p^d" to refer to the domestic price, but the reader should keep in mind that whether this price is above or below the world price depends on the country's comparative advantage.

3.1 *Rigid Policy*

Fixed Emission Intensities. The effects of trade liberalization on the environment depend on the environmental policy regime. We start with a simple case where government policy holds the emission intensity of production fixed. This scenario is instructive because it simplifies the analysis by ruling out a technique effect, and may be a realistic approximation of policy in many countries (at least in the short run) because much pollution regulation tends to target emissions intensities, rather than overall emissions. This approach also allows for the special case of no pollution regulation.

Consider a country importing the dirty good X. The domestic price is initially above the world price, and as trade barriers fall, the domestic relative price of X falls. As with growth, we can decompose the effects of trade liberalization into scale, composition and technique effects. This is illustrated in figure 3. The production frontier (for a given emission intensity) is depicted in the top half of the diagram,[41] and pollution is measured as a function of X in the bottom half.

Starting with producer price q_o at point A, a trade liberalization reduces the domestic producer price of X to q_1. Production moves from point A to C, and pollution falls from z_o to z_2. If we measure the scale of output at world prices p, then (hypothetical) movements along the dashed line through AB (with slope p) keep the scale of the economy constant. This allows us to decompose the change in pollution into a composition effect (A to B) which lowers pollution from z_o to z_1, and a scale effect (B to C) which raises pollution from z_1 to z_2. There is no technique effect in this example by assumption.

The scale effect is positive and tends to increase pollution. Trade increases production efficiency (measured at world prices), and this leads to more output, and hence more pollution.[42] The composition effect is negative, because protection is being removed from the polluting good, inducing producers to shift towards the clean good. In our simple model where only one good pollutes, the composition effect always dominates the scale effect, because trade liberalization has an unambiguous effect on the output of the polluting good.[43] If the economy has a comparative advantage in clean goods, as in this example, trade is good for the environment.

If instead home exports X, then trade liberalization raises p^d. Producers shift along the production frontier towards the dirty good. This both increases the scale of production and shifts the composition of output towards the polluting good: both the scale and composition effects reinforce each other and lead to an increase in pollution.

In summary, with fixed emission intensities, the composition effect is critical in determining the effects of trade liberalization. Moreover, the sign of the composition effect is ultimately determined by a country's

[41] More generally, we can distinguish between net and gross production frontiers, where the gross frontier represents potential output, and the net frontier represents net output after resources are allocated to abatement. This distinction is important if we want to capture technique effects in the diagram. Details can be found in Copeland and Taylor (2003).

[42] Note that trade liberalization generates a scale effect, even though it results in a movement along the production frontier, and not a shift of the frontier. In order to compare pollution across countries, we need to account for cross-country differences in the scale of production, which means that we have to choose a quantity index to measure scale at common reference prices. As a result, any movement along a strictly concave production frontier will yield both composition and scale effects.

[43] When both goods pollute, it is possible for the scale effect to dominate.

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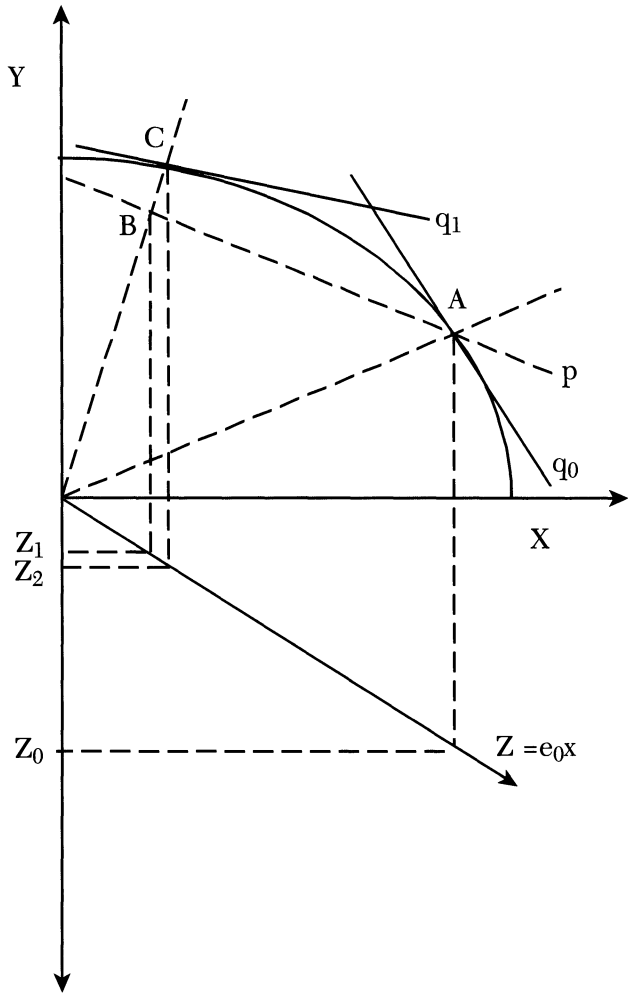

Figure 3. Fixed Emission Intensity

comparative advantage. If a country has a comparative advantage in clean industries, then clean industries expand with trade; and conversely, if it has a comparative advantage in polluting industries, then dirty industries expand with trade.

Fixed Emission Permits. Now suppose the government uses a marketable emission permit system to regulate pollution, and that it does not adjust the supply of permits in response to changes in the trade regime. Earlier, we noted the equivalence of permit and tax systems as a method of implementing the first best. But if we hold policy instruments fixed in the face of shocks to the economy, this equivalence breaks down.[44]

If X is imported, then producers shift towards the clean industry when trade is liberalized, as in the previous example. This reduces the derived demand for pollution.

[44] Rod Falvey (1988) obtains a similar non-equivalence result when comparing import tariff reform with import quota reform in models with multiple trade distortions.

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For given emission intensities, this would reduce pollution. But with a fixed supply of pollution permits, pollution will not change; instead the permit price falls. Producers switch to dirtier production techniques. This negative technique effect completely offsets the beneficial impact of the shift towards producing cleaner goods. Similarly, if X is instead exported, trade liberalization leads to an (upward) adjustment in pollution permit prices, but has no effect on pollution.

An important implication of our analysis is that with rigid pollution taxes or emissions intensities, the environmental effects of trade liberalization may be quite substantial. But if pollution quotas are in place, the environmental effects of trade liberalization may be negligible.[45]

Welfare Effects of Trade Liberalization. The welfare analysis of trade liberalization in the presence of environmental problems draws heavily on the theory of the second best (Richard Lipsey and Kelvin Lancaster 1956).[46] Prior to trade liberalization, there are two types of distortions: trade barriers and inefficient pollution policy.[47] Reductions in trade barriers can either alleviate or exacerbate the problems caused by inefficient pollution policy. Consequently, standard gains from trade theorems do not apply.

To determine the welfare effects of trade liberalization, consider the effects on the utility of the representative consumer of a small fall in the trade friction δ. Replace p with p^d in (7), and differentiate to obtain:

$$\frac{dV}{V_I} = -Mdp^d + (\tau - MD)dz \qquad (26)$$

Trade liberalization has two effects on welfare: the standard gains from increased trade and the induced change in the environment.[48]

The standard gain from trade effect is positive for both importers and exporters. If Home imports X, then $M > 0$ and the domestic price of X falls with trade liberalization. As a result $Mdp^d < 0$. If Home exports X, then $M < 0$ but the domestic price of X rises with trade liberalization. Once again we find $Mdp^d < 0$.

Changes in pollution, however, can undermine the benefits of trade liberalization. To see why, suppose emission intensities are constant and regulation is lax ($\tau < MD$). Then if home exports X, pollution rises with trade. Because the pollution tax is less than marginal damage, this increase in pollution is welfare-reducing $(\tau - MD)dz < 0$. The net welfare effect of liberalization is now ambiguous: the costs of increased pollution have to be compared with the benefits of increased goods consumption. If pollution is sufficiently damaging, pollution costs will dominate.

On the other hand, if home imports X, trade liberalization may yield a double dividend by reducing pollution and generating increased consumption.[49] With lax pollution

[45] Although full-blown marketable permit schemes are relatively rare in practice, similar results would be obtained if the regulator enforces ambient air or water quality standards. If trade liberalization increased the derived demand for pollution, a regulator enforcing a rigid air quality standard would respond by tightening up regulations, which would raise the shadow price of pollution.

[46] The welfare effect of trade liberalization in the presence of environmental distortions has been a major theme of the literature: see Baumol (1971), Pethig (1976), Siebert (1977), Kazumi Asako, (1979), and Copeland (1994).

[47] If an inefficient instrument is used to control pollution then there are three distortions to worry about: the inefficient choice of instrument; the inefficient level of pollution; and the inefficiently low level of trade. We assume the government uses efficient instruments; extending our analysis to the inefficient instrument case is left to the reader as an exercise.

[48] If we instead model trade barriers as tariffs (t), the welfare effects of trade liberalization can be written as $dV/V_I = tdM + (\tau - MD)dz$. A reduction in tariffs will raise imports, so the term tdM represents the gains from trade. As well, there is the effect on pollution noted above. The magnitude of the gains from trade term differs according to the type of trade barrier in place; but the basic point that the welfare effects of trade liberalization depend on the interaction between the trade and environmental distortion is robust.

[49] The standard "double dividend" literature (see Lans Bovenberg and Ruud de Mooij 1995; and Don Fullerton and Gilbert Metcalf 1997) considers the effects of pollution regulation in the presence of distortionary taxes on labor supply. That literature is also based on the interaction between two distortions.

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regulation ($\tau < MD$), the economy gains from reduced pollution and the standard gains from trade.

The instruments used also play an important role in determining the welfare effects of trade liberalization. If pollution regulation takes the form of a binding aggregate pollution quota, then trade must always raise welfare, even when marginal damage is high and pollution regulation is lax. Referring to (3.6), as long as the pollution quota is binding, pollution does not change with trade liberalization, and hence we have $(\tau - MD)dz = 0$. This leaves only the standard gains from trade, which as we have already shown must be positive.[50]

In summary, if pollution regulations are unresponsive, then the welfare effects of trade liberalization depend on the pattern of trade, the type of policy instrument used, and the existing stringency of pollution regulation. If the number of pollution permits is held fixed during trade liberalization, then freer trade has to raise welfare and has no environmental consequences. But if emission intensities are unchanged with trade, then trade increases pollution in countries with a comparative advantage in dirty goods, and decreases it in countries with a comparative advantage in clean goods. And when pollution policy does not fully internalize externalities, countries with a comparative advantage in dirty goods may lose from trade.

3.2 *Flexible Policy*

Now suppose government policy adjusts optimally in response to changes in the trade regime. Pollution is determined by setting the marginal benefit of polluting equal to marginal damage as in (11), where the goods price "p" is interpreted as the domestic price p^d. When trade is liberalized, p^d changes. By differentiating (11), we obtain, after some manipulation:

$$dz = \frac{p^d M}{I}\left[\frac{\varepsilon_{MD,I}}{\Delta}\right]dp^d + \left[\frac{\varepsilon_{G_z,P} - \varepsilon_{MD,P}}{\Delta}\right]dp^d, \tag{27}$$

where $\Delta > 0$, each of the elasticities is positive, and the change in p^d should be interpreted as coming from a change in the trade friction δ. Trade liberalization yields both an income effect (the first term) and substitution effects.[51]

First, consider the income effect. Because trade liberalization raises real income ($dI = -Mdp^d > 0$ when trade is liberalized) and environmental quality is a normal good, the income effect will always tend to reduce pollution. The pollution supply curve shifts back with liberalization and the strength of this income effect depends on the income elasticity of marginal damage, $\varepsilon_{MD,I}$.

The substitution effects of trade liberalization, however, move in opposite directions for dirty-good importers and exporters. There are two substitution effects, one in production and the other in consumption. On the production side, an increase in the price of the dirty good stimulates production of the dirty good, and this tends to increase the demand for pollution. On the consumption side, an increase in the price of the dirty

[50] The main point here is that if pollution is regulated with quotas, trade liberalization cannot exacerbate the pollution distortion. A similar point was made earlier in the literature on piecemeal trade policy reform, where Falvey (1988) showed that in an economy with multiple trade distortions, alleviating one trade distortion will not exacerbate other trade distortions if import quotas are the instrument of protection. See Copeland (1994) for further details on trade policy reform in a world with many goods and pollutants. With pollution quotas in place, uniform tariff reductions will increase welfare, but with pollution taxes (or fixed emission standards), then the welfare effects of trade liberalization depends on whether trade protection is biased towards clean or dirty goods. John Beghin, David Roland-Holst, and Dominique van der Mensbrugghe (1997) use a similar approach to investigate consumption-generated pollution, and Arja Turnen-Red and Alan Woodland (1998) consider multilateral reforms.

[51] The analysis of the effects of trade liberalization on environmental quality has received less attention than the effects on welfare. Lopez (1994), Rauscher (1997), and Copeland and Taylor (2003) consider these issues in more detail.

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good raises the level of the price index for consumption goods relative to the opportunity cost of environmental quality (given by τ). Consumers would like to substitute towards more environmental quality, and the policy maker responds by raising the pollution tax (the pollution supply curve shifts back for a dirty exporter). Therefore, the two substitution effects work against each other. One can show that the substitution effect in production dominates: the net substitution effect tends to increase pollution for a dirty-good exporter and reduce pollution for a dirty-good importer.[52]

Putting the substitution and income effects together, we can determine the impact of trade liberalization on pollution. For a dirty-good importer, trade liberalization will reduce pollution. The increase in income shifts back pollution supply, and the lower price of dirty goods leads to a reduction in pollution demand. Both income and substitution effects combine to improve environmental quality.

On the other hand, for a dirty-good exporter, pollution tends to rise via the substitution effect (the demand for pollution rises as the price of the dirty good rises) but fall via the income effect (the supply of pollution shifts back as real income rises). If the income elasticity of marginal damage is small,[53] then pollution rises in a dirty-good exporting country even though pollution policy is fully optimal. Conversely, if the income elasticity of marginal damage is large, then pollution falls.

If the income elasticity of marginal damage is increasing in real income, then we might expect pollution to rise in a low-income dirty-good exporter, but fall in a high-income dirty-good exporter (recall our example in (23)). As well, we would expect the policy response to differ across pollutants, because both income and substitution effects will vary. In addition, the impact of trade liberalization would also differ in settings where the policy process was subject to threshold effects or if abatement exhibited increasing returns. We know of no research, however, that investigates any of these channels.

Welfare Effects of Trade Liberalization with Efficient Policy. When policy is set optimally, then $\tau = MD$ and the effect of trade liberalization on welfare in (26) reduces to

$$\frac{dV}{V_I} = -Mdp^d \geq 0.$$

We are left with the standard gains from trade. If pollution externalities are fully internalized, trade must always increase welfare. Trade may lead to an increase in pollution if the economy has a comparative advantage in dirty goods, but this reflects an optimal tradeoff between environmental quality and consumption.

3.3 *The Determinants of Comparative Advantage*

It is apparent that composition effects play a key role in determining the effects of trade on the environment. But composition effects depend on a country's comparative advantage, and hence a major preoccupation of the literature has been an investigation of which countries attract dirty industries when trade is liberalized.

There are two major competing theories, although they are often not stated explicitly. The *pollution haven hypothesis* predicts that countries with relatively weak environmental policy will specialize in dirty-industry production. In many versions of this hypothesis, countries with weak environmental policy are also low-income countries. An alternative hypothesis is that environmental policy has little or no effect on the trade pattern; instead, standard forces, such as differences in factor endowments or technology, determine trade. For example, under this view,

[52] See Copeland and Taylor (2003). The sign of the net substitution effect depends on preferences and technology and hence can vary with assumptions.

[53] One can show that if $\varepsilon_{MD,I} \leq 1$, then pollution will rise in a dirty-good exporter.

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capital-abundant countries tend to export capital-intensive goods, regardless of differences in environmental policy. We will call this the *factor endowments hypothesis*, although it can be interpreted more broadly to encompass other motives for trade, such as technology differences.

We can illustrate these competing theories within our simple model by assuming there are two regions in the world: "North" and "South." We use an asterisk ("*") to denote Southern variables. North and South may have different factor endowments or pollution policy, but we assume they are otherwise identical.[54]

The interaction between factor endowments and pollution policy in determining the pattern of trade can be illustrated using a simple relative supply-and-demand analysis to determine autarky prices in each country. To construct relative demand, note that given our assumption that preferences over goods are homothetic and separable from environmental quality, the demand for X relative to Y is independent of income and can be written as $RD(p)$, where $RD'(p) < 0$. Moreover, because preferences are identical across countries, the relative demand curve is the same in each country. This is illustrated in figure 4 as the curve labeled RD.

