

Is Trade Good or Bad for the Environment? Sorting Out the Causality

Jeffrey A. Frankel

Andrew K. Rose

Kennedy School of Government
Harvard University, 79 JFK Street
Cambridge MA 02138-5801

Haas School of Business
University of California
Berkeley, CA 94720-1900

Tel: (617) 496-3834
Fax: (617) 496-5747
jeffrey_frankel@harvard.edu
<http://www.ksg.harvard.edu/fs/jfrankel>

Tel: (510) 642-6609
Fax: (510) 642-4700
arose@haas.berkeley.edu
<http://haas.berkeley.edu/~arose>

draft: February 22, 2002

Abstract

The debate over globalization and the environment can be given some much-needed focus by asking the specific empirical question: What is the effect of trade on a country's environment, for a given level of GDP? There is an apparent positive correlation between openness to trade and some measures of environmental quality. But this could be due to endogeneity of trade, rather than causality. This paper uses exogenous determinants of trade – geographical variables from the gravity model – as instruments to isolate the effect of openness. The finding is that trade may indeed have a beneficial effect on some measures of environmental quality. This is particularly true of SO₂ and organic water pollution, and to some extent NO₂. Across seven wider-ranging measures, the beneficial effect is only significant roughly half the time, but one can at least say that there is no evidence that trade has the detrimental effect on the environment that the race-to-the-bottom theory would lead one to expect. The primary effect appears to come via income itself: some of our results support the environmental Kuznets curve, which says that growth harms the environment at low levels of income and helps at high levels, and to support the proposition that openness to trade accelerates the growth process.

The authors would like to thank Ian Bowles, Bill Clark, Dan Esty, Arik Levinson, Joe Nye, Edward Parsos, Rob Stavins and other participants in the Environmental Economics and KSG Faculty Lunch seminars, both at Harvard, for useful comments.

Is Trade Good or Bad for the Environment? Sorting Out the Causality

Jeffrey Frankel and Andrew Rose

Opponents of globalization usually do not argue that it is bad for economic growth, as measured by GDP. Rather they fear adverse effects on such “non-economic” objectives as environmental quality.¹ If the term globalization is meant to capture the totality of industrialization, then there is little question that, at least at the early stages of economic development, environmental degradation is a consequence. If the human species still consisted of a few thousand hunter-gatherers, for example, man-made pollution would be close to zero. This is not the interesting question, however. The interesting questions are (1) whether economic growth eventually brings environmental improvement and (2) whether cross-border integration helps or hurts in this process. That first question is the much-studied environmental Kuznets curve, while the second is the focus of this paper.

The paper seeks to disentangle a variety of simultaneous causal relationships, on a cross-country data set. The question of central interest is the effect of international trade on the environment, for a given level of GDP. We consider certain causal relationships as already fairly well established:

- 1) Openness has a positive effect on countries’ real income per capita. Economists have long made the theoretical case, from the Smith-Ricardo idea of comparative advantage to the Helpman-Krugman model of trade under imperfect competition. The empirical case is also moderately strong.
- 2) Output has a positive effect on pollution through the physical scale of production, but at the same time,
- 3) At higher levels of income per capita, growth raises the public’s demand for environmental quality, which, given the right institutions, can translate into environmental regulation. People value both their economic standard of living as measured by GDP and the environment as well. Environmental regulation, if effective, then translates into a cleaner environment. While the effects described under propositions (2) and (3) go opposite directions, there is by now a rough conventional wisdom that the negative effect of growth on environmental quality dominates at low levels of income, while the positive effect may dominate at higher levels. This proposition is:

¹ The quotation marks are necessary around “non-economic,” because economists’ conceptual framework fully incorporates such objectives as environmental quality, even though pollution is an externality that is not measured by GDP.

- 4) The *environmental Kuznets curve*: the relationship between income per capita and some kinds of pollution is inverted-U-shaped. The World Bank (1992) and Grossman and Krueger (1993, 1995) brought to public attention this empirical finding.² Growth is bad for air and water pollution at the initial stages of industrialization, but later on reduces pollution, as countries become rich enough to pay to clean up their environments. The standard theoretical rationale is that production technology makes some pollution inevitable, but that demand for environmental quality rises with income.³

To portray the Kuznets curve as claiming that if countries promote growth, the environment will eventually take care of itself, would be an unfair caricature. This optimistic view applies to pollution only if it is largely confined within the home or within the firm.⁴ Most pollution, such as SO₂, NO_x, etc., is external to the home or firm.

² Grossman and Krueger (1993, 1995) found the Kuznets curve pattern for urban air pollution (SO₂ and smoke) and several measures of water pollution. Selden and Song (1994) found the pattern for SO₂, suspended particulate matter (PM), NO_x, and carbon monoxide. Shafik (1994) found evidence of the U shape for deforestation, suspended PM, and SO₂, but less for water pollution and some other measures. Among more recent studies, Hilton and Levinson (1998) find the U-shaped relationship for automotive lead emissions and Bradford, Schlieckert and Shore (2000) find some evidence of the environmental Kuznets curve for arsenic, COD, dissolved oxygen, lead and SO₂, while finding less evidence in the cases of PM and some other measures of pollution. Bimonte (2001) finds the relationship for the percentage of land that is protected area, within national territory. Harbaugh, Levinson, and Wilson (2000) point out that the relationship is very sensitive with respect, for example, to functional form and updating of the data set.

³ Theoretical derivations include Andreoni and Levinson (1998), Jaeger and Kolpin (2000), Pfaff and Chaudhuri (), Selden and Song (1995) and Stokey (1998), among others. Another explanation is that the compositional pattern results from the stages of economic development, the transition from an agrarian economy to manufacturing to services (Arrow, et al, 1995; Panayotou, 1993). This explanation is not inconsistent with the usual view, but it is less likely to require the mechanism of effective government regulation. In terms of our testable implications, if the Kuznets curve results solely from this composition effect, then high incomes should lead to a better environment even in the absence of democracy at the national level and even when externalities arise at the international level.

⁴ Perhaps 80 percent (by population) of world exposure to particulates comes from cooking fire smoke in poor countries, which need not involve any externality. Chaudhuri and Pfaff (1998) find a U-shaped relationship between income and indoor smoke, across households. In the poorest households, rising incomes mean more cooking and more indoor pollution. Still-higher incomes allow a switch to cleaner fuels. Engel curves can produce the relationship, with no role for government regulation.

For such externalities, higher income and a popular desire to clean up the environment are not enough. There must also be effective government regulation, which usually requires a democratic system to translate the popular will into action (something that was missing in the Soviet Union, for example), as well as the rule of law and reasonably intelligent mechanisms of regulation. That is at the national level; the requirements for dealing with cross-border externalities are greater still.

We will be testing the environmental Kuznets curve, along with the other propositions on this list. But it is not the central focus of the paper.

The central focus of the paper is, rather:

5) the effect of trade on the environment *for a given level of income per capita*.

This is an interesting question for two reasons. First, it is perhaps the most relevant fundamental question for policy. If it were established that trade had an adverse effect on the environment solely because openness raised countries' incomes, and the higher incomes damaged the environment, in practice few would conclude from this that we should try to turn back the clock on globalization. Few would choose deliberate self-impoverishment as a means to a clean environment.⁵

Secondly, the question is interesting because the answer is completely unknown. There are possible effects in both directions. Most widely discussed is the *race to the bottom hypothesis*, which says that countries that are open to international trade (and investment) will adopt looser standards of environmental regulation, out of fear of a loss in international competitiveness.⁶

Less widely recognized is the possibility of an effect in the opposite direction, which we will call the *gains from trade hypothesis*. Trade allows countries to attain more of what they want, which includes environmental goods in addition to market-measured output. How could openness have a positive effect on environmental quality, even for a given level of GDP per capita? One widely identified possibility is an

⁵ Meadows, et al (1972), and Daly (1993), could, however, be interpreted as arguing that trade is necessarily bad because it raises measured GDP which in turn harms the environment. For a general survey of the issues, see Esty (2001).

