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IS TRADE GOOD OR BAD FOR THE ENVIRONMENT? SORTING OUT THE CAUSALITY

Jeffrey A. Frankel
Andrew K. Rose

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ABSTRACT

What is the effect of trade on a country's environment, for a given level of GDP? Some have observed an apparent positive correlation between openness to trade and 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 three measures of air pollution. Statistical significance is lacking for Particulate Matter, but is moderate for NO2, and high for SO2. Results for broader environmental measures are not as encouraging, but one can at least say that there is little evidence that trade has the detrimental effect on the environment that the race-to-the-bottom theory would lead one to expect. The larger effect appears to come via income itself: our results generally 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.

Jeffrey A. Frankel
Kennedy School of Government
Harvard University, 79 JFK Street
Cambridge MA 02138-5801
and NBER
jeffrey_frankel@harvard.edu
http://www.ksg.harvard.edu/fs/jfrankel

Andrew K. Rose
Haas School of Business
University of California
Berkeley, CA 94720-1900
and NBER
arose@haas.berkeley.edu
http://haas.berkeley.edu/~arose

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 trade 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.

1. Hypotheses

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

[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. Frankel (2002) reviews recent controversies surrounding globalization and the environment.

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. The ratio of pollution to GDP can be improved through a composition channel and a technique channel. 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:

4) The *environmental Kuznets curve*: the relationship between income per capita and some kinds of pollution is roughly shaped as an inverted U. 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]

[2] Grossman and Kruger (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), NOx, 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), 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.

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, NOx, etc., is external to the home or firm. 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

[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 (2002) 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.

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 international ratcheting up of environmental standards.[7] A second possibility concerns

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[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.

[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.

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)

Trade economists 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.

Another 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

[8] Esty and Gentry (1997, pp. 157, 161, 163) and Schmidheiny (1992). Eskeland and Harrison (2002) find that, within given sectors in given developing countries, foreign plants are significantly more energy efficient and use cleaner types of energy than domestic plants.

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:

6) The *pollution haven hypothesis*: To the extent that countries are open to trade and investment, some (e.g., those with low demand for environmental quality) will adopt lax environmental standards to attract multinational corporations and export pollution-intensive goods, while others (e.g., those with high demand for environmental quality) will adopt high standards and import pollution-intensive goods. It is worth emphasizing 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

[9] A final possibility is that globalization offers interest groups that care particularly about the environment new weapons. Domestically, they can threaten to block the trend 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.] Across borders, the new weapons include consumer labeling for imports and corporate codes of conduct for multinationals.

choose high environmental standards for their own production, and import from others goods that embody pollution.[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.