Next, we need to determine the relative supply curves for each country. Using (4) and exploiting constant returns to scale, we can write relative supply as a function of K/L and prices:

$$RS(p,\tau,K/L)=\frac{x(p,\tau,K/L,1)}{y(p,\tau,K/L,1)}. \quad (28)$$

This yields a standard upward-sloping relative supply curve (increases in p increase the supply of X relative to Y). Because North and South differ in factor endowments and pollution policy, their relative supply curves will also differ. Figure 4 illustrates a couple of relative supply curves, labeled RS and RS^*.

[54] We rule out other differences to highlight the interaction between the pollution haven and factor endowment motives for trade.

The intersection of relative supply and demand curves determines autarky prices for each country, and we can then use these differences in autarky prices to infer the pattern of trade. We will use this model to consider the pollution haven and factor endowment hypotheses separately, and then consider how they interact.

Pollution Haven Hypothesis. The simplest version of a pollution haven model can be obtained by assuming countries are identical except for exogenous differences in pollution policy. Pethig (1976) used a Ricardian model in which countries differ only in exogenous emission intensities and showed that the country with weaker policy would export the polluting good. Graciela Chichilnisky (1994) assumed exogenous differences in the property rights regime—poor countries are simply assumed to have no property rights assigned to environmental resources, while rich countries have perfect policy.

Referring to figure 4, suppose North and South are initially identical. Then the two countries would have the same relative supply curve, which we illustrate as RS. Autarky prices would be the same, and there would be no trade. Now consider the effect of weaker pollution policy in the South than North ($\tau^* < \tau$). South's lower pollution tax will stimulate its X industry and contract Y (because resources move out of Y into X). This tells us that the country with the weaker pollution policy produces relatively more X for any given p; that is, South's relative supply curve will shift out to the right, as illustrated by RS^*.

We can therefore conclude that the autarky relative price of X is higher in the North than in the South: $p^A > p^{A^*}$. North has a comparative advantage in the clean good. The intuition is straightforward. Because North taxes pollution more heavily, relatively less of the polluting good is produced there, which pushes up its autarky price. This will generate trade. Once trade is opened, Northerners will import X from the South, and Southerners will import Y from

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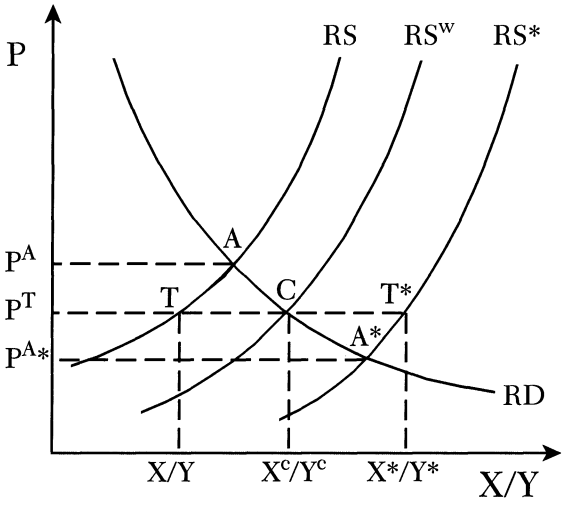

Figure 4. Trade Liberalization

the North. This contracts dirty-good production X in the North and stimulates it in the South. Moreover, because we have assumed that each country holds pollution taxes fixed, pollution moves in the same direction as X. Pollution rises in the country with weak pollution policy (here the South), and falls in the country with strict pollution policy (here the North). Trade induced by pollution policy differences creates a pollution haven in the country with weaker policy.

The welfare effects of such trade depend on the stringency of pollution policy, as we discussed in the previous section. If pollution policy is too weak, North must gain from trade, both because of an increase in purchasing power and because of the fall in pollution. South, however, may lose. Its income rises, but so does pollution. And if externalities are not fully internalized, the increase in pollution is harmful to the South.

The predictions of this simple pollution haven model are consistent with some criticisms of freer trade. North gains from trade by offloading some of its polluting production onto the South. Moreover, because the dirtiest industry is shifted to the parts of the world with weaker environmental policy, this "global composition effect" tends to raise world pollution.

Endogenous Pollution Havens: Income-Induced Policy Differences. A weakness of pollution haven models with exogenous policy is the exogenous policy. Although authors often motivate the pollution policy differences by income differences—such as a North-South income gap—pollution policies in these models do not respond when trade alters income levels. At best we should think of these as short-run models; at worst they contain a logical contradiction. The lack of a policy response affects both the positive and normative effects of trade even within a pollution-haven trading situation. To address this issue, we use our model to illustrate a simple version of the Copeland/Taylor (1994) pollution haven model where endogenous income-induced policy differences create, and, respond to, trade.

Consider two countries differing only in the scale of their endowment vector. That is, $K = \lambda K^*$ and $L = \lambda L^*$, where $\lambda > 1$. We also assume each country has the same number of consumers (which we normalize to one), so increases in L should be thought of as an increase in the supply of effective labor.

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Therefore, North's workers are more highly skilled than South's, but the ratio of capital to effective labor is the same in both. This means that North is richer than South, but because the K/L ratios are the same across countries, there is no incentive to trade in the absence of pollution policy.

We assume the regulator acts as a price taker in world goods markets when choosing pollution policy.[55] Because environmental quality is a normal good, the country with higher income chooses a higher pollution tax for any given goods price, and these differences in environmental policy create an incentive to trade. To demonstrate, refer to the relative supply curve given by (28). North and South have the same K/L ratio, but North's higher income means that its pollution tax is higher ($\tau > \tau^*$). Consequently, North's relative supply of X is to the left of South's for any given p. Figure 4 can therefore be used to infer the trade pattern again. North's high income gives it a comparative advantage in the clean good. When trade is opened, North will export the clean good (Y) and import the dirty good (X). The polluting industry will contract in the North and expand in the South. The low-income country becomes a pollution haven.

The effects of trade on pollution can be inferred from our earlier results. Pollution falls in the North, as both the substitution and income effects of trade liberalization induce the policy maker to choose less pollution. Pollution will rise in the South as long the income effect is not too strong.[56] Moreover, if income effects are not too strong, world pollution can rise with trade as well because the dirtiest industries shift to the country with weaker policy.[57] But because both North and South fully internalize pollution externalities, trade liberalization is welfare-increasing for both: income-induced policy differences are an efficient source of comparative advantage.

Overall, pollution haven models are consistent in their prediction that freer trade leads the country with weaker pollution policy to export the dirty good. In a model with endogenous policy, they predict that the low-income country has weaker policy and therefore the low-income country will export the dirty good. The effects of such trade on pollution and welfare, however, depend on the policy regime, as we have discussed above. A major weakness of the pollution haven models, however, is that they assume that policy differences are the only motive for trade.

Factor Endowments Hypothesis. The main alternative to the pollution haven hypothesis is what we have called the factor endowments hypothesis. We illustrate this in figure 5. Relative demand (RD) is as before. To isolate the pure factor endowment hypothesis, assume pollution taxes are identical and exogenous across countries, but relative factor endowments differ.[58] Specifically, suppose North is relatively capital abundant so that $K/L > K^*/L^*$.

Let RS^* denote South's relative supply curve. Because X is capital intensive and emission intensities are held constant, then North's capital abundance pushes its relative supply curve (RS) out to the right of South's. Hence the autarky relative price of X is lower in the North than in the South. With identical emission intensities across countries, the capital-abundant country (North) exports the capital-intensive (dirty) good. Trade expands the polluting, capital-intensive industry in the capital-abundant country (the North), and pollution rises in the North.

[55] That is, we assume that the regulator does not employ pollution policy to strategically manipulate the terms of trade in the goods market. This assumption is reasonable if we think of our model as a proxy for a world with many small Northern and Southern countries. We will turn, however, to the strategic trade policy issues later in this essay.

[56] In particular, if the elasticity of marginal damage with respect to income is less than or equal to one, then pollution rises with trade.

[57] See Copeland and Taylor (1994, 2003)

[58] That is, we assume that τ/p is identical across countries.

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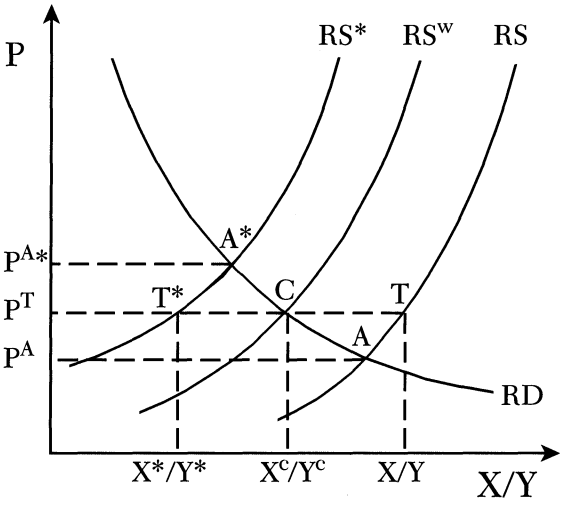

Figure 5. The Factor Endowments Hypothesis

Conversely, pollution falls in the capital-scarce country (the South) as the polluting industry contracts there.

Although we have illustrated the factor endowments hypothesis with a very simple example based on capital abundance, the key insight is that the impact of trade on the environment depends on a country's underlying production capabilities. Countries relatively abundant in factors used intensively in polluting industries will on average get dirtier as trade liberalizes, while countries that are relatively abundant in factors used intensively in clean industries will get cleaner with trade.

The predictions of this theory contrast sharply with those of the pollution haven hypothesis. If the factor endowments hypothesis is correct, and if a poor country is abundant in factors used intensively in clean industries, then its pollution will fall as trade is liberalized.

Factor Endowments and Endogenous Policy Differences. We have illustrated the pollution haven and factor endowment hypotheses in isolation, but of course countries differ in *both* their pollution policy and in their factor endowments. Rich Northern countries are likely to be both capital abundant *and* have stricter pollution policy than poorer Southern countries. North's strict pollution policy will tend to make it a dirty-good importer, but its capital abundance tends to make it a dirty-good exporter. The pattern of trade depends on which of these effects is stronger.[59]

If relative factor endowments are similar but North is richer than South, then pollution-haven effects dominate and North exports the dirty good. But if relative factor-endowment differences dominate relative income differences, then North will export the dirty good, despite having more stringent environmental regulation than the poor South.

Since this result reverses the pattern of trade under the pollution haven hypothesis, it has a number of important implications.

[59] The interaction between income differences and relative factor endowments in determining the pattern of trade is analyzed in Copeland and Taylor (1997, 2003), Yves Richelle (1996), and Werner Antweiler, Copeland, and Taylor (2001).

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When North is sufficiently capital abundant, trade will lead to an expansion of the dirty industry in the North, despite North's stricter pollution regulation and higher income. Although North's stricter environmental regulations do raise Northern production costs in X, this is more than offset by the relative abundance of factors used intensively in X. Trade need not induce dirty-industry migration from rich to poor countries, and in fact can lead to the opposite conclusion.

Moreover, this implies that if North is sufficiently capital abundant, and if the income elasticity of marginal damage is not too high, then trade will raise pollution in the North and lower it in the South. On the other hand, if the income elasticity of marginal damage is sufficiently high in the North, trade may reduce pollution in both North and South. This will occur if North's pollution supply shifts back far enough to offset the increased pollution demand induced by trade.

Finally, trade shifts dirty-good production from the country with weak pollution regulation (South) to the country where regulations are more stringent (North). This global composition effect tends to reduce global pollution.[60] This contrasts with the pure pollution haven model where trade tended to increase global pollution by shifting dirty-good production to countries with weak regulations.

Comparative Advantage Summary. As we have shown, the effects of trade on both the local and global environment depend on the distribution of comparative advantage across countries. Moreover, comparative advantage is determined jointly by differences in pollution policy and other influences, such as differences in factor endowments.

Pollution havens need not emerge if rich countries tend to be relatively abundant in factors used intensively in pollution-intensive industries. And if this is the case, then trade may lead to both a cleaner environment in poor countries, as well as a reduction in global pollution. It also means differences in pollution policy alone do not imply dirty industries will migrate to poor countries as a result of trade. Therefore, concerns about the loss of competitiveness in polluting industries may be misplaced. We should expect, however, to find heterogeneity across industries as well as countries in the roles played by policy and factor-endowment differences. Polluting industries that are intensive in unskilled labor or in natural resources may well be attracted to low-income countries both by natural-resource abundance and less stringent policy.

Even if rich countries do have a comparative advantage in dirty industries because of their factor abundance, this does not mean pollution policy is irrelevant for trade patterns. As our analysis indicates, for given levels of relative capital abundance, increases in the stringency of pollution policy will tend to erode a country's comparative advantage in dirty goods reducing their exports. Regulations are not irrelevant.

3.4 *The Empirical Evidence*

We now consider the empirical evidence. To limit the scope of our discussion, we focus here mainly on the empirical evidence linking liberalized trade with industrial pollution, although we also discuss some of the work on foreign investment and plant location.[61]

The literature has not always been clear about the hypotheses being tested. However, much of the attention has been directed towards three hypotheses about the effect of pollution regulation on trade flows. The first is simply that differences in pollution policy across countries or regions affect trade flows or plant location decisions. This might be

[60] For a formal demonstration see Copeland and Taylor (1997, 2003).

[61] For earlier reviews, see Levinson (1996) for a survey of the literature on plant location, and Jaffe et al. (1995) for a survey that reviews the empirical literature on the effects of environmental policy on plant location and trade in the United States. See also Wolfgang Keller and Levinson (2002). We discuss some of the papers reviewed by Jaffe et al., but our interpretation of their results differs in some cases.

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thought of as a test of the existence of a pollution haven "effect"—all else equal, a weakening of environmental policy will increase a country's net exports of dirty goods. This hypothesis is an implication of most theoretical work in the area. In terms of the model we presented in the previous section, regardless of a country's pattern of trade, a weakening of environmental policy will shift its relative supply curve outward, and thereby tend to increase its net exports of dirty goods.[62]

A much stronger version of the pollution-haven effect is what the literature has referred to as the pollution haven *hypothesis*. Under this hypothesis, free international trade leads to the relocation of dirty-good production from stringent regulation countries (the North) to lax regulation countries (the South). That is, the pollution-haven effect is so strong that it more than offsets other motives for trade in dirty goods. An often-stated corollary is that pollution-haven-driven trade raises pollution in the developing countries and lowers it in the developed world.

The major alternative to the pollution haven hypothesis is that the direction of trade in dirty goods is primarily determined by conventional determinants of comparative advantage-factor endowments and differences in technology. Under this hypothesis, the pollution-haven effect is swamped by other motives for trade. This view was behind Grossman and Krueger's (1993) evaluation of NAFTA, and references to it appear in numerous other studies. In our theory section, we presented one version of this view: under the factor endowment hypothesis, international trade leads to the relocation of dirty-good production from capital-scarce countries to capital-abundant countries. A corollary is that pollution levels should fall in capital-scarce countries and may rise in capital-abundant countries.

[62] If the country imports dirty goods, then its net exports of dirty goods are negative, and an increase in net exports means that its imports of dirty goods fall.

Although much of the empirical literature has focused on the above hypotheses, there have also been a few papers that try to estimate the effect of trade on environmental quality directly. These range from studies that simply add openness to trade as an additional explanatory variable in an EKC regression, to those that attempt to estimate the scale, technique, and composition effects of trade.

One of the major difficulties facing researchers in this area is that pollution data are very scarce. This scarcity has had a large impact on the evolution of the empirical literature. Many studies focus on the United States, simply for reasons of data availability. Some pollutants, such as SO_2, have been studied quite extensively, while others have been neglected, again because of data issues. Compounding this difficulty is that any credible examination of the pollution haven hypothesis needs data from some of the world's poorest countries. These countries have the least developed methods of accounting and monitoring.

In the following sections we describe and critique the methods and results from the empirical literature. To do so, we employ the models discussed in the earlier parts of this essay.

Dirty Industry Migration or Development? The first analyses in this area were relatively simple statistical exercises constructing and evaluating trends in dirty-good production, consumption, or trade. Given the lack of good cross-country pollution data, this literature "solves" the data problem by first classifying industries into the categories dirty or clean, and then constructing a broad cross-country panel of data on dirty and clean imports, exports, output, etc. for analysis. The categorization into dirty and clean is typically based on U.S. data. Industries may be categorized on the basis of their emission intensity (emissions per $ of output), toxic intensity (physical releases per $ of output), or the level of pollution-abatement costs as a fraction of value added.