⁶ What is competitiveness? Economists tend to argue that concerns regarding international competitiveness, if interpreted as fears of trade deficits, are misplaced, which would seem to imply they would not affect rational policy-making. Or else, to the extent competitiveness concerns can be interpreted as downward pressure on regulation commensurate with cost considerations, economists figure that they may be appropriate. But Esty and Gerardin (1998, p. 17-21) point out that competitiveness fears, under actual political economy conditions, may have a greater effect on environmental standards than is rational, particularly by creating a political drag against new regulation.

international ratcheting up of environmental standards.⁷ A second possibility concerns technological and managerial innovation.⁸ Multi-national corporations tend to bring clean state-of-the-art production techniques from high-standard countries of origin, to host countries where they are not yet known, for several reasons:

“First, many companies find that the efficiency of having a single set of management practices, pollution control technologies, and training programmes geared to a common set of standards outweighs any cost advantage that might be obtained by scaling back on environmental investments at overseas facilities. Second, multinational enterprises often operate on a large scale, and recognise that their visibility makes them especially attractive targets for local enforcement officials...Third, the prospect of liability for failing to meet standards often motivates better environmental performance...” -- Esty and Gentry (1997, p.161)

We think that openness encourages ongoing innovation, that this may be why countries that trade more appear to experience a sustained increase in growth rather than just the one-time increase in the level of real income predicted by classical trade theory. Trade speeds the absorption of frontier technologies and best-practice management. It then seems likely that openness could encourage innovation that would be beneficial to environmental improvement as well as economic progress.

A third possibility is that, because trade offers consumers the opportunity to consume goods of greater variety, it allows countries to attain higher levels of welfare (for any given level of domestically produced output), which, as under proposition (3) above, will raise the demand for environmental quality. Again, if the appropriate institutions are in place, this demand for higher environmental quality will translate into effective regulation and the desired reduction in pollution.⁹

Whether the race-to-the-bottom effect dominates the gains-from-trade effect is an empirical question.

Figure 1 is a schematic illustration of the causal relationships that are hypothesized above, and several others as well. Two controversial propositions are:

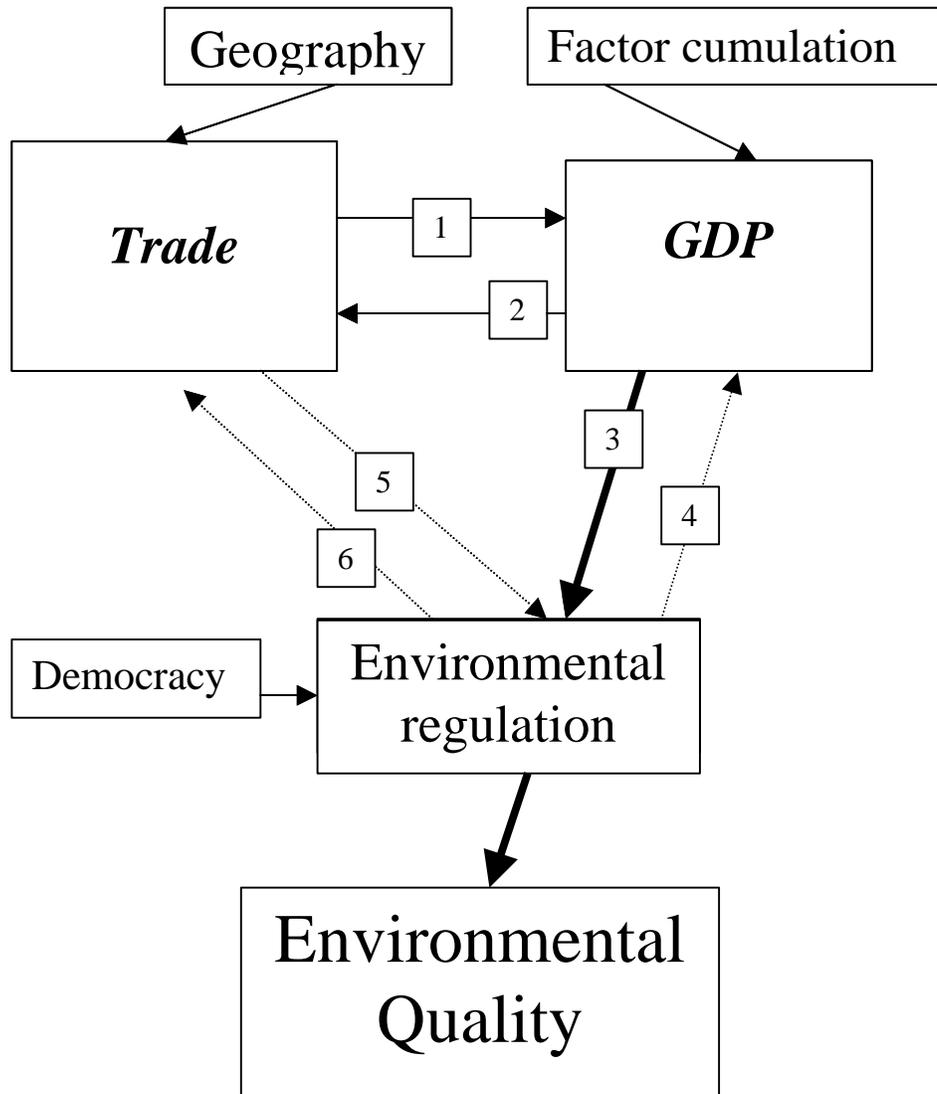
⁷ E.g., Vogel (1995), Porter (1995), and Braithwaite and Drahos (2000). This ratcheting up may be more effective for product standards than for standards regarding production processes and methods.

⁸ Esty and Gentry (1997, pp. 157, 161, 163) and Schmidheiny (1992) .

⁹ A fourth possibility is that globalization offers interest groups that care particularly about the environment a new weapon -- threats to block movement toward free trade unless they are bought off. This is by analogy with the “embedded liberalism” identified by Ruggie (1982), a post-war quid pro quo that gave workers an increased level of social protection, in exchange for an open international trading regime.

THE RELATIONSHIP BETWEEN TRADE AND ENVIRONMENT

Causal hypotheses



- | | |
|---|---|
| 1. Economic gains from trade | 2. Reverse causality from income to trade |
| 3. Environmental Kuznets curve | 4. Effect of regulation on productivity, whether negative (usual) or positive (Porter hypothesis) |
| 5. Effect of trade on environment, whether negative (race to the bottom) or positive (environmental gains from trade) | 6. Pollution haven hypothesis |



- 6) The *pollution haven hypothesis*: To the extent that countries are open to trade and investment, some with low demand for environmental quality will adopt lax environmental standards to attract multinational corporations and export pollution-intensive goods, while those with high demand for environmental quality will adopt high standards and import pollution-intensive goods.¹⁰
- 7) The *Porter hypothesis*: a tightening of environmental regulation stimulates technological innovation and thereby has positive effects on both the economy and the environment -- for example, saving money by saving energy.¹¹ The analytical rationale for this view is not entirely clear. (Is the claim that any sort of change in regulation, regardless in what direction, stimulates innovation, or is there something special about pro-environment regulation? Is there something special about the energy sector?) Nevertheless the Porter hypothesis is sufficiently widely discussed that it merits a position on our list of propositions to be taken into account.

This list of propositions includes important possible causal arrows running in both directions among each pair out of the three key endogenous variables – trade, income, and the environment. In estimating a system of equations, the simultaneity problems are formidable. Let us say that we find a positive correlation between trade and environmental quality. Eiras and Schaeffer (2001, p. 4), for example, find: “In countries with an open economy, the average environmental sustainability score is more than 30 percent higher than the scores of countries with moderately open economies, and almost twice as high as those of countries with closed economies.” Does this mean that trade is good for the environment? Not necessarily. It might be a result of the Porter hypothesis -- environmental regulation stimulates productivity -- together with the positive effect of income on trade. Or it might be because democracy leads to higher levels of environmental regulation, and democracy is causally intertwined with income and trade.

¹⁰ It is worth noting one of the differences between the race-to-the-bottom hypothesis and the pollution haven hypothesis: while the former implies an overall world level of environmental regulation that is less than optimal, the latter does not. Some countries may choose high environmental standards for their own production, and import from others goods that embody pollution. But, in any case, some economists’ research suggests that environmental regulation is not a major determinant of firms’ ability to compete internationally. When deciding where to locate, multinational firms seem to pay far more attention to such issues as labor costs and market access than to the stringency of local environmental regulation: Jaffe, Peterson, Portney and Stavins (1995), Low and Yeats (1992), and Tobey (1990). Other empirical researchers, however, have found more of an effect of environmental regulation: Lee and Roland-Holst (1997) and Smarzynska and Wei (2001). Theoretical analyses include Copeland and Taylor (1994, 1995, 2001) and Liddle (2001).