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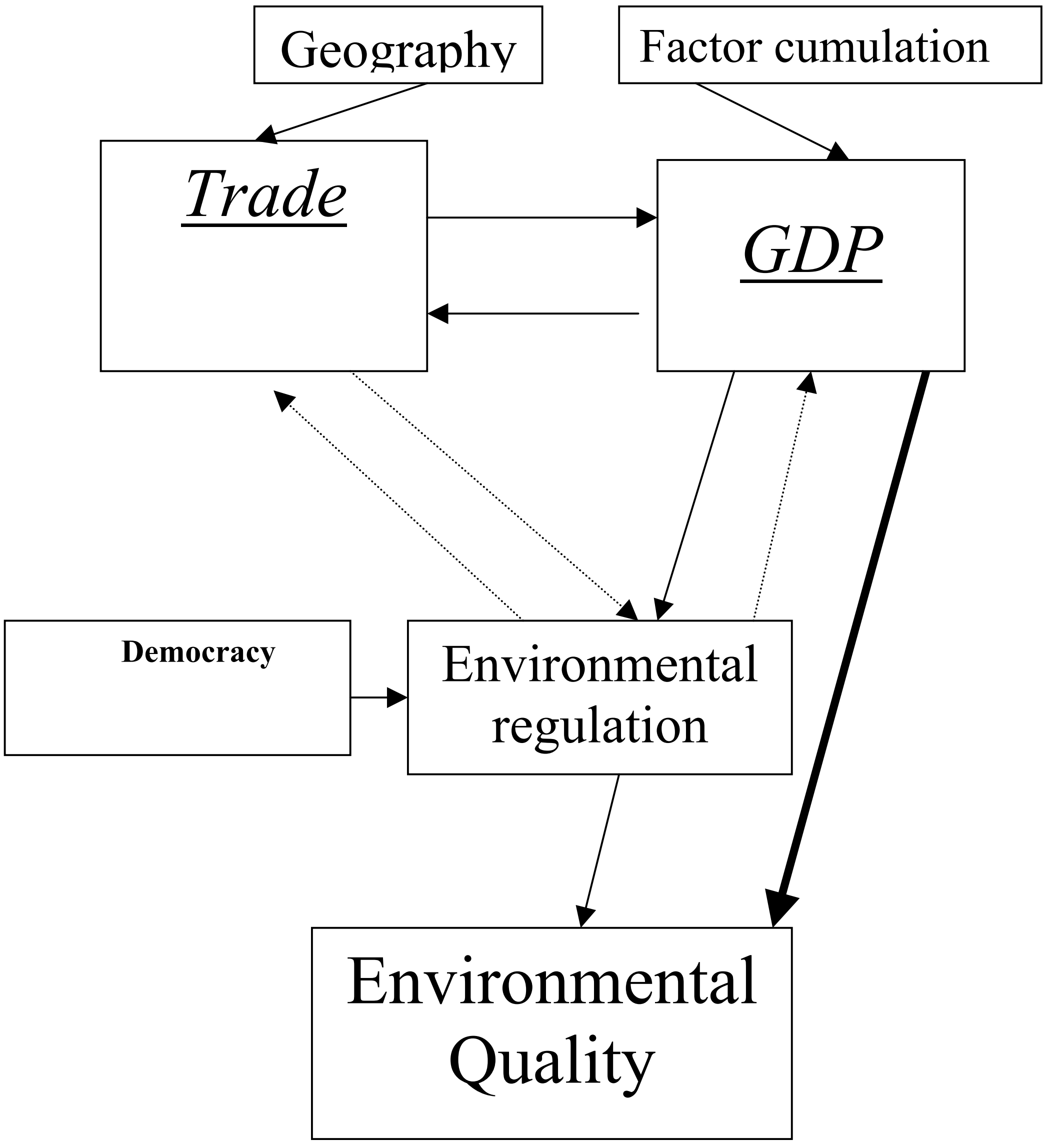
[10] Some economists' research suggests that environmental regulation is not a major determinant of firms' ability to compete internationally. When deciding where to locate, multinational firms seem to pay far more attention to such issues as labor costs and market access than to the stringency of local 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).

THE RELATIONSHIP BETWEEN TRADE AND ENVIRONMENT

Hypothesized causal relationships



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 adverse (race to the bottom) or positive (environmental gains from trade)
6. Pollution haven hypothesis

2. Endogeneity

This list of propositions includes important possible causal arrows running in both directions among each pair out of the three key endogneous 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.

A couple of studies 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, controlling for income. Antweiler, Copeland and Taylor (2001), which is probably the most careful existing study explicitly focused on the effects of trade on the environment, estimates an effect that is favorable (though only of borderline significance, statistically speaking). But neither study makes allowance for the problem that trade may be the result of other factors rather than the cause.

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?

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[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).

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 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 accumulation 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 accumulation variables in the

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

income equation: Concern has been expressed that investment is endogenous, or that human capital is.[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.

3. Results

We estimate a system of two equations:

Growth equation:

$$\begin{aligned}\ln(\mathrm{Y/Pop})_{90,i} &= \beta_0 + \alpha([\mathrm{X}+\mathrm{M}]/\mathrm{Y})_{90,i} + \beta_1 \ln(\mathrm{Pop})_i + \phi Z_i \\ &+ \gamma \ln(\mathrm{Y/Pop})_{70,i} + \delta_1(\mathrm{I/Y})_i + \delta_2 \mathrm{n}_i + \delta_3(\mathrm{School1})_i + \delta_4(\mathrm{School2})_i + \mathrm{u}_i\end{aligned} \quad (1)$$

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". "School_1" and "School_2" 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

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[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.

second line of the equation: initial income, investment, human capital and population 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:

$$\begin{aligned} & EnviroDamage_i = \varphi_0 + \varphi_1 (Y/pop_1)_{90,i} + \varphi_2 (Y/pop_2)_{90,i}{}^2 \\ & + \mu([X+M]/Y)_{90,i} + \pi(Polity)_{90,i} + \lambda(LandArea/Cap)_{90,i} + e_i . \end{aligned} \tag{2}$$