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TABLE 1
RANKING OF THE DIRTIEST MANUFACTURING INDUSTRIES

Rank	Air	Water	Metals	Overall
1	Iron and steel	Iron and steel	Nonferrous metals	Iron and steel
2	Nonferrous metals	Nonferrous metals	Iron and steel	Nonferrous metals
3	Nonmetal. min.	Pulp and paper	Indust. chemicals	Indust. chemicals
4	Petro. coal prod.	Misc. manufac.	Leather prod.	Petro. refineries
5	Pulp and paper	Indust. chemicals	Pottery	Nonmetal. min.
6	Petro. refineries	Other chemicals	Metal products	Pulp and paper
7	Indust. chemicals	Beverages	Rubber products	Other chemicals
8	Other chemicals	Food products	Electrical products	Rubber products
9	Wood products	Rubber products	Machinery	Leather products
10	Glass products	Petro. products	Nonmetal. min.	Metal products

Source: Mani and Wheeler (1997, p. 4)

While this method is clearly not ideal, it has its strengths. For example, the set of dirtiest manufacturing industries appears to be fairly stable across both countries and pollutants. Therefore, identifying a dirty industry may not be that difficult. For future reference, we present the top ten dirty (manufacturing) industries ranked by air, water, and metals discharges. The data in table 1 are drawn from Muthikumara Mani and David Wheeler (1997).

Given the similarities in the rankings across air, water, and metals discharges, it appears that identifying the dirtiest manufacturing industries is relatively simple. The five dirtiest sectors often selected for intensive study are: iron and steel (371), nonferrous metals (372), industrial chemicals (351), pulp and paper (341), and nonmetallic mineral products (369). Using the same methods to identify clean sectors, Mani and Wheeler (1997) classify textiles (321), nonelectrical machinery (382), electrical machinery (383), transport equipment (384), and instruments (385) as the five cleanest sectors in U.S. manufacturing.

Under the assumption that this categorization of manufacturing industries into dirty and clean holds across both time and space, researchers construct the cross-country data needed for their analysis. Taking these new data as their dependent variable, these studies proceed by linking variation in dirty- and clean-good trends to country characteristics such as income, income growth, or openness. The analysis may employ simple summary statistics such as the Balassa revealed comparative-advantage measure, or employ regression analysis to explore the sensitivity of the series to several potential determinants. In all of these studies, researchers are searching for pollution havens; and therefore, income differences, income growth rates, and measures of openness are the prominent explanatory variables.

An immediate limitation of these studies is apparent: by measuring trends in dirty-industry output rather than pollution levels,

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they have necessarily assumed that changes in the composition of a country's output correspond to changes in environmental quality. But if the techniques of production change over time because of trade, income growth, or technological progress, then a greater share of dirty-good output is consistent with both greater and lesser pollution levels. And as section 3.1 showed, changes in the composition of output tell us relatively little about environmental outcomes except perhaps in the short run if emission intensities are fixed. Since many of these studies cover quite significant stretches of time, skepticism is in order.

A second concern is that since the composition of national output is affected by many factors, researchers in search of pollution havens run the risk of attributing any change in the composition of output to pollution-haven-driven trade rather than some altogether distinct domestic process. This risk is magnified by the avoidance of theory—which would naturally suggest alternative hypotheses—and an almost single-minded focus on income levels as a determinant of changing trade patterns.

Despite these limitations, several authors have employed these methods to conclude, sometimes tentatively, that the rise in environmental control costs in the developed world has led to the creation of pollution havens in the South. For example, Patrick Low and Alexander Yeats (1992) find that over the 1965–88 period, the share of dirty goods in exports from industrial countries fell from 20 percent to 16 percent, but over this same time period the share of dirty goods in exports from many poor developing countries rose.[63]

Other researchers, employing slightly different country groups and methods, corroborate these findings.[64] Ravi Ratnayake (1998), in a study of New Zealand's trade patterns, notes that in 1980, 96 percent of its imports of dirty goods came from the OECD, but by 1993 this had dropped to 86 percent. At the same time, the share of dirty goods imported from the developing countries increased from 3 percent to 11 percent; but their share in clean-good imports only increased from 9 percent to 13 percent over this same period. Similarly, New Zealand's exports of dirty goods to developing countries fell from 59 percent of exports to only 46 percent, while its exports of clean goods rose.[65]

Similar results are presented in Robert Lucas, Wheeler, and Hettige (1992). They examine the toxic intensity of manufacturing output and GDP for over eighty countries during the 1960–88 period. They note that while toxic releases per unit of GDP fall as countries become richer, this only occurs because the composition of output in richer countries becomes cleaner. Coupling this with a finding that the greatest toxic intensity growth occurred in the poorest countries leads the authors to conclude that all of their results are consistent with the view that "stricter regulation of pollution-intensive production in the OECD countries has led to significant locational displacement, with consequent acceleration of industrial pollution intensity in developing countries."[66]

Nancy Birdsall and Wheeler (1992), in a study of pollution havens in Latin America, reach similar conclusions. They state: "Our

[63] See table 6-2, p. 94. Developing country reliance on dirty-good exports varies by region. In Eastern Europe the percent rises from 21 percent to 28 percent; in Latin America from 17 percent to 21 percent; in South-East Asia the share of dirty-good exports in total exports is flat at 11 percent; and in West Asia it rose from 9.2 percent to 13 percent.

[64] Xinpeng Xu (1999) finds little statistical evidence for a change in competitiveness based on a primarily OECD sample. The raw data, however, indicate that for OECD countries, environmentally sensitive goods have fallen from 24 percent of exports in 1965 to 18 percent in 1995; whereas for the "other" category these shares have moved from 18 percent in 1965 to 22 percent in 1995. See table 1, p. 1219.

[65] See Ratnayake (1998), tables 1 and 2, p. 82.

[66] See Lucas et al. (1992, p. 80).

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evidence is strongly consistent with the displacement hypothesis: Pollution intensity grew more rapidly in Latin America as a whole after OECD environmental regulation became stricter" (p. 167). Finally, in one of the most carefully constructed of these studies, Mani and Wheeler (1997) examine the production and consumption of dirty goods for several developing-country regions plus Europe, North America, and Japan over the 1965–95 period. Their conclusions are more tentative than most, but they note (p. 28):

> Our cross-country evidence has found a pattern of evidence which does seem consistent with the pollution haven story. Pollution-intensive output as a percentage of total manufacturing has fallen consistently in the OECD and risen steadily in the developing world. Moreover, the periods of rapid increase in net exports of pollution-intensive products from developing countries coincided with periods of rapid increase in the cost of pollution abatement in the OECD economies.

The trends these authors identify are not really at issue, but the inferences drawn from them are. To underscore this point, we make use of the models from section 3.1 to illustrate how the findings are consistent with *all* of the first three hypotheses outlined at the beginning of this section.

First suppose the pollution haven hypothesis is correct. Then as trade was liberalized throughout the sample period, we would expect to find each country specializing more in the goods in which it has a comparative advantage. The share of dirty goods in exports would fall in richer countries and rise in poorer countries, which is consistent with what has been found in these studies.

Next suppose that a pollution haven *effect* is present, but not necessarily strong enough to make South a net dirty-good exporter. Then consider the effects of a tightening of pollution policy in the North, as it was throughout this time period. Referring to figure 5, North's relative supply curve would shift to the left, as would world relative supply, pushing up the world price of dirty goods. As a result, some dirty-good production would shift from North to South, again causing the share of dirty goods in exports to rise in the South and fall in the North, as is consistent with the trends found by many authors in this branch of the literature.

Finally, suppose there is no pollution-haven effect at all, and the factor endowments hypothesis is correct. That is, suppose that pollution policy plays little or no role in influencing trade flows. As well, suppose there is capital accumulation in the South during this time period. This alternative scenario is presented in the two panels of figure 6 below.

In the left panel we again depict North's and South's relative supply curves. We assume that North is capital abundant and has a comparative advantage in the dirty industry. The initial world equilibrium is shown in the right panel at A with a price p^0.

Now consider the impact of an increase in South's capital stock.[67] Since capital accumulation favors the dirty industry, South's relative supply curve shifts outwards from RS^* to RS^{*1}. World relative supply shifts out as well from RS^W to RS^{W1}. The world price of dirty goods falls from p^0 to p^1 with the new equilibrium at point B in the right panel. We note, using the left panel, that the North specializes less in dirty goods since $N^1 < N$ while the South specializes more in dirty goods since $S^1 > S$. Therefore, capital accumulation in the South implies a development path concentrating on capital-intensive dirty industries. Heightened competition in world markets caused by Southern development leads the North to shift out of these sectors, thereby concentrating on relatively clean manufactures. As a result, figure 6 roughly mimics the trends reported by many authors—although the reasons for these

[67] We only need that Southern growth be biased towards the dirty sector, while Northern growth is either slower or not biased in this direction.

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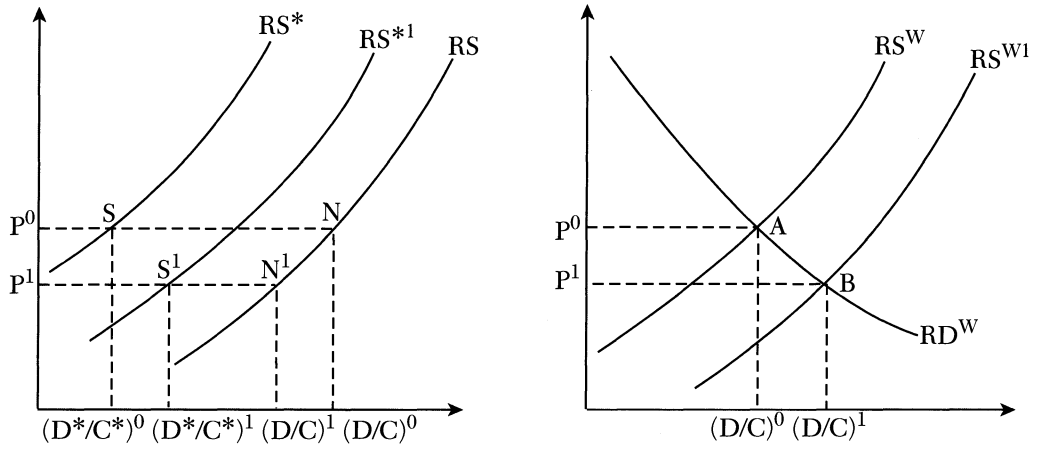

Figure 6. Southern Economic Development

trends are entirely different. Rather than finding dirty-industry migration and pollution-haven-driven trade, these studies may have instead found Southern economic development!

To disentangle these different possible explanations for the observed trends, researchers could adapt the theoretical framework set out in section 2 to sort out the competing effects theoretically and proceed to empirical testing.[68] Current work, however, has neglected the possibility of differential rates of factor accumulation across North and South to focus almost exclusively on the role of income.[69]

To see why the capital accumulation hypothesis is worth pursuing, we offer three pieces of evidence. First, Low and Yeats (1992) report that over 90 percent of all dirty-good production in 1988 was in OECD countries. This fact alone should tell us that the location of dirty-good production across the globe reflects much more than weak environmental regulations.

Second, note that one major difference between the capital accumulation explanation and the presence of a pollution-haven effect is the prediction for the world price of dirty goods. The price of dirty goods rises if a tightening of Northern regulation causes dirty-industry migration, but falls if Southern economic development is responsible (recall figure 6). As evidence on this score, we present in figure 7 the relative price of the five dirty-industry composites over the period 1965–2000. For ease of reading, (real) producer prices are normalized to unity in 1965.[70]

The figure clearly shows no strong upward trend in dirty-good prices over this period as would be predicted if a tightening of Northern pollution regulations drove trade. In fact, with the exception of pulp and paper,

[68] Since the data exhibits two-way trade in both dirty and clean goods, our competitive dirty and clean industries could be replaced by monopolistically competitive sectors with identical firms.

[69] Mani and Wheeler (1997) examine trends in domestic factor prices as a possible cause for changes in dirty-good output in the developed world, but our analysis here points to changes in factors of production in developing countries as the primary cause.

[70] The producer price series for each three-digit SIC industry are annual averages available from the Bureau of Labor Statistics website http://stats.bls.gov. These are then deflated by the GDP price deflators from the U.S. Department of Commerce, BEA at http://www.bea.doc.gov/ to render the price measured in terms of real U.S. 1982 dollars.

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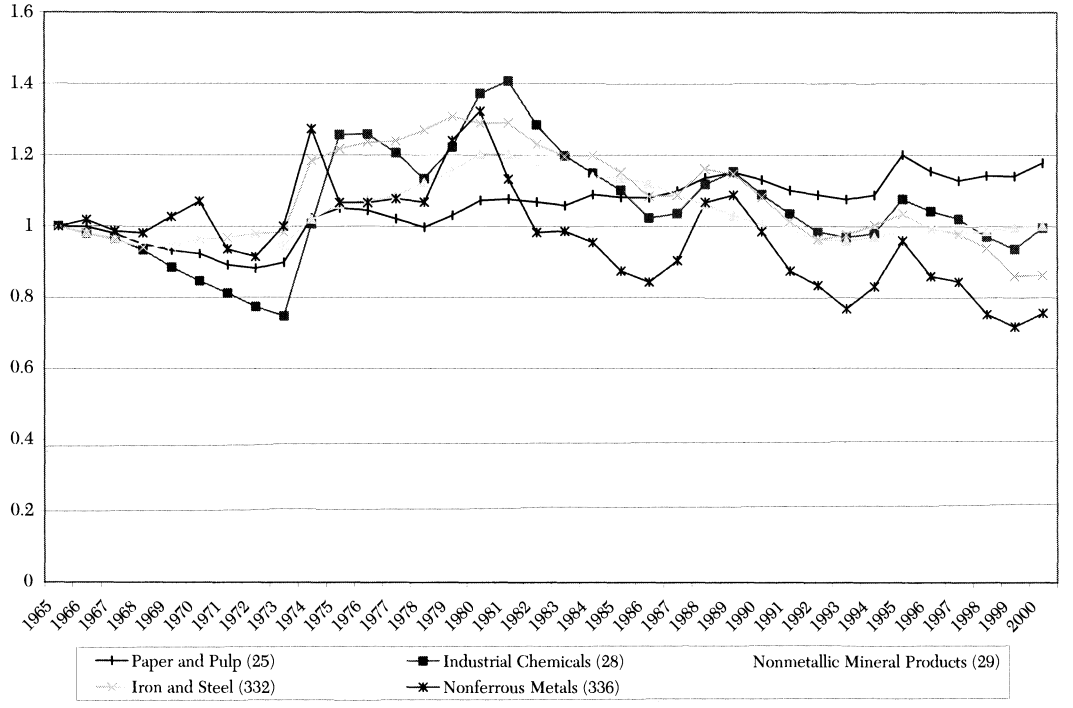

Figure 7. Trends in Dirty-Good Prices

all of the real producer price indices are either flat (as is the case for industrial chemicals and nonmetallic minerals) or declining as illustrated by both iron and steel and nonferrous metals. While other explanations can be found for these trends, on their face these data are inconsistent with the view that tighter regulation in the North drove up costs of production to such an extent that dirty industries had to migrate to less-suitable pollution havens in the South.[71]

The last piece of evidence for an alternative hypothesis is provided by the studies themselves. Several authors report that while their empirical results show all developing countries alter the mix of their production towards dirty goods, more open developing countries have a cleaner mix of industries than their closed counterparts. For example, Birdsall and Wheeler (1992; p. 167) note: "The econometric evidence, though at best exploratory, suggests that over the last two decades the more open economies have ended up with a cleaner set of industries". And Lucas et al. (1992; p. 80) qualify their results on the pollution havens by stating: "Pollution intensity has grown most rapidly in developing countries which are relatively closed to world market forces...The opposite seems to have been true, however, for more open economies."

If the pollution haven hypothesis were correct, we would expect to see the opposite. To see why, note that under the pollution haven hypothesis, South has a comparative advantage in dirty goods. Therefore import substitution policies by

[71] Technological progress is a possible explanation, but note since these are real prices we need to assume the rate of technological progress in dirty industries was greater than that in all of manufacturing. This is a harder case to sell. Changes in the demand for these products as incomes rise is also a possibility.