¹¹ Porter and van der Linde (1995).

A couple of studies do at least seek to isolate the independent effect of openness. Harbaugh, Levinson, and Wilson (2000, Table 4) report in passing a beneficial effect of trade on the environment, even controlling for income. But they make no allowance for the endogeneity of either trade or income. Nor do Antweiler, Copeland and Taylor (2001), which is probably the most careful existing study explicitly focused on the effects of trade on the environment and which estimates an effect that is favorable (though only of borderline significance).

Or let us say that we were to find a negative correlation between trade and environmental quality. Does this mean that trade is bad for the environment? Not necessarily. It might be a result of a negative effect of environmental regulation on growth, together with the positive effect of growth on trade.¹²

The endogeneity of trade is a familiar problem in the empirical literature on whether openness promotes growth. Rodrik (1995), for example, argues that the common finding of a positive correlation between trade and per capita income is "quite misleading on the importance it attaches to the role of export-orientation in the growth performance. It also has backward the causal relationship between exports, on the one hand, and investment and growth on the other." Similarly, Helpman (1988, p.6) asks "Does growth drive trade, or is there a reverse link from trade to growth?" Harrison (1995) concludes that "existing literature is still unresolved on the issue of causality."

Quite a few stories of reverse causality, running from income to trade, are possible. The mechanism that Rodrik, or Levine and Renelt (1992), have in mind runs as follows: an exogenous increase in investment in a developing country with a comparative disadvantage in producing capital goods will necessitate an increase in imports of such goods. Another mechanism is that trade might rise with income because foreign goods are superior goods in consumption. Many studies have sought to identify some direct measures of trade *policy*, hoping that they are exogenous. But, aside from difficulties in measuring trade policies, which are typically serious enough, a fundamental conceptual problem of simultaneity remains (e.g., Sala-i-Martin, 1991). What if free-market trade policies are no more important to growth than free-market domestic policies, but tend to be correlated with them? Then openness will be observed to be correlated with growth, even though trade does not cause growth. A final possible mechanism is a pattern whereby poor countries tend to depend fiscally on tariff revenue, and to reduce tariffs as they become more developed.

What is needed is a good instrumental variable, which is exogenous yet highly correlated with trade. The gravity model of bilateral trade offers a solution. This model says that trade is determined by indicators of country size (GDP, population, and land area) and of distance between the pair of countries in question (physical distance as well

¹² The same ambiguity attaches to correlations among the other pairs of variables. For example, Esty and Porter (2001) find a positive correlation between income and environmental regulation. Their preferred interpretation is the Porter hypothesis, but they are obligate to admit that "These findings do not establish causality." (p. 26).

as dummy variables indicating common borders, linguistic links, and landlocked status).¹³ Such geographical variables are plausibly exogenous. Yet when aggregated across all bilateral trading partners these variables are highly correlated with a country's overall trade, and thus make good instrumental variables. Such gravity instruments have recently been used to isolate the effect of trade in studies of growth (Frankel and Romer, 1999; Irwin and Tervio, 2001), studies of currency union (Frankel and Rose, 1996, 2002), and studies of inequality (Chakrabarti, 2000, and Gurkaynak and Krashinsky, 2001).

Income too is endogenous. We thus also use a second set of instrumental variables, for income per capita, from the growth literature: lagged income (the conditional convergence hypothesis), size (Frankel and Romer, 1999; Frankel and Rose, 2002), and rates of investment rates and human capital formation (the factor cumulation variables familiar from neoclassical growth equations: Solow, 1956; Barro, 1991; Mankiw, Romer and Weil, 1992).

As always, there is the possibility that some of our instrumental variables are in truth endogenous. This could be an issue with the factor cumulation variables in the income equation: Concern has been expressed that investment is endogenous, or human capital.¹⁴ To us, the geographic variables seem the least likely to be endogenous, not just in a causal sense, but also in the econometric sense, i.e., correlated with the error term in the trade equation. These are the instruments we need for testing our question of central interest, the effects of trade on the environment for a given level of income.

We estimate a system of two equations:

Growth equation:

$$\begin{aligned} \ln(Y/Pop)_{90,i} = & \mathbf{b}_0 + \mathbf{a}([X + M]/Y)_{90,i} + \mathbf{b}_1 \ln(Pop)_i + \mathbf{f}Z_i \\ & + \mathbf{g} \ln(Y/Pop)_{70,i} + \mathbf{d}_1 (I/Y)_i + \mathbf{d}_2 n_i + \mathbf{d}_3 (\text{School1})_i + \mathbf{d}_4 (\text{School2})_i + u_i \end{aligned} \quad (1)$$

where: the dependent variable is the natural logarithm of GDP (Y) divided by total population (Pop) at the end of 1990, measured in real PPP-adjusted dollars for country *i*; aggregate exports, aggregate imports, and gross investment are denoted “X”, “M” and “I” respectively; the growth rate of population is denoted “n”; “School₁” and “School₂” are estimates of human capital investment based, respectively, on primary and secondary schooling enrollment rates; “Z” denotes other controls; Greek letters denote coefficients; and “u” denotes the residual impact of other, hopefully orthogonal influences. We denote by “controls” the variables that derive from neoclassical growth theory and appear on the second line of the equation: initial income, investment, human capital and population

¹³ Frankel (1997) offers a comprehensive review of the gravity model.

¹⁴ E.g., Bils and Klenow (1998) argue that investment in human capital is endogenous with respect to growth. It is also possible that the political variables are endogenous, with richer countries tending to become more democratic.

growth.¹⁵ Variables other than GDP per capita and openness are computed as averages over the sample period. Following the norm in the growth literature, we measure openness as the ratio of trade to output.

Environmental quality equation:

$$\begin{aligned} Enviro_i = & \mathbf{j}_0 + \mathbf{j}_1(Y / pop_1)_{90,i} + \mathbf{j}_2(Y / pop_2)_{90,i} + \mathbf{j}_3(Y / pop_3)_{90,i} \\ & + \mathbf{m}[(X + M)/Y]_{90,i} + \mathbf{p}(Polity)_{90,i} + \mathbf{l}(LandArea / Cap)_{90,i} + e_i \end{aligned} \quad (2)$$

where: the dependent variable is a variety of measures of environmental quality, each estimated as separate equations; the first three variables are the three segments of a spline (split at the .33 and .66 percentiles) fit to the natural logarithm of real 1990 GDP (Y) divided by total population (Pop), taken from the Penn World Table 5.6 and so measured in real PPP-adjusted dollars, for country *i*; aggregate exports and aggregate imports as before are denoted “X” and “M”; Polity is a measure of how democratic is the structure of the government, ranging from -10 (“strongly autocratic”) to +10 (strongly democratic);¹⁶ and Land Area per capita is intended to allow for the likelihood that population density leads to environmental degradation (for a given level of per capita income).¹⁷ Again, allowing for the endogeneity of trade and income is the main new contribution of this paper.

We report results for seven measures of environmental quality, including three measures of air pollution concentrations and four others:

SO₂: sulphur dioxide, mean (in micograms per cubic meter), 1995

NO₂: nitrogen dioxide, mean (in micograms per cubic meter), 1995

PM: Suspended Particulate Matter, mean total (in micograms per cubic meter), 1995

BOD: Biochemical oxygen demand -- Organic water pollutant emissions (in kg per day)

¹⁵ Frankel and Romer (1999) and Irwin and Tervio (2000) adopt a more stripped-down specification by omitting these controls, following Hall and Jones (1999). They regress output per capita against distance from the equator and measures of country size, reasoning that the factor accumulation variables might be endogenous. Including the controls in the output equation might result in a downward-biased estimate of α , if some of the effect of openness arrives via factor accumulation. But inappropriately excluding these variables would also produce biased results and could be expected improperly to attribute too *large* an effect to trade. Our own preference is for the specification that includes the controls, in part because it is likely to avoid a possible upward bias in the openness coefficient.

¹⁶ It is taken from the Polity IV Project at the University of Maryland. Described in Marshall and Jaggers (2000).

¹⁷ Cropper and Griffiths (1994) study deforestation and find that, in addition to the usual Kuznets curve effect of per capita income, population density has a further adverse effect.

Def: annual deforestation, average percentage change, 1990-95

Energy: Energy depletion, in percent of GDP (“genuine savings”)¹⁸

CO₂/cap: Carbon dioxide emissions, industrial, in metric tons per capita

Of these seven, the four measures of local pollution -- SO₂, NO₂, PM, and BOD -- are probably the most relevant. As noted, CO₂ is a purely global externality, and unlikely to be addressed by regulation at the national level. Deforestation and Energy depletion are not measures of pollution, and measuring them involves some serious problems of composition and data reliability.¹⁹ But we thought that it was worth at least taking a look at these broader measures of environmental quality.

Results for the Growth Equation

We begin by estimating our output equation, equation (1), to replicate the common finding that there is a statistical association between trade and income. In Table I, we report OLS estimates of the impact of trade on output. The coefficient on initial GDP is a highly significant 0.71, representing a plausible degree of conditional convergence -- about 30 percent over a 20-year period. The estimated coefficient on trade, 0.33 in the OLS version, says that, holding constant for 1970 income, income in 1990 was 1/3 per cent higher for every 1.0 percentage point increase in the trade/GDP ratio. When multiplied by 3.45 (=1/(1-.71)) to convert to an estimated effect on long-run income, the effect on output is 1.14 per cent for every 1.0 percentage point increase in openness.

The effects of investment and both schooling variables are statistically significant and reasonable. Population growth has the negative sign hypothesized by the neoclassical model, but as in earlier work is the one growth determinant that is not statistically significant.

The next step is to estimate the corresponding output equation using IV estimation to account for the possible endogeneity of openness. The instrumental variables we choose come from a simple gravity model that uses as controls an aggregation of: the log of distance, the log of partner country population, the log of area, and dummy variables for common language, common land border, and landlocked status. After estimating the gravity model for a large data set on pairwise trade, we aggregate the exponent of the

¹⁸ Energy depletion is a measure computed for the World Bank’s *World Development Indicators*. It is equal to the product of unit resource rents and the physical quantities of fossil fuel energy extracted (including coal, crude oil, and natural gas). Table 3.15, available at http://www.worldbank.org/data/wdi2001/pdfs/tab3_15.pdf, explains the data computations.

¹⁹ It seems plausible that trade in wood products might lead to some chopping down of trees. For example, Brooks, et al. (2001), estimate that the Accelerated Tariff Liberalization initiative now underway in forest products may increase aggregate world trade in this sector by 2 percent and increase the world timber harvest by 0.5 per cent. But, as they note, this need not imply net deforestation, since planting increases as well.

fitted values across bilateral trading partners to arrive at a prediction of total trade for a given country. The correlation between actual trade shares and our generated instrument is a reassuringly high value of .72.²⁰ Table I also reports the IV estimate of equation (1). The estimate of interest to us here is α , the coefficient on openness. When we include initial income and other controls, the effect of trade on output is 0.43. The implied steady state impact is 1.6 ($=.43/(1-.73)$).

Results for the Environmental Degradation Equations

Table 2 reports the results of OLS estimation of equation (2), where the dependent variable is represented by various measures of pollution and of other sorts of environmental damage. Our central interest is in μ , the coefficient on openness.

The coefficient is negative for five measures -- insignificantly so for PM and energy depletion, borderline significant for NO₂, and highly significant for SO₂ and organic water pollution. It is positive for only two measures -- insignificantly so for deforestation and borderline-significant for CO₂.

The Kuznets curve shows up fairly well for most of the measures. (We leave aside, for the moment, the equation for carbon dioxide.) That is, growth in the low-income countries increases environmental degradation, and growth in the high-income countries reduces it. The effect in the low-income range is insignificant for SO₂, but is significant for energy depletion, borderline-significant for deforestation, and highly significant for suspended particulate matter. The effect in the high-income range is borderline significant for energy depletion and SO₂, significant for suspended particulate matter, and highly significant for deforestation. The two measures that do not exhibit a clear Kuznets curve are NO₂, where the positive effect does not show up until the middle third of the spline, and organic water pollution, where the positive effect appears at the highest-income level. In addition, growth continues to have a positive, indeed increasing, effect through all three segments in the case of CO₂.

Thus the OLS results are overall fairly supportive of both the Kuznets curve and the proposition that openness is at least as likely to help the environment, for a given level of income, as to hurt it. The only case where growth appears always detrimental for the environment -- and openness to exacerbate the problem -- is CO₂. This is the one gas on our list that is a purely global externality, where countries cannot expect to be able

²⁰ See Frankel and Rose (2002) for results of the estimation of the bilateral trade equation and details of the calculation of the gravity instrument, which corresponds closely to that used here. That paper also includes a response to a critique from Rodriguez and Rodrik (2001) and Rodrik (2000) regarding the gravity instruments. Part of the controversy concerns whether trade can be assumed to have similar effects on growth when the "globalization" arises from deliberate policy (such as trade liberalization) as when it arises from geographic and technologica*1 factors (such as proximity or declining shipping costs).

to address it by national regulation on their own, and indeed where fears of adverse effects on competitiveness are most acute.²¹

The contribution of this paper is to address the possibility that these apparent effects may be the spurious results of simultaneity. Table 3 estimates the environmental equation via instrumental variables, where the gravity-derived prediction of openness is the instrument for trade and the factor accumulation variables are the instruments for income.

The IV results are generally similar to the OLS results, but with a slightly different pattern across the various environmental measures. The coefficient on openness is again negative for five measures -- insignificantly so for CO₂, borderline significant for energy depletion and NO₂, and clearly significant for SO₂ and organic water pollution. It is again positive for only two measures -- deforestation and PM -- without any statistical significance in either case.

We interpret the absence of a general positive effect of openness on environment degradation as evidence against the “race to the bottom” hypothesis. Trade, if anything, appears to have a generally beneficial effect on most of our measures of environmental quality, for given levels of income. But one might still be concerned about a possible “pollution haven” hypothesis according to which economic integration results in some countries exporting pollution to others, even if the overall level of pollution does not rise. The hypothesis would be that countries that have a particularly high demand for environmental quality – e.g., the rich countries -- specialize in products that can be produced cleanly, and they let the poor countries produce and sell the products that require pollution.²² This hypothesis can be readily tested by adding to the equation the product of openness and income per capita. If rich countries take advantage of trade by exporting pollution-creating activities to poor countries, the interaction between openness and income should have a negative effect on the level of a country’s domestic pollution. When we tried this as an extension, we found that the estimated coefficient on the interactive term was positive in five out of seven cases, the opposite of the pollution haven hypothesis, and in no cases was statistically significant.

A parallel hypothesis would be that countries that are endowed with a particularly high supply of environmental quality – e.g., those with high land area per capita -- import

²¹ Of course, we cannot rule out that emissions of CO₂ also follow a Kuznets Curve, but that the peak is not reached until higher levels of income than yet experienced by rich countries. (Schmalensee, Stoker and Judson, 1996.) But, as Dua and Esty (1997, p. 74) point out, that the ability to control pollution would diminish with the geographical diffusion of the externality is exactly what one would expect.

²² E.g., Suri and Chapman (1998) find that middle-income countries’ growth only leads to lower domestic pollution if they increase imports of manufactures. Muradian, O’Connor and Martinez-Alier (2001) have found recent evidence that the imports of rich countries embody more air pollution than their exports.

pollution from those that are more densely populated. We tested this by adding the product of openness and land area per capita. The sign was positive in five out of seven cases, but in no cases was significant. The only case of statistical significance was an apparent negative effect of the interactive term in the equation for CO₂ emissions per capita, counterintuitively suggesting that sparsely populated open countries have lower emissions rather than higher. In any case, there is no evidence for the pollution haven effect. (Tables with the interactive terms are not reported here.)