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Southern countries would *lower* the share of dirty goods in Southern production and not raise it. Under the pollution haven hypothesis, relatively closed Southern countries should have a cleaner mix of industries; it is, after all, trade that is making them dirtier![72]

Alternatively, under the Southern economic development scenario, the observations on the mix of dirty industries have a natural explanation. In this view, North has a natural comparative advantage in dirty goods. Import substitution policies by Southern countries raise the share of dirty goods in Southern production. Therefore, under the factor endowment/economic development explanation, closed Southern economies should be relatively dirtier than their open counterparts. This is consistent with the empirical findings.

While our analysis of the role of Southern capital accumulation in explaining the evidence is only suggestive, our point is that there are reasonable alternatives to the simple pollution-haven explanations that need to be considered when interpreting the evidence. The literature focusing on trends in dirty-good production and trade has made a useful start in generating some stylized facts, but is still only in the early stages of explaining them.[73] Future analysis must rely more heavily on theory to suggest alternative hypotheses and discipline inferences from the available data. In particular, we suggest an investigation of the role of factor accumulation in determining the pollution intensity of national output. The search for pollution havens in the data has obscured the role capital accumulation and natural resources must play in determining dirty-industry migration and trade.

Environmental Stringency and International Competitiveness. A second branch of the literature uses data on the stringency of environmental policy to test whether or not environmental policy affects trade flows, foreign investment flows, or plant location choices. In our terminology, these studies can be interpreted as a test for the existence of a pollution-haven effect.

These studies came in two waves. Virtually all of the early work (up to about 1997) relied on cross-sectional data. These studies link the cross-sectional variation in trade or investment flows to industry-, country-, or region-specific measures of regulatory costs and other variables that affect trade and investment, such as factor costs. The almost universal conclusion drawn by authors of these studies is that environmental-policy differences across countries or regions have little or no effect on trade or investment flows. A second wave of more recent work explicitly accounts for the endogeneity of pollution policy and unobservable industry- or country-specific variables that may affect trade or investment flows. In sharp contrast to the earlier work, these studies have tended to find that differences in environmental policy do affect trade and investment flows. We will start by briefly reviewing the cross-sectional studies,[74] discuss some of the problems with this approach, and then review recent work.

[72] If a pollution-haven effect were operative, but North had a comparative advantage in dirty goods, then the model's predictions in this regard are more ambiguous. One the one hand, if South has a comparative advantage in clean goods, then in the absence of any environmental policy in the North, more closed Southern countries would have a dirtier mix of goods. But if North introduces and tightens environmental policy, then dirty-good production would shift to countries in the South that are both open and have relatively weak environmental regulations. This could mean that if the pollution-haven effect is operative, more open Southern countries may have a dirtier mix of goods than more closed Southern countries.

[73] However, future research must proceed carefully. For example, it would be useful to be more precise concerning the types of measurement error introduced by the classification of industries into dirty and clean. What assumptions are we making concerning this error? Is it correlated across time, countries, or industries?

[74] These were reviewed in more detail by Jaffe et. al. (1995) and Rauscher (1997).

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The studies using trade data are all motivated by the Heckscher-Ohlin-Samuelson (HOS) model of international trade. James Tobey (1990) is a widely cited study of this type. He regressed cross-country data on exports of five dirty commodity groups on country-specific measures of factor endowments and environmental stringency for a group of 23 countries.[75] In all the regressions reported, Tobey found the environmental stringency variable to be an insignificant determinant of net export flows. Moreover, in a follow-up omitted variable test conducted with a larger cross-section of countries, Tobey was not able to reject the hypothesis that environmental stringency had no effect on net exports.

However, while Tobey's analysis is perhaps the most cited study arguing against a link between environmental stringency and trade flows, its conclusions rest on tenuous foundations. His main results follow from a series of five cross-country regressions, one for each commodity group. Each of these regressions has only ten degrees of freedom. Not surprisingly then, the vast majority of the coefficients estimated are insignificant.[76] While the stringency variables are insignificant, so too are 55 of the 65 coefficients estimated. In fact, most of the factor endowments are insignificant most of the time. Only one of the twelve included factor endowments is significant in three commodity groups (capital); and only one other is significant in more than one commodity group (a specific variant of land). Insignificance is the norm in these regressions.[77]

Another approach is to link the cross-sectional variation in trade flows to industry characteristics. Joseph Kalt (1988) and Grossman and Krueger (1993) are examples of this approach.[78] A typical study of this type employs U.S. data on the cross-sectional pattern of trade in manufactures together with data on factor shares and pollution abatement costs. The standard study would estimate the following equation:

$$T_{it} = \beta_0 + \beta_1 S_{it} + X'\beta + \mu_{it} \qquad (29)$$

where T_{it} is a measure of trade flows in industry "i" in year t such as the value of net exports, S_{it} is an industry specific measure of environmental stringency, and X is a matrix of other controls which differ across studies. These controls are typically the cost shares of labor (sometimes disaggregated by skill class), the cost share of capital, and in some cases tariff rates. The set of industries studied is often the entire U.S. manufacturing sector, but sometimes the analysis is limited

[75] This approach builds on the empirical trade literature, in particular Ed Leamer (1984), who explains net export flows as a function of factor endowments. Tobey adapts this approach by adding a qualitative indicator of a country's environmental policies

[76] Student's t for a two-sided test is 2.22 at the 5 percent level when there are ten d.f. We will adopt this level as representing statistically significant.

[77] Further concern follows from an examination of the omitted variable test. Tobey expands his collection of countries from 23 to 58, and excludes environmental stringency as a regressor in his cross-country regressions. He then divides his sample of countries into three groups according to development level and compares the proportion of positive and negative residuals from his net export regressions within each development group. Tobey is unable to reject the null hypothesis of identical proportions of errors; therefore, excluding environmental stringency does not lead us to overpredict or underpredict net exports in a systematic way across country groupings. But this test relies on the assumption that the omitted variable (environmental stringency) is orthogonal to the set of included regressors (Tobey 1990, p. 199, assumption A1). This requires that (unmeasured) pollution regulations be orthogonal to all of the country characteristics described by its endowments of capital, land, minerals and oil. But these characteristics determine both a country's production structure (i.e. its demand for pollution) and its national income (i.e. the supply of pollution). If we really believed the maintained orthogonality assumption, why would we be interested in grouping countries according to development level to conduct such a test?

[78] See also Thomas Osang and Arundhati Nandy (2000), and Cees van Beers and Jeroen van den Bergh (1997).

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to the set of manufacturing industries that are most pollution intensive.

The measure of trade flows, T_{it}, differs across studies. Since the underlying model motivating the equation is the HOS model, net exports is the most comfortable choice. Since industries differ in scale so dramatically, most authors scale the dependent variable by industry shipments, value-added, or domestic consumption. The measure of environmental stringency is pollution abatement costs divided by industry value-added. This series is available for both capital and operating costs for all of U.S. manufacturing going back to the early 1970s. Most authors employ the operating cost series.

The almost universal finding in this literature is that pollution-abatement costs do not appear to explain the cross-sectional pattern of trade. In some studies, the sign of the coefficient on abatement costs is found to be counterintuitive, suggesting a positive relationship between tighter regulation and net (or gross) exports. This awkward sign on the pollution-abatement cost variable has not led to a wholesale reexamination of the estimation methodology, but instead is often cited as evidence in favor of the Porter hypothesis (see Michael Porter and Cees van der Linde 1995). Porter et al. argue that tighter environmental regulation spurs technological innovation, and hence tighter regulation could, in theory, raise exports or lower imports.[79]

Despite the sometimes troubling sign on the pollution-abatement cost variable, the inference drawn from these studies was that there is little connection between the stringency of environmental regulation and trade flows. The explanations for this finding by the authors of these studies varied, but most often included the fact that pollution-abatement costs are only a small fraction of total costs.[80]

Recent work, however, suggests that there are some more fundamental problems with this approach. Endogeneity of pollution-abatement costs, and unmeasured industry characteristics may well be responsible for the results found.

We illustrate the problem with the aid of figure 8. The left panel depicts a pollution demand and supply curve from our model of section 2. The right panel depicts import demand for the dirty good. This is graphed as a function of world prices, and shifts in response to changes in pollution taxes and another variable ξ which we assume is not observed by the researcher. We suppose increases in ξ shift in import demand.

The existing literature links pollution-abatement costs to imports, conditional on some observable control variables, such as factor endowments or costs. To see the logic behind this approach, first suppose pollution taxes are exogenous, and suppose the pollution tax rises from τ_0 to τ_1. Firms abate more intensively and abatement costs as a fraction of value-added rise. Pollution falls to z_1 along the given pollution demand curve D^0. (The pollution supply curve is not relevant at this point if we treat τ as exogenous).

In the right panel, the import demand curve shifts outward as less of the dirty good is produced. Imports rise to M^1. This exercise predicts a positive relationship between

[79] They state, "in this paper, we will argue that properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with them. Such 'innovation offsets' … will be common because reducing pollution is often coincident with improving the productivity with which resources are used"(p. 98). An entirely different view of regulation's effect on productivity is presented in Wayne Gray (1987).

[80] Another potential problem is suggested by the factor price equalization theorem of international trade. Suppose trade really is driven by differences in pollution policy. Then trade will reduce pressure on the environment in the North (which would tend to lower abatement costs there) and increase pressure on the environment in the South (which would tend to increase abatement costs). That is, trade could lead to some convergence in marginal abatement costs across countries, which would tend to make it more difficult to identify the effects of pollution policy on trade flows.

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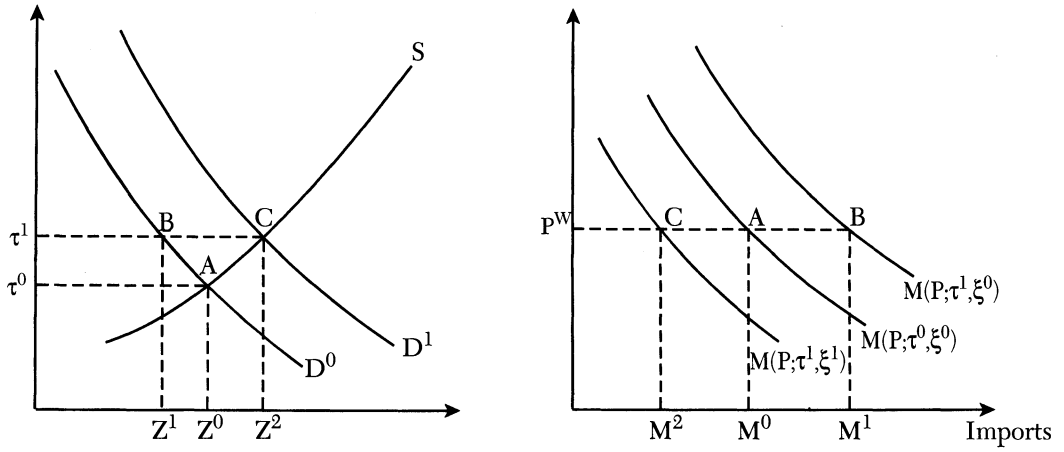

Figure 8. Imports and Pollution Regulation

the stringency of regulation, pollution abatement costs, and imports. Alternatively, if the country exported the dirty goods we would have found tighter regulation lowering net exports in this industry. In either case, the model predicts that we would observe a pollution-haven effect: tighter pollution regulation reduces the competitiveness of domestic industry.

This logic can break down if pollution regulation is endogenous. Again, start at point *A*, but now suppose that pollution taxes are determined by the intersection of pollution supply and demand. Now consider an increase in industry size (created for example by factor accumulation favoring the one industry shown). In our framework, this corresponds to an increase in ξ. In the left panel, pollution demand shifts outward and the pollution tax rises as increased pressure in placed on the environment. (The pollution supply curve may shift back as well due to higher income, further increasing the pollution tax, but for simplicity, we have not drawn this effect.) Pollution-abatement costs rise as before.

In the right panel, industry growth shifts the dirty-good import demand inwards and imports fall to M^2. Imports fall because factor accumulation raises domestic output. The increase in the pollution tax will dampen, but not reverse, the shift in the import demand curve. We now find a negative correlation between imports of dirty goods and pollution-abatement costs.

Therefore an unmeasured industry characteristic that shifts pollution demand rightwards and lowers imports will confound typical estimates. We have illustrated this potential problem by assuming that industry-specific growth creates comovements in pollution-abatement costs and imports. But many other determinants could work as well.

For example, suppose pollution-intensive goods have higher than average transport costs (the cement industry comes to mind). Then the domestic dirty-good industry has natural protection from imports. Transport costs shift pollution demand rightwards because the domestic price now exceeds the world price for the imported good. As well, a higher domestic delivered price lowers imports. If we fail to include transport costs in our estimation, then our cross-sectional results will again be tainted. If transport costs are higher in pollution-intensive industries, we may find pollution-abatement costs negatively related to imports.

Alternatively, suppose pollution-intensive industries are natural-resource intensive.

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This is surely true for many of the dirtiest industries in manufacturing, as evidenced by table 1.[81] If natural-resource intensity is not accounted for, we are again missing a shift right in pollution demand—because natural resources are a complementary factor—and a shift left in import demand—because domestic production is higher than would be predicted on the basis of conventional factor endowments. As a result, estimations may again reveal a negative relationship between pollution-abatement costs and imports.

A related problem arises if trade and environmental policy are linked via the government's policy process. In this case, import penetration and pollution-abatement costs are determined simultaneously. Antweiler et al. (2001) discuss two possible links between trade and environmental policy. The first arises when a government is politically motivated. Suppose factors specific to polluting industries are hurt by trade liberalization that reduces a tariff on dirty-good imports. Then a politically motivated government may be tempted to compensate these factors by weakening environmental regulation after trade liberalization occurs. As a consequence, imports rise by less than expected, pollution-abatement costs are lower than expected, and the correlation between pollution-abatement costs and imports is weakened.[82]

The second arises when the economy is large and has the ability to manipulate world markets by altering pollution policy. A dirty-good importer has an incentive to impose an optimal tariff to improve its terms of trade. If a negotiated tariff reduction takes place, the government has an incentive to look for an alternative instrument to use in place of the tariff. Relaxing its pollution regulations will provide an implicit subsidy to the polluting industry and therefore can be a second-best instrument to generate beneficial terms of trade effects. Again we find that a policy linkage leads governments to lower pollution taxes when imports rise, and raise pollution taxes when exports rise. Consequently, if these tariff-substitution effects are present in the data, it will be difficult to identify any direct competitiveness effect arising from tighter regulation.

While the analysis above may be suggestive of potential problems, it is not proof of them. The empirical literature, however, reveals ample evidence consistent with these concerns.

Kalt (1988) finds a positive relationship between net exports and pollution abatement costs, which on its face is directly opposite to what is expected. The relationship becomes negative, however, once natural-resource industries are excluded. This negative effect is further enhanced when one of the dirtiest industries—the chemicals industry—is removed. One explanation for these results is unmeasured industry heterogeneity. If pollution-abatement costs are positively related to unmeasured natural-resource intensity, and natural resources are a productive factor, then these industries will have larger domestic production. Pooling across industries that vary in their reliance on natural resource intensity could well produce the spurious positive result. Removing these industries leads to the expected result.

In addition, if the chemical industry is large and productive, its success may well have created the tighter regulations it faces and enlarged its world market. In our

[81] Further evidence on this score is provided in David Robison (1988) who calculates the direct plus indirect pollution-abatement costs embodied in 1$ of output for twenty two-digit sectors in the United States in 1977. On this metric, the top six dirtiest sectors are electric utilities (5.4 percent), agricultural fertilizers (2.5 percent), copper (2.4 percent), ferrous metals (2.2 percent), paper (2.0 percent), and other nonferrous metals (1.8 percent); See table 1, p. 704.

[82] Paavo Eliste and Per Fredrikkson (1999) find increases in the stringency of regulation offset to some extent by an increased value of government transfers (including tariffs). This evidence is consistent with the political economy motivations discussed here. Van Beers and van den Bergh (1997) interpret their finding that tighter home-country regulation lowers imports as suggesting a political-economy link between tariffs and environmental regulation

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framework, both unmeasured natural-resource intensity and industry productivity shift pollution demand rightwards and import demand leftwards, obscuring the simple higher pollution-abatement cost–lower imports link.[83]

Grossman and Krueger also report counterintuitive signs for their pollution-abatement cost variable in four of the six cross-industry regressions explaining U.S. imports from Mexico. In only two of these cases is the negative relationship statistically significant at the 5 percent level. Nevertheless, the results are troubling, and the authors themselves note the strange sign on this cost variable may be arising from omitted variable bias.