The Kuznets curve continues to hold up under the IV estimation of Table 3. Growth worsens the environment in the low-income range in the case of five measures: insignificantly for deforestation, with borderline significance for organic water pollution and CO₂, and with high significance for energy depletion and PM. The two measures that show growth reducing pollution in this range, NO₂ and SO₂, are not statistically significant. In the high-income range, growth improves the environment in five cases: insignificantly for NO₂, PM and energy depletion, and significantly for SO₂ and deforestation. The two cases where growth appears still to damage the environment in the high-income range, and significantly so, are again CO₂ and water.²³

The polity variable shows up with the expected negative sign in almost all cases: as expected, democracy is good for environmental protection. The effect is clearly significant statistically for NO₂, SO₂, PM, and energy depletion, under either OLS or IV estimation, and insignificant only for the case of water pollution. Even for CO₂, the estimated effect is beneficial, though only significant under IV estimation. The one case of an apparent detrimental effect, deforestation, is not statistically significant. We note, in passing, that area per capita has the expected negative sign in five out of seven cases, though it is not always significant.

Conclusions and a Calculation

Trade can have several sorts of effects on the environment. We have found evidence that, for any given level of income, trade appears to have a generally beneficial effect on some measures of environmental quality, though not all. This is particularly true of SO₂ and organic water pollution. Across seven measures, the beneficial effect is only significant roughly half the time. But one can at least say that there is no evidence that trade has the detrimental effect on the environment that the race-to-the-bottom theory would lead one to expect, and the evidence is also against the pollution haven hypothesis. In addition, trade helps promote economic growth, which in turn is an indirect channel of effect on the environment. At low levels of income this effect is detrimental to the environment, at high levels beneficial.

An interesting question is whether, within the class of low-income countries, the direct beneficial effect of openness is large enough to offset the indirect effect via income. The openness coefficient is too variable across measures of pollution and is estimated too imprecisely to allow us to answer this question reliably. But an illustrative

²³ For the case of water pollution, this apparent finding is surprising.

calculation may still be instructive. The environmentally damaging phase of the Kuznets curve is particularly strong for energy depletion, so let us take this case. Table 1 reports that for every 1 percentage point increase in openness, income rises by an estimated 0.3 percentage points (over the subsequent 20 years). The relevant coefficient from Table 2 implies that, in a poor country, this economic growth in turn induces energy depletion of $8.5 \times 0.3 = 2.6$. At the same time, the 1 percentage point increase in openness diminishes energy depletion by an estimated 3.3 for a given level of income. Taking the difference of the two effects produces an estimated beneficial net effect.

We must be sure not read much into this calculation of the net effect. The difference is not statistically significant. Furthermore, the net effect is much better than this for some of the measures of environmental damage, and much worse for others. But if it is necessary to attempt an overall verdict, it is also worth recalling two key points. Even if the two effects of trade on pollution cancelled out, that would still leave the country with a higher level of income and no change in environmental quality. Furthermore, once the country gets past the peak in the Kuznets curve, the two effects of openness, indirectly via income and directly, go the same direction.

This optimistic story does not hold for the case of CO₂. Here there is no evidence that the Kuznets curve ever turns down on its own. Furthermore, openness is estimated under OLS to have a detrimental effect even for a given level of income, although, encouragingly, the latter effect disappears under IV estimation. Clearly trade and growth alone won't do it; international cooperation is also needed to address this sort of global environmental problem.

References

Andreoni, James, and Arik Levinson 1998, "The Simple Analytics of the Environmental Kuznets Curve," *NBER Working Paper* no. 6739, September.

Antweiler, Werner, Brian Copeland and M. Scott Taylor, 2001, "Is Free Trade Good for the Environment?" *NBER Working Paper* No. 6707. *American Economic Review*, 91, no. 4, September, 877-908.

Arrow, K., R. Bolin, P. Costanza, P. Dasgupta, C. Folke, C.S.Holling, B.O. Jansson, S.Levin, K.G. Maler, C.Perrings, and D.Pimentel, 1995, "Economic Growth, Carrying Capacity, and the Environment," *Science* 268, 520-521, April 28.

Barro, Robert, "Economic Growth in a Cross Section of Countries," *Quarterly Journal of Economics*, CVI (May 1991), 407-444.

Bils, Mark, and Peter Klenow, 1998, "Does Schooling Cause Growth or the Other Way Around?" *NBER Working Paper* no. 6393, Feb.

Bimonte, Salvatore, 2001, "Model of Growth and Environmental Quality: A New Evidence of the Environmental Kuznets Curve," Department of Economics, Università di Siena, April; available from the SSRN Electronic Paper Collection: http://papers.ssrn.com/paper.taf?abstract_id=286740

Bradford, David, Rebecca Schlieckert and Stephen Shore, 2000, "The Environmental Kuznets Curve: Exploring a Fresh Specification," *NBER Working Paper* no. 8001.

Braithwaite, John, and Peter Drahos, Global Business Regulation, Cambridge University Press, UK.

Brooks, D.J., J.A. Ferrante, J. Haverkamp, I. Bowles, W. Lange, and D. Darr, 2001, *Economic and Environmental Effects of Accelerated Tariff Liberalization in the Forest Products Sector*, Northwest Research Station, Forest Service, USDA.

Chakrabarti, Avik, 2000, "Do Nations That Trade More Have a More Unequal Distribution of Income?" Journal of Economic Development, Dec.

Chaudhuri, Shubham, and Alex Pfaff, 1998, "Does Air Quality Fall or Rise as Household Incomes Increase?" Columbia University, March.

Copeland, Brian, and M. Scott Taylor, 1994, "North-South Trade and the Environment," Quarterly Journal of Economics 109, 755-787.

Copeland, Brian, and M. Scott Taylor, 1995, Trade and the Environment: A Partial Synthesis," American Journal of Agricultural Economics 77, 765-771.

Copeland, Brian, and M. Scott Taylor, 2001, "International Trade and the Environment: A Framework for Analysis," NBER Working Paper No. 8540, Oct.

Cropper, Maureen and Charles Griffiths. 1994. "The Interaction of Population Growth and Environmental Quality." American Economic Review, AEA Papers and Proceedings 84(2): 250-254.

Daly, Herman, 1993, "The Perils of Free Trade," Scientific American, Nov., 51-55.

Dua, Andre, and Daniel Esty, 1997, *Sustaining the Asia Pacific Miracle: Environmental Protection and Economic Integration*, Institute for International Economics: Washington DC.

Eiras, Ana, and Brett Schaefer, 2001, "Trade: The Best Way to Protect the Environment," *Backgrounders*, The Heritage Foundation no. 1480, September 27.

Esty, Daniel, 2001, "Bridging the Trade-Environment Divide," Journal of Economic Perspectives, Summer 15, no. 3, 113-130.

Esty, Daniel, and Bradford Gentry, 1997, "Foreign Investment, Globalisation, and the Environment," Globalization and the Environment, edited by Tom Jones (Organization for Economic Cooperation and Development: Paris).

Esty, Daniel, and Damien Girardin, 1998, "Environmental Protection and International Competitiveness: A Conceptual Framework," Journal of World Trade, 32, no. 3, June, 5-46.

Esty, Daniel, and Michael Porter, 2001, "Measuring National Environmental Performance and Its Determinants," Yale Law School and Harvard Business School, April.

Frankel, Jeffrey, 1997, Regional Trading Blocs in the World Trading System, Institute for International Economics, Washington DC.

Frankel, Jeffrey, and David Romer, 1999, "Does Trade Cause Growth?" *American Economic Review*, 89, no. 3, June, 379-399.

Frankel, Jeffrey, and Andrew Rose, 2002. "An Estimate of the Effect of Common Currencies on Trade and Income," KSG Working Paper, April 10, 2001. Forthcoming, Quarterly Journal of Economics, May.

Grossman, Gene, and Alan Krueger, 1993, "Environmental Impacts of a North American Free Trade Agreement," in The U.S.-Mexico Free Trade Agreement, Peter Garber, ed., Cambridge MA, MIT Press.

Grossman, Gene, and Alan Krueger, 1995, "Economic Growth and the Environment," Quarterly Journal of Economics, 353-377.

Gurkaynak, Refet, and Harry Krashinsky, 2001, "What Does Trade Do? The Effect of Trade on Inequality and Growth," Princeton University, July.

Hall, Robert, and Charles Jones, "Why Do Some Countries Produce So Much More Output per Worker than Others?" *Quarterly Journal of Economics*, 114, no.1 (Feb. 1999), 83-116.

Harbaugh, William, Arik Levinson, and David Wilson, 2000, "Reexamining the Empirical Evidence for an Environmental Kuznets Curve," NBER Working Paper No. 7711, May.

Harrison, Ann, 1995, "Openness and Growth: A Time-Series, Cross-Country Analysis for Developing Countries," *NBER Working Paper* No. 5221, August.

Helpman, Elhanan. 1988, "Growth, Technological Progress, and Trade," *National Bureau of Economic Research* Reprint no. 1145.

Hilton, F.G. Hank, and Arik Levinson, 1998, "Factoring the Environmental Kuznets Curve: Evidence from Automotive Lead Emissions," *Journal of Environmental Economics and Management* 35, 126-141.

Irwin, Douglas, and Marko Tervio "Does Trade Raise Income? Evidence from the Twentieth Century," NBER Working Paper 7745 (2000).

Jaeger, William, and Van Kolpin, 2000, "Economic Growth and Environmental Resource Allocation," August.

Jaffe, Adam, S. Peterson, Paul Portney and Robert Stavins, 1995, "Environmental Regulation and the Competitiveness of U.S. Manufacturing: What Does the Evidence Tell Us?" *Journal of Economic Literature*.

Levine, Ross, and David Renelt, 1992, "A Sensitivity Analysis of Cross-Country Growth Regressions," *American Economic Review* 82, no. 4, 942-963.

Liddle, Brantley, 2001, "Free Trade and the Environment-Development System," *Ecological Economics* 39, 21-36.

Low, P., and A. Yeats, 1992, "Do 'Dirty' Industries Migrate?" in P. Low, ed., *International Trade and the Environment*, World Bank, 1992, 89-104.

Mankiw, N. Gregory, David Romer and David Weil, 1992, "A Contribution to the Empirics of Economic Growth," *Quarterly Journal of Economics* CVII, 407-437, 1992.

Marshall, Monty, and Keith Jagers, 2000, "Political Regime Characteristics and Transitions, 1800-1999: Dataset Users Manual," *Polity IV Project*, University of Maryland, College Park; www.bsos.umd.edu/cidcm/inscr/polity.

Meadows, Donella, Dennis Meadows, Jorgen Randers, and William Behrens, 1972, *The Limits to Growth*, Universe Books, New York.

Muradian, Roldan, Martin O'Connor and Joan Martinez-Alier, 2001, "Embodied Pollution in Trade: Estimating the 'Environmental Load Displacement' of Industrialised Countries," *FEEM Working Paper No. 57*, July, Milan.

Panayotou, Theo, 1993, "Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Development," Working Paper WP238, Technology and Employment Programme (International Labor Office: Geneva).

Pfaff, Alexander, and Shubham Chaudhuri, "Household Income, Fuel Choice and Indoor Air Quality: Microfoundations of an Environmental Kuznets Curve," Columbia University.

Porter, Michael, 1998, The Competitive Advantage of Nations .

Porter, Michael, and Claas van der Linde, 1995, "Toward a New Conception of the Environment-Competitiveness Relationship," Journal of Economic Perspectives 9, No. 4.

Rodrik, Dani, 1995, "Getting Interventions Right: How South Korea and Taiwan Grew Rich," NBER Working Paper No. 4964; Economic Policy, no. 20.

Rodríguez, Francisco, and Dani Rodrik, "Trade Policy and Economic Growth: A Skeptic's Guide to the Cross-National Evidence," *NBER Macroeconomics Annual 2001* (Cambridge, MA: MIT Press, 2001).

Rodrik, Dani, 2000, "Comment on Frankel and Rose," unpublished, Kennedy School of Government, Harvard University.

Ruggie, John, 1982, "International Regimes, Transactions, and Change: Embedded Liberalism in the Postwar Economic Order," International Organization 36, Spring.

Sala-i-Martin, Xavier, 1991, "Comment," NBER Macroeconomics Annual 6, 368-378.

Schmalensee, R., T. M. Stoker and R.A.Judson, 1996, "World Carbon Dioxide Emissions: 1950-2050," Review of Economics and Statistics, forthcoming.

Selden, Thomas, and Daqing Song, 1994, "Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions," Journal of Environmental Economics and Management 27, 147-162.

Selden, Thomas, and Daqing Song, 1995, "Neoclassical Growth, the J Curve for Abatement, and the Inverted U Curve for Pollution," Journal of Environmental Economics and Management 29, 162-168.

Shafik, Nemat, 1994, "Economic Development and Environmental Quality: An Econometric Analysis," Oxford Economic Papers 46, 757-773.

Smarzynska, Beata, and Shang-Jin Wei, 2001, "Pollution Havens and Foreign Direct Investment: Dirty Secret or Popular Myth?" *NBER Working Paper* No. 8465, September.

Solow, Robert, 1956 "A Contribution to the Theory of Economic Growth," Quarterly Journal of Economics 70, February, 65-94.

Stokey, Nancy, 1998, "Are There Limits to Growth?" International Economic Review 39, no. 1, February, 1-31.

Suri, Vivek, and Duane Chapman, 1998, "Economic Growth, Trade and Energy: Implications for the Environmental Kuznets Curve," Ecological Economics 25, 2, May, 147-160.

Tobey, James A., 1990, "The Effects of Domestic Environmental Policies on Patterns of World Trade: An Empirical Test," Kyklos 43, 191-209.

Vogel, David, 1995, Trading Up: Consumer and Environmental Regulation in a Global Economy, Harvard University Press .

World Bank, 1992, *Development and the Environment*, World Development Report (Oxford University Press: NY).

Table 1: Income equations

```

. *
. * Income equation with controls, OLS, and IV (gravity)
. *
. reg lrgdpch pwtopen lpop lrgdpchi invrat popg sch1 sch2, robust

```

Regression with robust standard errors

Number of obs =	106
F(7, 98) =	378.1
Prob > F =	0.000
R-squared =	0.940
Root MSE =	.279

lreal gdp/cap	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
pwtopen	.003	.001	4.51	0.000	.0018752	.0048228
lpop	.065	.021	3.17	0.002	.024446	.106223
lrgdpchi	.711	.052	13.56	0.000	.6068329	.8148625
invrat	.016	.006	2.75	0.007	.0043862	.0270059
popg	-.055	.050	-1.10	0.273	-.1540046	.0439813
sch1	.002	.002	1.04	0.299	-.0014603	.0047019
sch2	.007	.002	3.37	0.001	.0029775	.0115193
_cons	1.019	.446	2.29	0.024	.1344121	1.902896

```

. ivreg lrgdpch (pwtopen = elhsfs) lpop lrgdpchi invrat popg sch1 sch2, robust

```

IV (2SLS) regression with robust standard errors

Number of obs =	102
F(7, 94) =	329.25
Prob > F =	0.0000
R-squared =	0.9382
Root MSE =	.28273

lrgdpch	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
pwtopen	.004	.001	4.28	0.000	.0022838	.0062404
lpop	.078	.024	3.28	0.001	.0308508	.1253222
lrgdpchi	.726	.057	12.71	0.000	.612585	.8393506
invrat	.013	.006	2.17	0.032	.0011504	.0257221
popg	-.047	.058	-0.82	0.416	-.1614204	.0673297
sch1	.001	.002	0.83	0.407	-.0020093	.0049089
sch2	.007	.003	2.82	0.006	.0022168	.0127724
_cons	.750	.496	1.51	0.135	-.238326	1.737495

```

Instrumented: pwtopen
Instruments: lpop lrgdpchi invrat popg sch1 sch2 elhsfs

```

Table 2: Environmental degradation equations

. * Splines for Real GDP per capita: Real income is replaced by
 . * a three-piece spline, split at the .33 and .66 percentiles.