Further support for our interpretation is evident in related literatures. For example, consider Daniel Trefler's well-known (1993) empirical paper on endogenous trade protection. Trefler notes that empirical research had found only an embarrassingly small impact of tariff reductions on trade flows. He suggests that it arises from the treatment of trade barriers as exogenous. Trefler adopts a cross-sectional regression framework quite similar to that discussed above and estimates a standard one-equation model treating import barriers as if they were exogenous. He finds nontariff barriers have a small negative effect on imports. When non-tariff barriers are treated as endogenous, the results are striking: Trefler's estimate for the impact of trade restrictions on imports is ten times higher.[84]

More direct evidence is presented in Levinson (1999), who examines the relationship between state-to-state hazardous waste shipments and import taxes on hazardous waste. Levinson regresses state-to-state waste shipments on state characteristics, distances, and waste tax rates. With no correction for endogeneity or unobserved heterogeneity, he finds a positive and statistically significant relationship between import taxes and imports of disposal waste. Once he accounts for the potential endogeneity, he finds a strongly negative and significant relationship. Higher waste taxes deter imports of hazardous waste.

These two studies show how endogeneity and unobserved characteristics can lead entire literatures astray. Given the wide variance in results reviewed here, it is likely that similar problems abound in the literature on the effects of pollution policy on international trade flows. Two recent studies have made some progress on this front. Levinson and Taylor (2002) present a simple model with endogenous pollution policy to suggest an empirical strategy testing for the impact of regulations on trade flows. They identify industry size, natural-resource intensity, political-economy concerns, and tariff substitution as likely candidates creating a link between regulation and imports. They then estimate a two-equation model adopting a methodology similar to Trefler (1993). The results are similarly striking. In the cross-section regressions with no correction for endogeneity there is little relationship between net exports and pollution abatement control expenditures; however, once they instrument for pollution-abatement costs, the results change dramatically. Tighter pollution regulations lower net exports significantly.

Similarly, Josh Ederington and Jenny Minier (2003) examine the link between pollution abatement costs and imports in a setting where imports and control costs are determined simultaneously. They motivate their work on the basis of tariff-substitution as outlined above. In their fixed-effects implementation they find a small but statistically significant relationship between pollution control costs and imports. A 1-percent point change in costs raises import penetration by 0.53 percent points. In contrast, their

[83] Osang and Nandy (2000) employ both industry and time fixed effects which makes it more difficult to attribute their results to unobserved (constant) industry attributes. The endogeneity of regulation, however, could still be responsible for the results.

[84] See table 5, p. 150, column 1.

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3SLS estimates which account for the possibility that pollution policy responds to import flows endogenously yields an unbelievably large impact, with a 1-percent increase in pollution-abatement costs raising import penetration by 30 percent. Further work along these lines is certainly required.

Similar results have been found in the literature on plant location. The main conclusion from studies using cross-sectional data from U.S. states was that differences in pollution policy across states do not affect plant location decisions (see Levinson 1996 for a review). These studies are subject to the same types of endogeneity problems discussed above (see Vernon Henderson 1996). In response to this problem, several recent studies have used panel data and found negative and statistically significant effects of environmental policy on plant location or manufacturing activity.

Randy Becker and Vernon Henderson (2000) used a panel of U.S. county-level data. The measure of the stringency of environmental regulations was whether or not a county had attained the Clean Air Act's national air quality standards. Since states are required to enforce strict environmental regulations in counties not in compliance with the national standards, nonattainment status is taken as an indicator of relatively more stringent environmental policy after the Act was passed. This study addresses three problems in the earlier plant-location literature. First, many studies had used a state-level indicator of the stringency of environmental regulation. This use of aggregate state-level data meant that regulatory differences within states could not be accounted for, and so much potential variation in the data was lost. Second, since the air quality standard was set at the national level, and not in accordance with conditions within individual counties, the endogeneity problem we discussed about is mitigated. Finally, the use of panel data allowed them to control for unobserved heterogeneity across locations. The results are striking, as plant births for polluting industries in non-attainment counties were 26–45 percent below those in attainment counties. This suggests that air quality regulations had a significant negative effect on plant location.

Other researchers have confirmed these results. Matthew Kahn (1997) found that the growth of manufacturing activity was reduced in non-attainment counties. Michael Greenstone (2002) found a negative effect on plant-level growth and employment in polluting industries in non-attainment counties. John List et al. (2003) control for additional endogeneity issues and also find strong evidence that the Clean Air Act affected plant location in the United States.

Keller and Levinson (2002) use different data to provide further evidence that environmental policy affects investment decisions, and that endogeneity problems were at least partly responsible for the failure of the earlier literature to find a significant effect. They use U.S. state-level data on foreign direct investment inflows from 1977–94. Their measure of the stringency of environmental regulations is an index of pollutant abatement costs per unit of output in the state (which they adjust to take into account industrial composition effects within the state).[85] They first replicate the results of earlier studies by using a pooled OLS regression of direct foreign investment on the index of abatement costs, *without* including state effects. The results indicate that DFI appears to be *positively* correlated with abatement costs, although in some cases the coefficient is insignificant. This is the same type of result the earlier cross-sectional studies found. Once they include state fixed effects, however, they find that the coefficient on abatement costs is negative and significant, as theory would predict.[86]

[85] The issue here is that states that attract polluting industries will have higher average abatement costs even if they face the same regulations as other states, because of the composition effect. Levinson (2001) proposes an index to correct for this.

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This strongly suggests that unobserved state-level variables correlated with abatement costs and investments were driving the earlier results.

Summary. There is still much more work to be done on this issue. The investment and plant location studies have all used U.S. data, and most have relied on the Clean Air Act.[87] Nevertheless, this growing body of work represents a significant reversal of the earlier findings that pollution policy did not affect trade or investment. There are very few studies, however, that explicitly account for endogeneity of pollution policy when examining the impact of tighter pollution regulations on trade flows. But even if this work stands up to further testing and scrutiny, it is important to emphasize the evidence found supports the existence of a *pollution-haven effect* only. The evidence indicates that after controlling for other factors affecting trade and investment flows, more stringent environmental policy acts as a deterrent to dirty-good production. None of this work presents evidence that this deterrent effect is strong enough to be the primary determinant of the direction of trade or investment flows.

It seems likely, however, that differences in pollution policy may have a larger effect on trade and investment flows in the future. Some elements of pollution-abatement costs have been rising quite rapidly over time. For example, in 1984 pollution-abatement capital expenditures represented only 2.8 percent of new capital expenditures in all U.S. manufacturing industries, but by 1993 this share had risen to 7.0 percent. The increase in pollution abatement operating costs is much smaller from .63 percent of total costs in 1984 to only .79 percent in 1993.[88] Unless we are willing to assume that these costly investments are somehow undone by Porter's "innovation offsets," or merely reflect problems in survey methods, rising pollution-abatement costs must have some effect on trade flows and perhaps world prices.

Scale, Composition and Technique Effects. Finally we turn to a group of studies attempting to estimate and then add up the scale, composition and technique effects arising from trade liberalization. Although the notion of scale, composition and technique effects predates Grossman and Krueger (1993), economists did not pay much attention to this conceptual breakdown until they employed it to assess the environmental impact of NAFTA.[89] As such the Grossman and Krueger study was the first to fashion a logical argument along these lines.

On the basis of their estimated EKC for sulfur dioxide, Grossman and Krueger concluded that any income gains created by NAFTA would tend to lower pollution in Mexico. This followed since Mexico's then current per-capita income placed them on the declining portion of their estimated hump-shaped EKC. Since the shape of the EKC was taken to reflect the relative strength of scale versus technique effects, Mexico was literally now over the hump. Future income gains would call forth tighter regulation and lower pollution.

To evaluate the composition effect of trade, Grossman and Krueger relied on both the evidence presented in their cross-sectional regressions and the results from CGE

[86] Although the effect is significant, it is not large—a doubling of abatement costs reduces direct foreign investment by about 10 percent.

[87] Attempts to examine the pollution haven effect between rich and poor countries directly are hampered by data limitations. Gunnar Eskeland and Ann Harrison (2003) examine inward investment into four developing countries and find little or no evidence that either emission intensity or differences in U.S. environmental policy across industries affect inward investment into these countries. They do not have data, however, on host-country environmental policy, and although they do control for unobserved differences across countries, they have only four different host countries to work with.

[88] These figures are drawn from Osang and Nandy (2000). As well, see the discussion of potential errors in reporting capital expenditures on pollution abatement in Jaffe et al. (1995; p.142)

[89] Grossman and Krueger (1993) credit a 1990 government report for the introduction of the scale, composition, and technique effect terminology.

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work by Druscilla Brown, Alan Deardorff, and Robert Stern (1991). The cross-sectional regressions discussed earlier indicated that U.S. comparative advantage was in human and physical capital-intensive industries, which suggested that NAFTA would shift Mexican production towards low-skilled, and presumably less pollution-intensive, manufactures. While it is difficult to isolate the pollution consequences of this composition effect, Grossman and Krueger note that CGE estimates from Brown et al. (1991) indicate a fall in the demand for electric utilities output in Mexico. This occurs via the industrial restructuring created by the trade liberalization. Since utilities are major polluters—especially with regard to sulfur dioxide—it appears that the composition effect for Mexico was likely to be slightly beneficial to the environment. In contrast, utility output was forecast to rise slightly in both the United States and Canada.

These conclusions are altered somewhat if we assume NAFTA spurs capital accumulation in Mexico. For example, Brown et al. present CGE results assuming a NAFTA-inspired 10 percent increase in Mexico's capital stock. In this case, while the trade liberalization per se appears to be beneficial to Mexico's environment, a 10 percent increase in the capital stock drives up electric utility output by 9 percent, which would tend to increase emissions from utilities.

Similar results obtain when Grossman and Krueger calculate the change in toxic releases implied by the industry reallocations predicted for NAFTA. Again using the CGE output from Brown et al. (1991), trade liberalization alone appears to lower toxic releases in Mexico while it raises them in the United States and Canada. If we again assume a NAFTA-induced change in Mexico's capital stock, then toxic releases rise in Mexico.

Combining the evidence on scale, technique, and composition effects, Grossman and Krueger concluded that trade liberalization alone via NAFTA should be good for the Mexican environment, but if NAFTA led to increased capital accumulation, then the picture is less clear.

Despite the limitations mentioned previously, the Grossman-Krueger study was far ahead of existing work in this area. They employed a theoretically based methodology for thinking about the environmental impacts of trade, and presented empirical evidence on these scores. Future research was left to improve on their start and to deal with some unanswered questions.[90]

Judith Dean (2002) estimates the impact of trade and growth on water quality in several Chinese provinces and interprets her results in the context of scale, composition, and technique effects. Dean adopts a reduced form model that is a special case of the continuum pollution-haven model presented in Copeland and Taylor (1994). There are two productive factors: emissions and an aggregate of all other factors; two industries, which differ only in their pollution intensity; emissions are in variable supply; and China is treated as a small open economy with existing trade restrictions. Since industries differ only in their use of emissions, this is a two-sector pollution haven model very similar to that discussed earlier.

Since sectors do not differ in their conventional factor use, Dean is unable to weigh pollution-haven motives against more conventional factor endowment determinants. She finds a fall in trade restrictions (proxied by a reduction in the black-market premium) raises pollution directly; that is, pollution demand shifts right with trade liberalization. In the context of the model, this suggests China's low income makes it a pollution haven. But since the fall in trade restrictions also raises income (and hence would shift pollution supply left), the overall impact on emissions in China is unclear.[91]

[90] Matthew Cole and Anthony Raynor (2000) attempt to measure the environmental impact of the Uruguay Round of trade liberalization by calculating the implied scale, composition, and technique effects. Their methods follow Grossman and Krueger's work closely.

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Antweiler, Copeland, and Taylor (2001) develop a theoretical model to divide the impact of trade on pollution into scale, technique and composition effects and then estimate and add up these effects using data on sulfur dioxide concentrations from the Global Environment Monitoring Project. Both factor endowment and pollution haven motives for trade are allowed for. This research differs from the existing literature in the prominence given to the role of theory in developing and examining the hypotheses, and in the use of a consistent data set to estimate all three effects of trade. Grossman and Krueger did not separately identify the scale and technique effects in their empirical work, and their examination of the composition effect of trade was based on data distinct from that used in estimating their scale and technique effects. Moreover, the evidence they presented on composition effects was specific to Mexico. In contrast, Antweiler et al. estimate the composition effect jointly with the scale and technique effects on a dataset including over forty developed and developing countries.

Antweiler et al. estimate a reduced form equation for sulfur dioxide concentrations based on a model much like that developed in the early part of this essay. Among other things, they control for relative factor endowments, scale of production activity, determinants of policy (such as per-capita income), and openness to international trade.

Previous studies had looked for the effects of openness by simply adding it as an extra explanatory variable.[92] But both the pollution haven hypothesis and the factor endowment hypothesis predict that openness to trade will alter the composition of national output in a way that depends on a nation's comparative advantage. Therefore, Antweiler et al. capture the composition effect of trade by interacting a measure of openness with country characteristics determining comparative advantage. Under the pollution haven hypothesis, a country's income relative to the world average is relevant; under the factor endowments hypothesis, capital abundance relative to world averages is relevant.

This approach receives some support in the data. After accounting for variables capturing scale and technique effects, simple measures of openness per se, measured in a variety of ways, have very little impact on pollution concentrations.[93] This is not surprising, since the theory predicts openness per se is not relevant. In contrast, when openness is conditioned on country characteristics, they find a highly significant, but relatively small, impact on pollution concentrations. In theory, this impact represents the composition effect created by further trade liberalization.

To weigh the relative strength of pollution haven and factor endowment motives, they calculate country-specific elasticities of pollution concentrations with respect to an increase in openness.[94] These elasticities should reflect a country's comparative advantage in dirty goods. A positive value for a country implies trade liberalization shifts its pollution demand to the right (reflecting a comparative advantage in dirty goods); a negative value implies trade liberalization shifts its pollution demand to the

[91] The innovation in Dean's paper is the direct link she draws between income growth and trade restrictions. But little is said about this link and no formal modeling of the process is given. For example, if the link is the typical efficiency gains small open economies achieve from trade liberalization then it would be necessary in the empirical work to treat these gains as proportional to net trade flows as they represent terms of trade effects. If they occur via other means such as technology transfer or direct productivity effects, then it would be necessary to incorporate them into the model's implicit abatement production functions. Neither are attempted, nor is there any discussion of the controversial empirical literature linking more open trade policies with economic growth

[92] See, for example, Gale and Mendez (1998).

[93] See table 2, p. 30 from our 1998 NBER working paper 6707 that shows that none of our five different measures of openness had a significant effect on pollution concentrations.

[94] The magnitude of the elasticity is the percent change in SO_2 concentrations associated with a 1-percent change in trade intensity $(X+M)$/GDP (via the composition effect).

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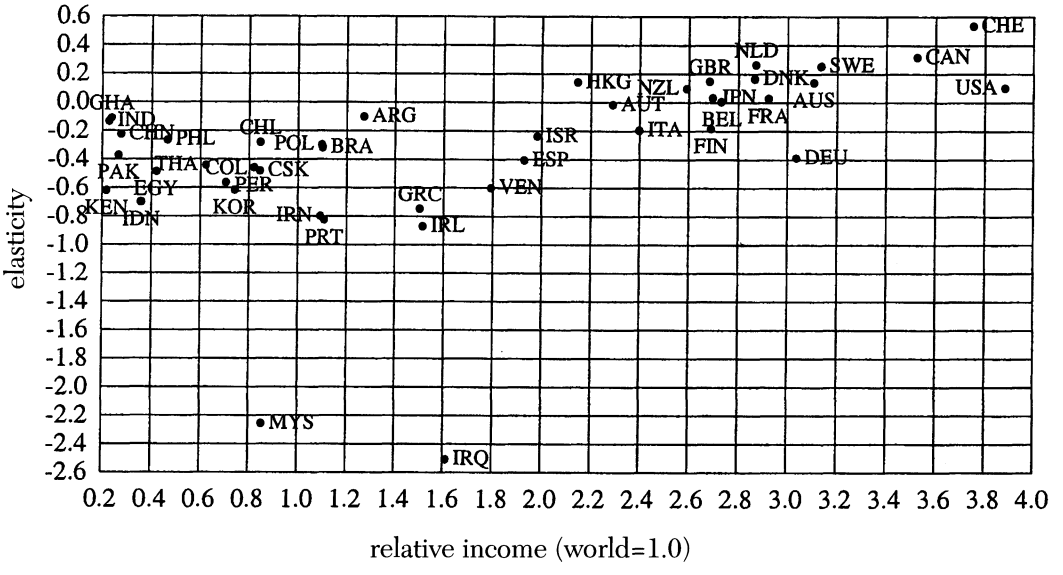

Figure 9.

left (reflecting a comparative advantage in clean goods).