OLS regressions

. *
 . *
 . * Estimation of pollution equation, a function of income, trade, democracy and size

. reg co2perc incl-inc3 pwtopen polity lareapc, robust

Regression with robust standard errors

	Number of obs =	100
	F(6, 93) =	37.07
	Prob > F =	0.0000
	R-squared =	0.7526
	Root MSE =	2.4294

emissions of co2 / cap	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
incl	1.037	.406	2.56	0.012	.2312251	1.842008
inc2	2.113	.827	2.55	0.012	.4699467	3.755439
inc3	7.049	1.282	5.50	0.000	4.503515	9.593509
pwtopen	.016	.008	1.97	0.052	-.0001296	.032725
polity	-.025	.022	-1.13	0.263	-.0696164	.0192251
lareapc	.161	.154	1.04	0.301	-.1459042	.4671842
_cons	-8.099	3.03	-2.67	0.009	-14.12257	-2.076243

. test incl inc2 inc3
 (1) incl = 0.0
 (2) inc2 = 0.0
 (3) inc3 = 0.0

	F(3, 93) =	57.60	Prob > F =	0.0000
--	-------------	-------	------------	--------

. reg defp incl-inc3 pwtopen polity lareapc, robust

Regression with robust standard errors

	Number of obs =	96
	F(6, 89) =	7.94
	Prob > F =	0.0000
	R-squared =	0.2670
	Root MSE =	1.1167

annual deforestation	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
incl	.558	.338	1.65	0.102	-.1131407	1.228917
inc2	-1.071	.460	-2.33	0.022	-1.984712	-.1568467
inc3	-1.035	.338	-3.06	0.003	-1.706029	-.3630194
pwtopen	.002	.003	0.78	0.437	-.0033326	.0076449
polity	.033	.030	1.08	0.281	-.0274542	.0933718
lareapc	-.112	.076	-1.49	0.141	-.2628435	.0379788
_cons	-2.356	2.37	-0.99	0.323	-7.068778	2.357222

. test incl inc2 inc3
 (1) incl = 0.0
 (2) inc2 = 0.0
 (3) inc3 = 0.0

	F(3, 89) =	7.88	Prob > F =	0.0001
--	-------------	------	------------	--------

```
. reg enrdam incl1-inc3 pwtopen polity lareapc, robust
Regression with robust standard errors
```

```
Number of obs = 98
F( 6, 91) = 3.07
Prob > F = 0.0089
R-squared = 0.1653
Root MSE = 6.8583
```

energy depletion (%GDP)	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
incl1	6.701	2.210	3.03	0.003	2.310476	11.09073
incl2	4.288	2.902	1.48	0.143	-1.47727	10.05339
incl3	-3.197	1.842	-1.74	0.086	-6.855637	.4612429
pwtopen	-.013	.009	-1.53	0.130	-.0305804	.0039884
polity	-.446	.167	-2.68	0.009	-.7765009	-.1149375
lareapc	.249	.419	0.59	0.554	-.5835411	1.081669
_cons	-45.384	15.583	-2.91	0.005	-76.33765	-14.42956

```
. test incl1 incl2 incl3
```

```
( 1) incl1 = 0.0
( 2) incl2 = 0.0
( 3) incl3 = 0.0      F( 3, 91) = 5.86      Prob > F = 0.0010
```

```
. reg no2m incl1-inc3 pwtopen polity lareapc, robust
Regression with robust standard errors
```

```
Number of obs = 36
F( 6, 29) = 7.13
Prob > F = 0.0001
R-squared = 0.2077
Root MSE = 39.866
```

NO ₂	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
incl1	-373.491	209.562	-1.78	0.085	-802.0938	55.1116
incl2	169.749	57.176	2.97	0.006	52.81202	286.6866
incl3	-19.707	14.786	-1.33	0.193	-49.94719	10.53242
pwtopen	-.302	.159	-1.91	0.066	-.6266813	.0218449
polity	-3.854	.975	-3.96	0.000	-5.847568	-1.861281
lareapc	-5.897	6.055	-0.97	0.338	-18.28116	6.486311
_cons	2740.844	1499.377	1.83	0.078	-325.7254	5807.414

```
. test incl1 incl2 incl3
```

```
( 1) incl1 = 0.0
( 2) incl2 = 0.0
( 3) incl3 = 0.0      F( 3, 29) = 7.55      Prob > F = 0.0007
```

```
. reg sulfdm incl1-inc3 pwtopen polity lareapc, robust
Regression with robust standard errors
```

```
Number of obs = 41
F( 6, 34) = 40.04
Prob > F = 0.0000
R-squared = 0.6789
Root MSE = 23.351
```

SO ₂	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
incl1	46.351	68.589	0.68	0.504	-93.03795	185.7394
incl2	29.202	17.0379	1.71	0.096	-5.421597	63.82617
incl3	-16.540	8.827	-1.87	0.070	-34.47801	1.398082
pwtopen	-.303	.082	-3.72	0.001	-.4690819	-.1377736
polity	-6.561	2.081	-3.15	0.003	-10.78989	-2.331318
lareapc	-3.223	1.398	-2.30	0.027	-6.064381	-.3806328
_cons	-248.434	488.917	-0.51	0.615	-1242.032	745.1641

```
. test incl1 incl2 incl3
```

```
( 1) incl1 = 0.0
( 2) incl2 = 0.0
( 3) incl3 = 0.0      F( 3, 34) = 2.07      Prob > F = 0.1222
```

```
. reg suspm incl-inc3 pwtopen polity lareapc, robust
Regression with robust standard errors
```

```
Number of obs = 38
F( 6, 31) = 13.45
Prob > F = 0.0000
R-squared = 0.7147
Root MSE = 52.835
```

suspended PM	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
incl1	332.443	100.885	3.30	0.002	126.687	538.1996
incl2	-113.061	54.189	-2.09	0.045	-223.5813	-2.541169
incl3	-46.614	22.426	-2.08	0.046	-92.35144	-.8770822
pwtopen	-.256	.323	-0.79	0.435	-.9140907	.4029555
polity	-7.459	3.378	-2.21	0.035	-14.34902	-.5689337
lareapc	-10.514	4.576	-2.30	0.028	-19.84621	-1.182096
_cons	-2128.872	724.849	-2.94	0.006	-3607.211	-650.5336

```
. test incl1 incl2 incl3
```

```
( 1) incl1 = 0.0
```

```
( 2) incl2 = 0.0
```

```
( 3) incl3 = 0.0
```

```
F( 3, 31) = 10.86
```

```
Prob > F = 0.0000
```

```
. reg water incl-inc3 pwtopen polity lareapc, robust
Regression with robust standard errors
```

```
Number of obs = 69
F( 6, 62) = 2.20
Prob > F = 0.0547
R-squared = 0.1877
Root MSE = 6.7e+05
```

organic water pollution BOD	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
incl1	462513.3	427084.3	1.08	0.283	-391216	1316243
incl2	-348204.2	306688.4	-1.14	0.261	-961265.5	264857.1
incl3	478785.8	246735.2	1.94	0.057	-14430.69	972002.4
pwtopen	-5403.064	2122.56	-2.55	0.013	-9646.001	-1160.127
polity	-20465.7	22229.98	-0.92	0.361	-64902.79	23971.39
lareapc	-124713.4	56856.9	-2.19	0.032	-238368.7	-11058.07
_cons	-2215670.0	2721277.0	-0.81	0.419	-7655426	3224085

```
. test incl1 incl2 incl3
```

```
( 1) incl1 = 0.0
```

```
( 2) incl2 = 0.0
```

```
( 3) incl3 = 0.0
```

```
F( 3, 62) = 1.28
```

```
Prob > F = 0.2895
```

```
**
```