These elasticity estimates (from Antweiler et al. 2001) are plotted against per-capita income in figure 9 above. If the pollution haven hypothesis were an accurate description of world trade in dirty goods, we would expect to see a strong negative relationship in figure 9. Rich countries would have a comparative advantage in clean goods. The opposite should be true for poor countries. Nothing like this pattern emerges from the figure. In fact, the relationship is positive, suggesting the composition effect of trade is more likely to be pollution increasing for high-income countries. And, since capital-to-labor ratios are higher in richer economies, the figure suggests that factor-endowment determinants of trade appear to dominate pollution-haven motives, and richer countries appear to have a comparative advantage in emission-intensive goods.

To some extent this result should not be surprising. Although the methods here are different, the conclusions were foreshadowed in earlier work. Xu (1999) reports that in 1995, almost 80 percent of the world's exports of environmentally sensitive goods come from the OECD countries. Walter (1973) calculates the direct and indirect environmental control costs in both U.S. exports and imports to find that U.S. exports are actually very dirty by this measure, more than 15 percent more than its imports.[95] Figure 9 is also consistent with the CGE evidence of Brown et al. (1991) predicting a reallocation of energy-intensive manufactures towards the United States and Canada as a result of NAFTA.

Although the evidence in figure 9 suggests that there is a composition effect of trade that varies across countries, the estimated effect is quite small. One possible explanation for this, which is worth further investigation, is that the factor-endowment effects and pollution-haven effects tend to roughly

[95] See Walter (1973), p. 67. 1.75 percent of the value of U.S. exports consisted of pollution-related costs, which is about 15 percent higher than the 1.51 percent estimated for U.S. imports.

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offset each other. High-income countries are capital abundant, which leads to a comparative advantage in dirty goods, but they also have stricter environmental policy which works in the opposite direction and would tend to lead to a comparative advantage in clean goods. Therefore a small net effect is consistent with strongly offsetting motives.

A second novel aspect of this paper is its method for separately estimating scale and technique effects. Previous work had been unable to separately identify these effects. The problem arises because both scale and technique effects are closely related to income levels. As a result, any increase in income is likely to shift both pollution supply and demand, making identification difficult. Antweiler et al. address this problem by exploiting the within-country variation in their dataset. Under the assumption that pollution policy is set at the national level, pollution supply is common for all cities within a given country. But cities differ in the scale of their output. Therefore, differences within countries across cities in their scale can be used to distinguish between scale and technique effects.[96]

The estimates indicate that a 1-percent increase in the scale of economic activity raises pollution concentrations by approximately .25–.5 percent, but the accompanying increase in income drives concentrations down by approximately 1–1.5 percent via a technique effect. As a result, income gains created by freer trade lead to a net reduction in pollution concentrations from scale and technique effects.

The estimated gap between the scale and technique effect seems large, and should be investigated further.[97] It is consistent, however, with the work of Sheoli Pargal and David Wheeler (1996), who study the link between informal pollution regulation and community characteristics in India. Using plant-level data, they find a 1-percent increase in community income drives pollution down by 2.8–4 percent; while a 1-percent increase in output raises pollution by between .6–.7 percent. [98] The strong policy response is also consistent with the results of Hilton and Levinson (1998) on lead.

The full effect of trade liberalization on pollution z requires that estimates of scale, composition, and technique effects be added up. Differentiating their reduced form for pollution concentrations with respect to a change in trade frictions β yields:

$$\frac{dz}{d\beta}\frac{\beta}{z} = \pi_1 \frac{dS}{d\beta}\frac{\beta}{S} - \pi_3 \frac{dI}{d\beta}\frac{\beta}{I} + \pi_4 \qquad (30)$$

where the π_i are estimated elasticities. The first term on the right-hand side is the scale effect, the second the technique effect, and the last the trade-created composition effect. If output and income change proportionately, (30) can be simplified to:

$$\frac{dz}{d\beta}\frac{\beta}{z} = \left[\pi_1 - \pi_3\right]\frac{dI}{d\beta}\frac{\beta}{I} + \pi_4 \qquad (31)$$

Equation (31) is very useful, but since Antweiler et al. do not estimate how a fall in trade frictions affects income levels (i.e. $dI/d\beta$) further information is required.

One approach is simply to restrict conclusions to the sample-average country. Taking the average value across countries yields $\pi_1 = 0.26$ and $\pi_3 = 1.57$ and $\pi_4 = -0.38$. If trade raises incomes, then $dI/d\beta > 0$ and this implies that for the average country in their sample, free trade leads to reduced SO_2 pollution in cities. That is, for this pollutant, free trade is good for the environment. However, the effects are likely to be quite small. Most CGE models predict that even large trade liberalizations have only relatively small impacts on income and output. Combining this with small estimated composition effects of trade

[96] This is not the only means for separating these effects. The authors also exploit variation across time, and cross-country variation in the relationship between GDP and GNP.

[97] Country specific estimates differ with some point estimates of the net effect being positive. The hypothesis that scale dominates technique is however rejected by every individual country in the sample.

[98] See Pargal and Wheeler (1996, table 2, p. 1324.)

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on the environment, the net effect of trade on the environment is likely to be quite small.

Finally, although this work tends to confirm earlier work that suggested that the effect of trade on the environment is small, the explanation for this result is different. Earlier work tended to suggest that policy had no effect on trade patterns. In Antweiler et al., policy plays an important role in dampening the factor endowment effect.

One final interesting aspect of the Antweiler et al. analysis is its implications for the literature on the environmental Kuznets curve. To isolate the role of international trade in the data, they attempt to distinguish between the pollution consequences of income changes brought about by changes in openness from those created by factor accumulation. This means their results can be used to investigate the hypothesis discussed in section 3 that the pollution consequences of economic growth are dependent on the underlying source of growth.

As noted above, income gains created by freer international trade are, for an average country, beneficial to the environment. Neutral factor accumulation (an increase in income holding the capital labor ratio constant creates only scale and technique effects, and using the estimates mentioned earlier, one can conclude that it, too, is good for the environment in an average country.

However, growth via capital accumulation turns out to worsen the environment. To provide some idea of the magnitudes involved, Antweiler et al. conduct a back-of-the-envelope calculation assuming a constant capital share in GDP of 1/3. Using the same method as above, the full impact of capital accumulation is given by:

$$\frac{dz}{dk}\frac{k}{z} = \pi_1 \frac{dS}{dk}\frac{k}{S} + \pi_2 - \pi_3 \frac{dI}{dk}\frac{k}{I} \qquad (32)$$

where π_2 is the elasticity of pollution with respect to a change in a nation's capital-to-labor ratio. This was estimated to be approximately $\pi_2 = 1$. The scale and technique elasticities π_1 and π_3 are as given before. If capital's share in income is 1/3, and population growth is zero over the time period considered, then (32) can be simplified. And employing the estimates given, we obtain:

$$\frac{dz}{dk}\frac{k}{z} = \pi_2 + \frac{1}{3}\left[\pi_1 - \pi_3\right] = 1 + \frac{1}{3}\left[.26 - 1.57\right] = .56 > 0 \qquad (33)$$

Growth via capital accumulation alone raises pollution concentrations for our average country, even after taking into account the income effect on environmental policy.

This is an interesting result, despite its back-of-the-envelope flavor. It suggests that researchers investigating the environmental Kuznets curve need to pay more attention to the sources of economic growth. As well, it suggests that trade liberalization plus capital accumulation is far less environmentally friendly than trade liberalization alone.[99] We would stress, however, that once we depart from the standard analysis of trade liberalization to include its potential effects on capital accumulation, we should also include its potential role in facilitating technology transfer and accelerating technological change. Unless these are biased towards polluting sectors, these induced effects would tend to work in the opposite direction from that of capital accumulation.

A couple of other recent studies seek to identify the effect of trade on environmental quality. Matthew Cole and Robert Elliot (2003) use national emission data to investigate several pollutants. They are not able to distinguish between scale and technique effects, but use Antweiler et al.'s approach to attempt to isolate the composition effect of trade. They confirm the Antweiler et al results for SO_2, and obtain similar results on composition effects for CO_2. But they find that BOD and NOx appear to respond differently, suggesting that it is indeed important to expand the scope of work to include

[99] This confirms a point made by Grossman and Krueger (1993).

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other pollutants. In a model with many pollutants and goods, there is no reason to expect that the relative importance of pollution-haven versus factor-endowment motives will be the same across all pollutants.

Jeffrey Frankel and Andrew Rose (2002) use an EKC framework in which openness to trade is added as an additional explanatory variable. They test whether the endogeneity of trade could account for the results in Grossman and Krueger (1993) and Antweiler et al. (2001) that free trade appears to be associated with improvement in environmental quality. To do so, they use a single year of the GEMS SO_2 data and instrument for openness using geographical variables. Their main finding is that controlling for the endogeneity of openness does not significantly affect these earlier results.

Summary. The studies reviewed in this section share the goal of explaining variation in pollution levels by reference to scale, composition and technique effects. While there has been some success in this regard, much more work needs to be done.

Along empirical lines, several avenues are open. For example, since the authors have not estimated the impact of trade liberalization on income levels, factor accumulation, or technological progress, it should be clear that other methods to "add up" the estimated scale, composition, and technique effects are possible. One such exercise was illustrated above, but clearly more analysis along these lines is warranted.

Similarly, most of the results at this point are specific to sulfur dioxide. Relatively few other pollutants have been studied, and there is little reason to expect the results to be similar across all pollutants. Theory predicts that differences in abatement costs, marginal damages, and the dispersion of pollutants would all lead to differences in the effects of trade on the environment. Relatively large cross-country datasets exist for some other pollutants, although the specific modeling strategy will need to be amended somewhat.

As well, Antweiler et al. estimated a relatively simple supply and demand model linking real income gains to changes in policy, but left underexplored the relationship between political economy elements and pollution outcomes. A sketch of a political economy theory is presented but the extension of empirical methods to capture and account for these influences is left untouched. Finally, their method of conditioning on country characteristics to weigh the relative strength of pollution haven versus factor endowment motives is admittedly coarse and inelegant. Further refinement along these lines should be possible.

4. *Policy Implications*

We now consider some of the policy issues that motivated much of this literature.[100] The policy literature is ultimately concerned with two issues—the use of environmental policy as a substitute for trade policy, or more generally, the effects of environmental policy on competitiveness; and the use of trade policy to achieve environmental objectives.

The "race to the bottom" debate, for example, arises from concerns that trade liberalization will put pressure on governments to weaken environmental policy to shield firms from increased foreign competition. The debate over whether countries should be allowed to ban imports of, or require labeling of genetically modified organisms is fueled by a concern that such policies may be disguised protectionism. At root, both of these issues are driven by the possibility that environmental policy will be used to distort trade flows.

The U.S. bans on tuna imports from Mexico to protect porpoises and on shrimp to protect turtles were both examples of

[100] Our review of the policy literature is highly selective. Some other surveys of the recent policy literature include Rauscher (2001) and Alistair Ulph (1997). Daniel Esty (1994) is a good nontechnical introduction to the major policy issues, and Jagdish Bhagwati and T.N. Srinivasan (1996) is a good introduction to the distortions and targeting approach to these issues.

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attempts by the United States to achieve environmental objectives in other countries by restricting trade. Another example can be found in suggestions that trade liberalization should be curtailed because it may shift polluting industries to poor countries and create pollution havens.

In some cases, these concerns reinforce each other. Proposals to circumvent "green dumping" by tying trade agreements to harmonization of environmental standards, or by treating weak environmental policy as a subsidy subject to countervail, can be seen as attempts to modify trade agreements to respond to both competitiveness and environmental concerns.

4.1 *Environmental Policy as a Substitute for Trade Policy*

One of the most contentious issues in the debate over trade and the environment is the possibility that environmental policy may be used as a substitute for trade policy. A major concern is that once trade agreements reduce trade barriers, governments will weaken environmental policy to help domestic firms compete with their foreign rivals. Consequently, freer trade may harm the environment because of an endogenous weakening of environmental policy. We refer to this motive as tariff substitution, as environmental policy is substituting for the lack of available trade-policy instruments, typically because tariffs and quotas are constrained by trade agreements.

To investigate this issue we must first identify why governments have an incentive to protect local firms (so there is a need for a trade agreement). The literature has focused on three motives for protection: (1) the *terms of trade motive* arises in standard competitive trade models when a country is large enough so that its trade policy can affect world prices; (2) a *strategic motive* for protection arises in models where there is market power at the firm level—in these models, governments can intervene to try to give their firms a strategic advantage over foreign firms; and (3) a *political economy motive* for protection arises even in small competitive economies when governments respond to interest group pressure.

Although the details of government behavior vary across the motives for protection, the same key insight emerges from each: signing a free trade agreement limits the instruments of protection available, but does not eliminate the pressure on the government to protect. If the government has access to instruments that can substitute for trade policy, then they can be used to undermine a trade agreement. This has important implications for the linkage of trade and environmental policy. To discuss these issues in more detail, we review some of the theory and evidence below.

Tariff Substitution. Consider a competitive world economy with two countries, and suppose governments have only two policy instruments available: trade taxes and pollution taxes. Both instruments affect a country's import demand and export supply and, we assume, can affect its terms of trade. As well, both policies affect environmental quality.

First suppose governments choose both trade and environmental taxes noncooperatively. Each government uses its two instruments to maximize the utility of its representative consumer. Let t be Home's ad valorem import tariff and let τ be its pollution tax; and let M denote imports and E denote exports. The corresponding Foreign variables are denoted with an asterisk (*). Any tax revenue is rebated in lump sum to the consumer.

Consider Home's problem. Suppose Home imports the pollution-intensive good and exports the clean good. With these policy instruments, the consumer's budget constraint is:

$$I = G(p(1+t), K, L, z) + tMp \qquad (34)$$

The government chooses tariffs and pollution policy to maximize consumer's utility subject to the budget constraint (34) for given levels of Foreign's policy instruments. The first order conditions for the choice of t and τ are:

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$$-M\frac{dp}{dt}+tp\frac{dM}{dt}+(\tau-MD)\frac{dZ}{dt}=0 \quad (35)$$

$$-M\frac{dp}{d\tau}+tp\frac{dM}{d\tau}+(\tau-MD)\frac{dZ}{d\tau}=0 \quad (36)$$

where we recall that MD denotes marginal damage. Noting home imports must equal foreign exports (E^*), we have

$$\frac{dM}{dt}=E_p^*\frac{dp}{dt}$$

and by substituting this into (35) and (36), we can find the optimal policy pair:

$$\tau = MD \quad (37)$$

$$t=\frac{1}{\varepsilon^*} \quad (38)$$

where $\varepsilon^* \equiv pE_p^*/E^* > 0$ is the elasticity of the foreign export supply function.

The solution reflects the policy targeting literature: externalities are fully internalized with environmental policy, and tariffs target the terms of trade (see, for example, Avinash Dixit 1985). When governments are unconstrained in their choice of policies, there is no incentive to weaken environmental policy to give local firms a competitive edge over foreign firms—this can be more effectively accomplished by using tariffs alone.

Similar results apply to an exporter of pollution intensive goods (the Foreign country in our example). The foreign government's optimal policy is to fully internalize externalities and either protect its import-competing industry (Y) or equivalently to tax exports of the polluting good.

When both countries use trade policy to improve their terms of trade, the world ends up in a standard noncooperative tariff game. This pushes them inside the global Pareto frontier because trade barriers drive a wedge between prices in the two countries. Both countries can therefore gain from a trade agreement that moves them back to the frontier. This is the motive for entering into a free-trade agreement in our model.

Suppose the two countries reach a binding agreement to eliminate tariffs.[101]

What happens to environmental policy? Setting the tariff equal to zero in (36) yields:

$$\tau = MD + M\frac{dp/d\tau}{dz/d\tau} < MD. \quad (39)$$

In response to the free trade agreement, Home's optimal pollution tax diverges from marginal damage. Home still has an incentive to protect its import-competing firms, but with trade barriers eliminated, it has to fall back on second best instruments. If environmental policy is the only other instrument available, Home provides an implicit subsidy to its import-competing industry by setting the pollution tax below marginal damage.

The discussion above has focused on the incentives facing the importer of polluting goods. The exporter of polluting goods also has an incentive to look for an alternative to trade policy. In this case, as mentioned previously, Foreign has an incentive to reduce the world supply of the polluting good, and hence elimination of tariffs will cause it to tighten up environmental policy:

$$\tau^* = MD^* - E^*\frac{dp/d\tau^*}{dz^*/d\tau^*} > MD^*. \quad (40)$$

In this model, importers of pollution-intensive goods have an incentive to relax environmental policy to subsidize local production, while exporters have an incentive to tighten policy to tax production.[102]

[101] As is well known, a large country can "win" a trade war in the sense that it is better off in the tariff-ridden equilibrium than in free trade. But because such an equilibrium lies inside the Pareto frontier, even a "winner " of the trade war has an incentive to negotiate. As Wolfgang Mayer (1981) notes, any point on the Pareto frontier can be implemented with free trade combined with a lump sum transfer. A large country would demand a lump sum transfer (or some other concession) in return for free trade.

[102] On this point see William Baumol and Wallace Oates (1988), Markusen (1975), and others.

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The result here is a special case of a more general result, which is that when there are multiple policy instruments available to governments, a free trade agreement that restricts only a subset of instruments is an incomplete contract that can be undermined as governments substitute towards unconstrained instruments.[103] In this context, the option of manipulating environmental policy to improve the terms of trade creates a loophole in the trade agreement.

The result that governments can use environmental policy as a substitute for trade policy also appears in both the strategic trade and political economy literatures. In strategic trade papers, there is typically a two-stage game: government policy is set in the first stage, and imperfectly competitive firms move in the second stage. As James Brander and Barbara Spencer (1985) showed, if governments can make binding policy commitments in the first stage, they can give their firms a strategic advantage in the latter stage. In these models, once trade taxes and subsidies are eliminated, governments have an incentive to switch to other instruments, including environmental policy if available (see Barrett 1994; Klaus Conrad 1993; Peter Kennedy 1994).

To identify this motive, consider a partial equilibrium model with three countries, East, West and South. East and West each have one firm producing a dirty good that is sold only to the South—that is, all production is exported.[104] And, for clarity, assume only one country, say West, is policy-active. The game proceeds in two stages. In the first stage, West chooses its pollution tax τ, and in the second stage, the two firms choose output simultaneously.

Because the model is partial equilibrium, and there is no domestic consumption of the dirty good, we can write West's welfare function as:

$$W = \pi(x, x^*, z) - D(z)$$

where π is profits of West's firm, x and x^* are West and East output of the dirty good, z is West's pollution ($\pi_z > 0$), and D is the pollution damage function.

If there were no Eastern firm, the West's government would simply choose the pollution tax so that the marginal benefit of polluting equals marginal damage:

$$\pi_z = MD \tag{41}$$

where MD$\equiv dD/dz$. Moreover, in response to the pollution tax, the firm would choose its emissions level such that

$$\tau = \pi_z \tag{42}$$

And hence the solution would be implemented with a pollution tax set equal to marginal damage ($\tau = MD$).[105]

However, when the Western firm competes with its Eastern rival, the Western government has an incentive to use environmental policy to help its firm gain a strategic advantage over its rival. In this case, West's optimal pollution policy is determined by:[106]

$$\pi_z + \pi_{x^*} \frac{dx^*/d\tau}{dz/d\tau} = MD \tag{43}$$
$$(-) \quad (-)$$

Reducing the pollution tax (and therefore raising emissions) yields two benefits now—there is the direct reduction in the domestic firm's costs (hence the increase in profits given by π_z); but as well, there is a strategic

[103] See Copeland (1990) for an early model of this process and Kyle Bagwell and Robert Staiger (2001) and Ederington (2001, 2002) for recent examination and suggested solutions.

[104] Home and Foreign goods may be either homogeneous or imperfect substitutes—we need Home's demand to fall when foreign output rises.

[105] Note however the role played by no domestic consumption in West.

[106] Because the Western government moves first, it uses the first-order conditions from the second-stage Cournot game to predict how its policy affects the final outcome. Because the Western firm maximizes profits treating eastern output as given, we have $\partial\pi/\partial x = 0$, which we have used to get (43).

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effect—a reduction in Home's pollution tax lowers the Home firm's costs. This shifts out the Home firm's reaction function in the output game, and causes the Foreign firm to reduce its output (as long as reaction functions slope downward)[107]. That is, a weakening of Home's environmental policy allows the Home firm to credibly commit to produce more output, which leads to higher profits for Home. The Home firm always has an incentive to commit to more output, but such a commitment is not credible. A weakening of Home's environmental policy helps the local firm out by making such a commitment credible.

The optimal pollution policy for the Home country can now be written as:

$$\tau = MD - \pi_{x^*} \frac{dx^*/d\tau}{dz/d\tau} < MD \qquad (44)$$

where Home provides an implicit subsidy to the domestic firm by setting the pollution tax below marginal damage. Again we find environmental policy distorted.

And finally, in the political economy literature, governments respond to political pressure and use policies to redistribute income from one interest group to another. If trade policy and environmental policy are the available instruments, then once tariffs are eliminated, governments will manipulate environmental policy to help favored groups. Pollution taxes will be above or below marginal damage depending on the political strength of competing interest groups. To illustrate the implications of this approach for environmental policy, consider a simple political support model. Suppose there are two agents: Labor and Capital, and suppose their utility functions take the form:[108]

$$U = \frac{I}{\beta(p)} - D(z)$$

where I is income, β is a price index, and D the pollution damage function which is increasing and convex. The production side of the model is the basic competitive model we used earlier in the essay. Assume a small open economy (with goods prices fixed) to eliminate the terms of trade motive for intervention.

Suppose that the government places a higher weight on capitalists than workers, and suppose that the only instrument available is the pollution tax. The government chooses pollution to maximize:

$$W = U^L + (1+\lambda)U^K$$

where U^L is the utility of Labor, and U^K is the utility of Capital. Then solving as before for the optimal pollution tax now yields:

$$\tau = 2\beta\frac{dD}{dz} - \lambda\beta\frac{\partial U^K}{\partial z} = MD - \lambda\beta\frac{\partial U^K}{\partial z} \qquad (45)$$

An increase in allowable pollution raises the return to capital and lowers the return to labor in the model of section 3. Consequently, capitalists prefer more pollution than at the socially efficient point (where $\tau = MD$); that is, in the relevant range, we have $\partial U^K/\partial z > 0$. If the government gives preferential treatment to capitalists so that $\lambda > 0$, then it will subsidize the pollution intensive industry by setting a pollution tax below social marginal damage. If the government gives preferential treatment to labor, then $\lambda < 0$ and the pollution tax is above social marginal damage.

Our analysis of tariff substitution has focused on production-generated pollution. Similar issues arise when pollution is generated by consumption (such as with automobile emissions), although there are some important differences as well.

For production-generated pollution, environmental policy tends to be directed at local firms, and so most of the scope for manipulating policy for protective purposes lies in either loosening or tightening policy

[107] Typically, this literature makes assumptions on demand and cost conditions to ensure that reaction functions slope down and a stability condition is satisfied.

[108] This linear form ensures the marginal utility of income is unaffected by redistributions across the two groups in society and is a common assumption in the political economy literature. This simplifies the calculations tremendously but is not necessary for our main point here.

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to raise or lower local firms' production costs as we have illustrated above.[109] On the other hand, when pollution is generated during consumption (such as with automobile emissions), environmental policy targets the characteristics of products, and so applies to both local and imported products. Consequently policy aimed at consumption-generated pollution can be used to restrict market access for nonconforming foreign products, as well as to affect production costs of both local and foreign firms.

Although the details will differ across model types, the terms-of-trade, strategic trade, and political economy models all predict that governments have an incentive to take advantage of product standards to protect local firms. To avoid the use of product standards as a protectionist device, trade agreements typically require a *national treatment* rule. Under a pure national treatment regime, countries are allowed to impose any environmental standards they choose, but the standards applied to foreign products should be no less stringent than that applied to local products. That is, a national treatment regime attempts to circumvent protectionist tendencies by enforcing a nondiscrimination rule. Unfortunately, a national standard does not eliminate the potential for governments to manipulate environmental policy for protective purposes.

This follows quite straightforwardly from the logic behind "Raising Rivals' Costs" in Steven Salop and David Sheffman (1983). For example, if it is easier for local firms to comply with an environmental regulation than foreign firms, then the imposition of the regulation can favor local firms at the expense of foreign firms, which creates an incentive for a strategically motivated government to over-use the policy. These issues have been at the root of several trade disputes such as bans on beef hormones and genetically modified organisms.

Discussion. While the terms-of-trade, strategic trade, and political economy models all can generate the prediction that freer trade will increase the incentive for governments to manipulate environmental policy, they are subject to several criticisms. Criticisms fall into three categories: (1) exogenous restrictions on instrument choice; (2) fragility of results; and (3) lack of empirical evidence. We discuss these in turn.

All of the models suffer from a common weakness, which is that they typically assume that environmental policy is the *only* available substitute for trade policy. In the political economy models, the government wants to increase the income of some interest groups at the expense of other groups. Environmental policy can accomplish this indirectly by affecting cost conditions and thereby affecting factor returns via market effects. However, a more direct way of raising income is simply to use direct transfers. If these are ruled out, taxation rules can be manipulated, or direct production subsidies can be used. That is, there are many other instruments typically available to governments that will do a better job of transferring income, and likely at lower cost per dollar transferred.

Similarly, in the terms of trade or strategic trade models, if a tariff is eliminated, governments could take advantage of the well-known result that a tariff is equivalent to a consumption tax combined with a production subsidy. That is, if the government signs a treaty to eliminate tariffs, it can exactly replicate the effect of the tariff by using domestic

[109] Countries have sometimes attempted to make access to local markets contingent on the process by which goods were produced in the source country. That is, countries may wish to block access to local markets unless foreign producers meet certain environmental standards. This method of protection is for the most part not legal under WTO rules, and has been a considerable source of controversy. The U.S. ban on imports of tuna from Mexico because Mexican fishing practices led to porpoise deaths is perhaps the most prominent example. For a discussion of this and other cases, see Esty (1994).

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tax and subsidy policies—there is no need to manipulate environmental policy.[110]

Moreover, environmental policy is less effective and more costly than these other instruments. For the most part, the literature has dealt with this problem by restricting the policy space. Most models simply assume that environmental policy and tariffs are the only available instruments. But once we open up the possibility that governments have other instruments available, the likelihood that these models will predict trade agreements will lead to strategic manipulation of environmental policy is substantially diminished.

This weakness in these models has been recognized for quite some time—Dani Rodrik (1995) identified it as one of the key challenges for the political economy literature, and Jay Wilson (1996) pointed out its implications for the environmental "race to the bottom" literature. However, it remains a fruitful area for further research.[111]

A second critique of this literature takes the restrictions on the policy space as given, but argues that the results are either extremely fragile, or rely on an incredible degree of coordination across levels of government. For example, it is well known that results in the strategic trade policy literature are sensitive to assumptions about both market conduct and market structure. The same is true here. If we alter the partial equilibrium model above by assuming the domestic and foreign firm sell differentiated products and choose prices rather than quantities, then the relationship between the optimal pollution tax and marginal damage is reversed. In this case, we write domestic welfare in terms of prices:

$$W = \pi(p, p^*, z) - D(z) \tag{46}$$

and solving for the optimal pollution tax, we find:

$$\tau = MD - \underset{(+)}{\pi_{p^*}} \underset{(-)}{\frac{dp^*/d\tau}{dz/d\tau}} > MD \tag{47}$$

the pollution tax is above marginal damage. The reason for this is well known (Jon Eaton and Gene Grossman 1986; Barrett 1994): with price competition, domestic and foreign prices are strategic complements. Consequently, the home firm has an incentive to commit to a higher price, because the foreign firm would respond by raising its price as well and both firms would benefit from the higher prices. The home government can help its firm make this commitment credible by taxing it; that is, by tightening environmental policy. In doing so, Home's reaction function shifts out and home gets a strategic benefit from the increase in foreign price.

The key point here is that once we alter our assumptions on market conduct to allow for price competition, the Home government's incentive to give its firm a strategic advantage leads to an argument for an export tax and not an export subsidy. If we remove the ability of government's to use export taxes, then exporting countries have an incentive to *tighten*, not loosen environmental policy.

Even if we retain our homogenous product, Cournot model, the policy implications are also sensitive to assumptions about entry and market structure. As Barrett (1994) noted (following earlier work by Dixit 1984), when there are two or more domestic firms, part of the potential rents from exporting are dissipated as the two domestic firms compete with each other. The optimal policy to counter this competition is an export tax (or quota), which in our case is a tightening of environmental policy. Therefore, the government has an incentive to subsidize the domestic firms to give them a strategic advantage in their competition with the foreign firm, but on the other hand, there is an

[110] If production subsidies are disallowed by trade rules, then we can resort to R&D subsidies that lower marginal costs. If R&D subsidies are not available, there are many other ways of subsidizing firms that may be more palatable than weakening environmental policy.

[111] Stephen Coate and Stephen Morris (1995) develop a model where the electorate is imperfectly informed about whether the government is corrupt. Governments may use inefficient instruments to transfer income to avoid revealing their type.

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incentive to tax the domestic firms to encourage cartelization by domestic firms. In simple linear models, the taxation motive tends to dominate once there are more than a small number of domestic firms. This implies that once we move to a model with several imperfectly competitive domestic firms, we find the standard result that emerges from competitive models, which is that the government has an incentive to raise the pollution tax above marginal damage to tax domestic firms to improve the terms of trade.

Criticism also comes from environmental economists who note while trade policy is almost exclusively determined by central governments, much of environmental policy is set at the local, regional, or state level. Therefore, in order to put into place the terms of trade motivation for altering environmental policy we need a great deal of coordination between different levels of government. Moreover, since states, regions, and even cities differ greatly it is not clear this cooperation would be forthcoming since their constituents may well be hurt by a price change that at the national level, would be welfare improving.

Political economy models fare better in this regard since local authorities have it in their power to relax environmental standards to help local firms. However, these models are not immune from all of the problems mentioned above. For example, several authors have considered political economy models with both trade and environmental policy, using a Grossman-Helpman (1994) framework. Schleich (1999) pointed out that the usual targeting results hold in this model, so that if tariffs are available, there is no incentive to distort environmental policy (because in these models, the government wants to minimize the social cost of raising the income of favored groups). And as we demonstrated above, the political economy approach does not always imply that environmental policy will be too weak. If a polluting sector has relatively weak political influence, then environmental policy may be tightened in that sector to free up resources for other favored sectors. As Paola Conconi (2003) points out, if environmental groups are sufficiently strong relative to industry groups, then pollution policy may be more stringent than the Samuelson rule requires.

Overall, the theoretical literature on tariff substitution does predict that governments may have incentives to manipulate environmental policy to help domestic firms in response to trade liberalization. There is no uniform prediction as to whether policy will be too tight or too weak, since predictions are sensitive to assumptions on the set of available instruments and market conduct. This is an area where empirical evidence is badly needed to examine where and when tariff substitution may operate.

As long as the bulk of the evidence suggested that pollution policy had no measurable effects on competitiveness, as was the case at the time of the review by Jaffe et al. (1995), then it was easy to dismiss tariff-substitution as having little practical relevance. Recent findings by Levinson (1999), Becker and Henderson (2000), Greenstone (2002), Ederington and Minier (2003), and others demonstrate that pollution policy can indeed be used as an instrument of protection. If this work holds up to further scrutiny, it is important evidence that concerns over tariff substitution need to be taken seriously. It is important to note though that these studies contain evidence that pollution regulations matter; they don't provide evidence that governments alter pollution regulations in order to influence trade outcomes. The empirical evidence on this score is very limited with only a couple of studies attempting to test for policy substitution.

Gawande (1999) finds evidence that governments do substitute nontariff barriers for other instruments of protection, suggesting that the concern about loopholes in trade agreements is well founded. Eliste and Fredriksson (forthcoming) argue that governments weaken environmental policy to

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shelter industries newly exposed to freer trade and provide some evidence from the farm sector to support this. Ederington and Minier (2003) use four-digit U.S. manufacturing data from 1978–92 and find that their measure of the stringency of environmental regulation (abatement costs) has a negative and statistically significant relation with net import flows. This is consistent with the prediction that environmental policy is responsive to pressures from foreign competition. This is an area where much more empirical work is required to help clarify the policy debates.