Table 3: Environmental degradation equations

IV regressions

```
. *
. * Estimation of pollution equations, a function of income, trade, democracy and size
. *
```

```
. ivreg co2perc (incl-inc3 pwtopen = elhsfs incf1-incf3) polity lareapc, robust
IV (2SLS) regression with robust standard errors      Number of obs =    96
                                                    F( 6,    89) =   43.49
                                                    Prob > F      =   0.0000
                                                    R-squared    =   0.7695
                                                    Root MSE    =   2.1073
```

emissions of	Robust					
CO ₂ per cap	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
incl	.700	.479	1.46	0.147	-.2506002	1.651539
inc2	3.754	1.043	3.60	0.001	1.680344	5.827068
inc3	6.322	1.318	4.80	0.000	3.702777	8.940313
pwtopen	-.001	.010	-0.06	0.949	-.0213223	.0199778
polity	-.080	.037	-2.19	0.031	-.1529869	-.0075785
lareapc	.033	.163	0.20	0.840	-.2904868	.3563754
_cons	-4.876	3.184	-1.53	0.129	-11.20329	1.450801

```
Instrumented:  incl inc2 inc3 pwtopen
Instruments:  polity lareapc elhsfs incf1 incf2 incf3
```

```
. test incl inc2 inc3
( 1) incl = 0.0
( 2) inc2 = 0.0
( 3) inc3 = 0.0      F( 3,    89) =   37.28      Prob > F =   0.0000
```

```
. ivreg defp (incl-inc3 pwtopen = elhsfs incf1-incf3) polity lareapc, robust
IV (2SLS) regression with robust standard errors      Number of obs =    92
                                                    F( 6,    85) =   10.69
                                                    Prob > F      =   0.0000
                                                    R-squared    =   0.2756
                                                    Root MSE    =   1.1288
```

annual	Robust					
deforestation	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
incl	.545	.436	1.25	0.215	-.3218014	1.412437
inc2	-.736	.593	-1.24	0.218	-1.915416	.4428395
inc3	-1.262	.510	-2.48	0.015	-2.275795	-.2486893
pwtopen	.001	.003	0.37	0.713	-.0055138	.0080241
polity	.027	.027	1.00	0.320	-.0266874	.0806927
lareapc	-.078	.084	-0.94	0.351	-.2445592	.087756
_cons	-2.367	3.035	-0.78	0.438	-8.401125	3.666521

```
Instrumented:  incl inc2 inc3 pwtopen
Instruments:  polity lareapc elhsfs incf1 incf2 incf3
```

```
. test incl inc2 inc3
( 1) incl = 0.0
( 2) inc2 = 0.0
( 3) inc3 = 0.0      F( 3,    85) =   11.24      Prob > F =   0.0000
```

```
. ivreg enrdam (incl-inc3 pwtopen = elhsfs incf1-incf3) polity lareapc, robust
IV (2SLS) regression with robust standard errors      Number of obs =    93
                                                    F( 6, 86) =    3.57
                                                    Prob > F      = 0.0033
                                                    R-squared    = 0.1601
                                                    Root MSE    = 7.0469
```

energy depletion	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
incl1	8.526	3.132	2.72	0.008	2.299406	14.75191
incl2	4.257	3.654	1.16	0.247	-3.006933	11.51994
incl3	-2.922	2.094	-1.40	0.166	-7.084741	1.240289
pwtopen	-.033	.020	-1.67	0.099	-.0723321	.0062907
polity	-.521	.190	-2.74	0.007	-.8982336	-.1435188
lareapc	.314	.505	0.62	0.536	-.6895735	1.317237
_cons	-57.089	20.293	-2.81	0.006	-97.42937	-16.74794

```
Instrumented:  incl1 inc2 inc3 pwtopen
Instruments:   polity lareapc elhsfs incf1 incf2 incf3
```

```
. test incl1 inc2 inc3
( 1) incl1 = 0.0
( 2) incl2 = 0.0
( 3) incl3 = 0.0      F( 3, 86) =    6.84      Prob > F =    0.0003
```

```
. ivreg no2m (incl-inc3 pwtopen = elhsfs incf1-incf3) polity lareapc, robust
IV (2SLS) regression with robust standard errors      Number of obs =    35
                                                    F( 5, 28) =    .
                                                    Prob > F      = 0.0000
                                                    R-squared    = 0.2120
                                                    Root MSE    = 39.012
```

NO ₂	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
incl1	-492.924	324.925	-1.52	0.140	-1158.503	172.6544
incl2	207.138	100.288	2.07	0.048	1.706976	412.5686
incl3	-20.821	10.991	-1.89	0.069	-43.3357	1.694193
pwtopen	-.324	.186	-1.75	0.092	-.7043395	.0561261
polity	-4.448	1.216	-3.66	0.001	-6.938388	-1.956846
lareapc	-5.792	6.445	-0.90	0.376	-18.99402	7.40949
_cons	3593.957	2331.116	1.54	0.134	-1181.117	8369.031

```
Instrumented:  incl1 inc2 inc3 pwtopen
Instruments:   polity lareapc elhsfs incf1 incf2 incf3
```

```
. test incl1 inc2 inc3
( 1) incl1 = 0.0
( 2) incl2 = 0.0
( 3) incl3 = 0.0      F( 3, 28) =    4.01      Prob > F =    0.0172
```

```
. ivreg sulfdm (incl-inc3 pwtopen = elhsfs incf1-incf3) polity lareapc, robust
IV (2SLS) regression with robust standard errors
```

Number of obs =	40
F(6, 33) =	7.78
Prob > F =	0.0000
R-squared =	0.6618
Root MSE =	24.318

SO ₂	Robust		t	P> t	[95% Conf. Interval]	
	Coef.	Std. Err.				
incl	-22.492	190.106	-0.12	0.907	-409.2647	364.2804
inc2	39.992	58.752	0.68	0.501	-79.54006	159.5247
inc3	-20.144	9.920	-2.03	0.050	-40.32547	.037861
pwtopen	-.210	.089	-2.36	0.025	-.3912915	-.0286649
polity	-6.359	2.437	-2.61	0.014	-11.31825	-1.400341
lareapc	-1.420	2.230	-0.64	0.529	-5.957359	3.116873
_cons	240.566	1373.882	0.18	0.862	-2554.618	3035.575

```
Instrumented: incl inc2 inc3 pwtopen
Instruments: polity lareapc elhsfs incf1 incf2 incf3
```

```
. test incl inc2 inc3
( 1) incl = 0.0
( 2) inc2 = 0.0
( 3) inc3 = 0.0
```

F(3, 33) =	3.36	Prob > F =	0.0302
-------------	------	------------	--------

```
. ivreg suspdm (incl-inc3 pwtopen = elhsfs incf1-incf3) polity lareapc, robust
IV (2SLS) regression with robust standard errors
```

Number of obs =	37
F(6, 30) =	9.80
Prob > F =	0.0000
R-squared =	0.7024
Root MSE =	54.128

suspended PM	Robust		t	P> t	[95% Conf. Interval]	
	Coef.	Std. Err.				
incl	497.615	137.231	3.63	0.001	217.3518	777.8776
inc2	-172.283	79.002	-2.18	0.037	-333.6254	-10.93971
inc3	-33.763	27.233	-1.24	0.225	-89.37924	21.85389
pwtopen	.037	.293	0.13	0.900	-.561858	.6363146
polity	-8.524	3.950	-2.16	0.039	-16.59092	-.4579705
lareapc	-7.098	4.469	-1.59	0.123	-16.22478	2.0296
_cons	-3325.855	973.424	-3.42	0.002	-5313.852	-1337.857

```
Instrumented: incl inc2 inc3 pwtopen
Instruments: polity lareapc elhsfs incf1 incf2 incf3
```

```
. test incl inc2 inc3
( 1) incl = 0.0
( 2) inc2 = 0.0
( 3) inc3 = 0.0
```

F(3, 30) =	11.71	Prob > F =	0.0000
-------------	-------	------------	--------

```
. ivreg water (incl-inc3 pwtopen = elhsfs incf1-incf3) polity lareapc, robust
IV (2SLS) regression with robust standard errors      Number of obs =      66
                                                       F( 6, 59) =      2.18
                                                       Prob > F      = 0.0581
                                                       R-squared    = 0.0749
                                                       Root MSE    = 7.3e+05
```

```
-----+-----
organic water |               Robust
pollution BOD |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-----+-----
      incl1 |    1339044   857329.6     1.56  0.124   -376468.5   3054557
      incl2 |   -310917.9  382285.7    -0.81  0.419   -1075870   454034.1
      incl3 |    645040.4  296639.3     2.17  0.034    51466.46  1238614
    pwtopen |    -9960.8    3743.8    -2.66  0.010   -17452.07   -2469.6
      polity |  -45944.98  35426.57    -1.30  0.200   -116833.4  24943.43
    lareapc |  -168457.5   64550.7    -2.61  0.011   -297623.1  -39291.82
      _cons |  -8185083   5717722    -1.43  0.158   -1.96e+07  3256052
-----+-----
```

```
Instrumented:  incl1 inc2 inc3 pwtopen
Instruments:   polity lareapc elhsfs incf1 incf2 incf3
-----+-----
```

```
. test incl1 incl2 incl3
( 1)  incl1 = 0.0
( 2)  incl2 = 0.0
( 3)  incl3 = 0.0      F( 3, 59) =      1.77      Prob > F =      0.1623
```