If governments do engage in tariff substitution, then it is still not clear how trade agreements should be modified to deal with the issue. There is a trade off between two different objectives: closing loopholes in trade agreements by constraining the use of domestic policy instruments in an effort to prevent tariff substitution; and allowing governments flexibility to respond to local changes in local conditions and preferences.

In the case of product standards, there has been a gradual shift away from a pure national treatment regime to one that requires increased use of scientific evidence to justify environmental policies that impede trade. This may inhibit tariff substitution, but it reduces the flexibility of governments to implement their own environmental policy. A movement towards increased harmonization of product standards, as in the EU, goes even further in this direction.

In the case of production-generated pollution, governments have retained more flexibility to adjust their environmental policy, but at the possible cost of increased tariff substitution. This is because explicit export subsidies are subject to countervail laws under the WTO, but the use of implicit subsidies by weakening environmental policy are not. One of the main reasons for this seeming inconsistency in the treatment of subsidies is that the informational requirements of determining the "correct" environmental policy are high. Even in our simple framework, the optimal pollution tax varies across pollutants, locations, and depends on preferences and its interaction with other pollutants. Consequently, a regime that attempts to forestall tariff substitution by allowing "green countervail" would likely be unworkable.

Bagwell and Staiger (2001) have addressed this issue in their work on self-enforcing trade agreements. If trade agreements are negotiations to allow market access to trading partners, and if these obligations bind, then they show that even if the trade agreement does not constrain domestic policy, it nevertheless removes tariff substitution motives. If each government maximizes its objective function subject to its market access commitments, then the solution is to minimize the cost of achieving those objectives. This eliminates the temptation to use environmental policy to reduce imports, since some other policy would have to be altered to counteract the negative effects on foreign market access. Although this is an elegant solution to the problem, it requires that we monitor country's market access commitments very closely to eliminate possible abuses. Since any measure of market access will involve trade flows and prices, shifts in comparative advantage or demand shocks would likely alter measured "market access." As a result, evaluating whether a country has met its market access commitments may be no less difficult that determining its "correct" environmental policy.

4.2 *Trade Policy as a Substitute for Environmental Policy*

The other major policy issue we want to discuss is whether trade policy should be used to achieve environmental objectives. This issue arises most frequently in two contexts. First there is simply a concern that trade may increase pollution, and therefore restrictions on trade can reduce pollution. Second, there are many issues where people in one country want to achieve an environmental objective in another country.

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Examples include proposals to ban tropical timber imports to protect rain forests, and the banning of tuna imports into the United States from Mexico to protect dolphins. We examine each of these cases in turn.

On theoretical grounds the question of whether we should use trade restrictions to deal with the general issue of trade-induced increases in pollution is quite clear-cut. Trade restrictions are not a first-best instrument to deal with local environmental problems. Return to our small open economy model, replace trade frictions with a tax on trade, and assume environmental policy is not optimal. Assume Home exports dirty goods. For concreteness, assume Home levies a specific export tax of t on exports. Then p^d in our previous analysis is simply $p - \tau$.[112] Home's representative consumer has utility:

$$U = V(p-t, I, z), \quad \textit{where}$$

$$I = G(p-t, K, L, z) + tE \tag{48}$$

and E is exports of X. Home's pollution level is determined endogenously for any given pollution tax τ by[113]

$$\tau = G_z(p-t, K, L, z). \tag{49}$$

Now consider trade liberalization. The effect on welfare of a change in the export tax for given τ is:

$$\frac{1}{V_1}\frac{dU}{dt} = t\underset{(-)}{\frac{dE}{dt}} + (\tau - MD)\underset{(-)}{\frac{dz}{dt}}. \tag{50}$$

An increase in trade barriers has two effects on welfare. It reduces exports, which is harmful as standard gains from trade are lost. And it reduces pollution because the export sector pollutes. Solving for the optimal tax on exports we find:

$$t = -(\tau - MD)\underset{(+)}{\frac{dz/dt}{dE/dt}} \tag{51}$$

If pollution policy fully internalizes externalities (τ = MD), the optimal tax on trade is zero. Rather than using trade barriers, countries can more effectively control environmental problems with instruments that are finely tuned to deal with the source of the problem, such as pollution taxes or quotas. This well-known result follows from the policy targeting literature (see Dixit 1985).

If environmental policy does not fully internalize externalities, then trade policy can be used as a second-best instrument to control pollution. Suppose, for example, the pollution tax is exogenously set to zero. Then *if the only other available instrument* is a tax on trade, its optimal level is:

$$t = MD\frac{dz/dt}{dE/dt} > 0 \tag{52}$$

By restricting trade, the pollution-intensive export sector is prevented from expanding to take advantage of trading opportunities, and this reduces pollution and raises welfare.

While the use of trade policy for environmental ends seems simple and attractive, there are several problems with the analysis above. The first is simply that because of the complicated general equilibrium effects of trade liberalization determining the optimal second best trade policy to avoid environmental damage can be quite complicated (see Copeland 1994).

Second, even if environmental policy is imperfect, trade may still be beneficial. As we demonstrated in section 3, the welfare results of trade liberalization depend on both a country's comparative advantage and the instruments it uses for environmental protection. If a country has a comparative advantage in dirty goods, then the welfare impact of freer trade depends on whether imperfect regulation targets emission

[112] An export tax on X is analytically equivalent to an import tariff on Y—we could do the whole analysis in terms of a tariff on Y and get exactly the same result.

[113] The pollution tax revenue is included in the national income function G. If we had alternatively written G as a function of the pollution tax t, (instead of as a function of z), then we would have to add the pollution tax revenue to the G function to get total national income.

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intensities or overall pollution. If it is the former, losses can occur; if it is the latter, gains are assured. Alternatively, if a country has lax regulation but a comparative advantage in clean goods, then trade is necessarily welfare improving because it takes pressure off the environment.

Finally, there is very little evidence in favor of pollution-haven-driven trade. The earliest evidence on pollution havens fails to control for other determinants of comparative advantage; the evidence from the cross-sectional HOS studies is ambiguous and not quite to the point;[114] and the evidence presented in Antweiler et al. (2001) favors a factor endowments view of world trade in dirty goods. Overall, the composition effects that are needed to drive the pollution haven hypothesis are hard to find in the data. As well, there is evidence provided by many authors that income gains have a large positive effect on environmental quality. The current empirical evidence therefore supports a view where the technique effects arising from trade liberalization may be significant, and composition effects may in fact move dirty good production away from low-income developing countries to high-income developed countries. Moreover, the few studies that have attempted to estimate the aggregate effect of increased trade on environmental quality have found the effects to be small, and possibly positive.

We should note, however, several caveats. The first is that the evidence is incomplete. The available studies deal with only a subset of possible pollutants, and there is very little empirical work examining how trade affects natural resource degradation. Natural resource degradation may be a key environmental impact of trade in resource-rich less developed countries.[115] As well, we know of no empirical work specifically linking international trade to global pollutants. Since the studies define environmental outcomes quite narrowly, we should be wary of claiming too much. The evidence is also subject to further scrutiny. Given the existing problems in the literature and the embryonic nature of some of the research, future work with different pollutants, datasets, or countries may alter the results considerably.

There is also evidence that in some situations trade liberalization has caused great environmental problems, be it in the Maquiladora region of Mexico or elsewhere. And environmental groups in the United States and elsewhere have presented a series of case studies or examples of environmental debacles linked to international trade. At present there is a tension between this evidence and the results of empirical work in the academic community. The difference may arise from sample selection if these agencies are not looking for the "good news" stories, or they may reflect a real gap between the impact trade has on widely measurable environmental outcomes used by academic researchers, and the more narrowly defined outcomes reported by these agencies. More careful work is needed to investigate the effects of trade on a much broader spectrum of environmental indicators.

Perhaps the major weakness in the theoretical argument that trade restrictions are a useful second-best instrument to deal with environmental problems is that theory is usually silent on why environmental policy is not available. While there are surely countless stories as to why this may be true—asymmetric information, bureaucratic red tape, political economy factors, indivisibilities—the literature does not explain why tariff setting is immune from these problems while environmental policy is hobbled by them. Instead we are asked to believe that

[114] Even if researchers find a negative relationship between pollution regulations and competitiveness this does not imply that income-induced differences in pollution regulations are the only or even the most important determinant of trade. Regulations can of course matter to costs, while the pollution haven hypothesis remains a poor description of trade in dirty goods.

[115] For theoretical work on this point, see Chichilnisky (1994) and Brander and Taylor (1997).

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whatever is responsible for constraining environmental policy has no effect whatsoever on our ability to target trade policy perfectly. This is a rather strong assumption. This is an issue that needs more study in a political economy framework where the choice of instrument is itself an endogenous outcome.

Intervening in Foreign Environmental Policy. The other major argument for using trade policy to achieve environmental outcomes arises when citizens in one country want to influence environmental policy in another. This can occur naturally if pollution is global. It can also arise when citizens of one country "care" about environmental outcomes in other countries for humanitarian or selfish reasons.[116] While there is in principle nothing wrong with the desire to affect foreign policy, the method of altering policy is rarely what economic theory would suggest is efficient. The first-best policy in these situations calls for a negotiated agreement in which the foreign country uses environmental policy instruments to target pollution in return for a possible transfer from Home. These transfers could be implicit in the size of cutbacks nations must make to join a global pollution agreement, or could be explicitly tied to pollution reductions.[117] There is a large literature on international agreements that deal with transboundary or global environmental problems (see Barrett 2003) and the solutions typically involve negotiation plus some mechanism for transfers. Trade policy may still be useful as part of an enforcement mechanism in these agreements, because it can help to implement a more severe penalty for deviations from agreements, but it does not substitute for environmental policy.[118]

Alternatives to negotiation are unilateral attempts to punish, cajole or influence foreign environmental policy with trade policy instruments. For example, if a country is large enough to influence the world price of the dirty good, then it can try to use trade policy to lower the price of the dirty good so that foreign countries generate less pollution (see Markusen 1975).

Such a policy, however, suffers from a number of problems. It is unlikely to be effective unless all countries coordinate their trade policy and therefore concerns of leakage arise. For example, consider a three-country model. Suppose both East and West produce X; and West's production of X is dirty while East's is clean. If Home unilaterally tries to reduce West's pollution with a tariff, then West can instead export to East, and East can export to Home. Home's tariff on West's dirty production may have almost no effect on pollution in a multi-country world.

As well, a trade restriction can have perverse effects if there are alternative uses for a fixed factor used by the environmentally intensive industry. Suppose North uses a tariff to restrict lumber imports from South in an effort to protect forest habitat in the South (which Northern residents value). Then with the economic viability of the lumber industry diminished, Southern producers may burn the forest and convert the land to agricultural use.[119]

5. *Conclusions*

With the increased integration of the global economy, it has become difficult to ignore the international consequences of domestic environmental policy regulation. And with rising concern over environmental quality both at home and abroad, an assessment of how trade policy affects the environment has become unavoidable.

Despite the novelty of these developments, research on trade and the environment is not new. Work in the 1970's raised

[116] For example, I might be in favor of conservation efforts in foreign countries so that I can visit a nature park, benefit from the biodiversity, or ski in their pristine wilderness.

[117] See Copeland and Taylor (1995, 2000) for a discussion of transfers and global pollution.

[118] See Nuno Limao (2001) for recent work on this issue.

[119] See Edward Barbier and Carl Schultz (1997).

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many of the key issues of second-best policy analysis: free trade need not be welfare improving if environmental costs are not internalized; trade policy can be used as a substitute for environmental policy; and a commitment to free trade may create incentives to distort environmental policy. In many ways, however, this early work provided more questions than answers. Optimal second best policy is very sensitive to the market structure, assumptions on technology, and empirical magnitudes. Consequently, one can draw on this early literature to support a wide spectrum of policy proposals.

The major contribution of the recent wave of research (which began in the early 1990's) has been to shift the literature towards a focus on empirically motivated questions that are important to the resolution of policy debates. While this work is still new, we can identify three conclusions that are emerging. These conclusions should be the subject of further investigation, and some are them rest on more evidence than others, but if correct, they yield important implications for ongoing policy debates.

The first conclusion is simply that there is now a great deal of evidence supporting the view that rising incomes affect environment quality in a positive way. This suggests that when we assess the effects of growth and trade on the environment, we cannot simply associate increased economic activity with increased environmental damage. Beneficial changes in environmental policy will likely follow and this leaves the net impact on the environment unclear.

This is an important piece of evidence, but it has led the literature to focus almost exclusively on the impact of income effects. While incomes per capita are likely to be an important determinant of pollution policy (or pollution supply), actual pollution outcomes reflect the impact of other national characteristics as well (since they determine pollution demand). Theory suggests that linking environmental outcomes to income per capita alone is unlikely to be successful, just as predicting the pattern of trade in dirty goods by relative income levels alone is unlikely to be successful. Recent research finding a sensitivity of the environmental Kuznets curve to time periods or data may reflect the workings of important excluded national characteristics. If so, this would echo our concerns with an empirical literature that focuses too heavily on the role of income levels play in explaining the location of dirty good production and international trade. Future research should move away from estimating highly restricted models of pollution determination to consider alternatives giving a larger role to natural resources, capital abundance and other more conventional factors. Moreover, at a theoretical level it is still not well understood how the income effect interacts with the policy process, particularly in the context of political economy influences.

A second major finding from the research of the last five years is that the previous consensus that environmental policy does not affect trade and investment flows was premature. A number of recent studies find that both trade and investment are influenced by pollution regulations. This work illustrates the benefits of combining theory and empirical work. Once we interpret pollution levels and the stringency of regulation as equilibrium outcomes, then pollution abatement costs are no longer independent of industry attributes. Consequently, measures of trade performance (such as import penetration) and pollution abatement costs are both endogenous variables. Therefore, the common finding of a weak or nonexistent relationship between pollution abatement costs and import penetration is likely to be a symptom of econometric problems and not evidence that environmental regulations are irrelevant. And the occasional finding of a positive relationship between pollution abatement costs and measures of competitiveness is surely not prima facie evidence of the "Porter Hypothesis." Examining this endogeneity problem further should be a major focus of future empirical work.

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A third, and more tentative, conclusion is that there is little convincing evidence to support the pollution-haven hypothesis. While there is evidence of a pollution-haven *effect*, it is only one of many factors that determine trade patterns, and there is no evidence that it is the dominant factor.

Although the policy debate is often characterized as a conflict between those for and against globalization, it is really a struggle over how the rules governing trade should evolve. The fundamental issues involve the trade-off between allowing governments flexibility to pursue independent environmental policies (which sometimes may involve implicit or explicit restrictions on trade), and constraining the ability of governments in order to close loopholes in trade agreements. At present there is little evidence that environmental policy has been used to substitute for tariff protection. While tightening environmental standards does have cost and competitiveness consequences so too do almost all domestic policies. In the absence of strong evidence of abuse, we come down on the side of flexibility. Environmental policy should not be overly constrained by trade agreements.

We also find little reason for trade policy to be used to achieve environmental ends either at home or in foreign countries. While restricting imports from countries with objectionable policies may indeed have environmental effects, these can easily be negative. Lowering the access of developing countries to developed country markets is likely to lower their incomes and reduce their desire to adopt tighter environmental standards. It may also introduce perverse incentives by reducing the value of natural resources and therefore exacerbate environmental problems arising from the lack of property rights enforcement. And while the empirical evidence to date is not conclusive, trade restrictions on imports of developing countries may well lead them to adopt an even dirtier slate of production. This is not to say that concerned citizens in developed countries should sit idly by while the environment in developing countries worsens; rather it suggests these advocates adopt more efficient policies to enact positive change by supporting the use of direct financial incentives, tied aid and capacity-building exercises in developing countries.

And what about the bottom line? Is free trade good or bad for the environment? Most available studies suggest that the effect is small, but an answer to this question requires more careful empirical work guided by theory. Trade affects the environment via scale, composition, and technique effects, and these effects can all be expected to vary across countries. Some recent work has demonstrated how these effects can be isolated and estimated. Future work in this area should be attempting to refine, extend, and improve on these methods. Moreover, current work has looked at only a very few pollutants, and there is very little empirical work assessing the effects of trade on renewable resources. Finally, while Antweiler, Copeland, and Taylor (2001) find only small effects of trade on pollution concentrations, they also find relatively large impacts from changes in a nation's factor composition. This suggests that the effects of capital mobility on environmental outcomes will be different than the effects of trade. More work is needed here, but until then it would be unwise for countries to use trade protection as a means to improve their environment.

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