The dependent variable is any of three of measures of pollution or other measures of environmental damage, each estimated as separate equations. The first two variables are per capita income and per capita income squared, for country *i*. The EKC hypothesis predicts that the coefficient on the latter is negative, so that the pollution curve eventually turns down. As an alternative to the quadratic functional form, we also tried the three segments of a spline (split at the .33 and .66 percentiles) fit to the natural logarithm of per capita income. Per capita income is again defined as real 1990 GDP (Y) divided by total population (Pop), taken from the Penn World Table 5.6, which is measured in real PPP-adjusted dollars. Aggregate exports and aggregate imports as before are denoted "*X*" and

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[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.

"*M*"; Polity is a measure of how democratic is the structure of the government, ranging from -10 ("strongly autocratic") to +10 (strongly democratic).[16] 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 focus on results for three measures of air pollution:

SO_2: sulphur dioxide, mean (in micograms per cubic meter), 1995

NO_2: nitrogen dioxide, mean (in micograms per cubic meter), 1995

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

We have also looked at four other measures of environmental quality:

CO_2/cap: Carbon dioxide emissions, industrial, in metric tons per capita

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

Energy: Energy depletion, in percent of GDP ("genuine savings")[18], and

Water: Access to clean water (percentage of rural population) 1990-1996.

Of these seven, the three measures of local air pollution -- SO_2, NO_2, and PM -- are the most relevant. As noted, CO_2 is a purely global externality, and unlikely to be addressed

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[16] It is taken from the Polity IV Project at the University of Maryland., described in Marshall and Jaggers (2000). Barrett and Graddy (2000) also find that an increase in civil and political freedoms significantly reduces some measures of pollution.

[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.

[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.

by regulation at the national level. Deforestation[19] and Energy depletion are not measures of pollution, and measuring them involves some serious problems of composition and data reliability, as does water access. But we thought that it was worth at least taking a look at these broader measures of environmental quality.

3.1 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.

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[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.

[Table 1 about here.]

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 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)).

The Porter Hypothesis reverses conventional economics wisdom by suggesting that aggressive efforts to protect the environment can be good for productivity growth. A crude way to test this hypothesis is to include measures of environmental quality on the right-hand side of the growth equation, using the polity variable as an instrument to

[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 critiques from Rodriguez and Rodrik (2001) and Rodrik (2000) regarding the gravity instruments. The most difficult 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 technological factors (such as proximity or declining shipping costs).

control for the endogeneity of environmental quality. When we tried this, we found no support for the hypothesis of a positive effect on growth. [Results not reported here].

3.2 Results for Pollution: Race to the Bottom, or Gains from Trade?

Table 2 reports the results of OLS estimation of equation (2), where the dependent variable is represented by the three measures of air pollution. The estimated effect of the polity variable on pollution is always negative, suggesting that improved governance has a beneficial effect. It is generally significant statistically. The same is true of land area per capita, offering some evidence that population density has an adverse effect on pollution.

Of greater interest is the relationship with per capita income. The estimated coefficient on the quadratic term is negative for all three measures of air pollution, confirming the EKC hypothesis: after a certain point, growth is good for the environment. Statistically, it is highly significant in the case of SO2 and NO2, and moderately significant in the case of PM.

When we used a spline function in place of a quadratic, the results again tend to support the EKC [Table A2]. That is, increases in income in the low-income countries increases pollution, and in the high-income countries reduces it. The adverse effect in the low-income range is insignificant for SO2, but is highly significant for suspended particulate matter. The effect in the high-income range is significant for PM, borderline significant for SO2, and insignificant for NO2. The measure that does not exhibit a clear Kuznets curve in the spline case is NO2, where the adverse effect does not show up until the middle third of the spline.

The quadratic specification is far more common than the spline in the literature, and is probably better. It is less arbitrary in its cut-off points and yet more sparing in degrees of freedom. Also it allows one to try to identify the level of income at which pollution peaks. The OLS point estimates say that PM peaks at an income level of $2,882 per capita, SO2 at $5770 per capita, and NO2 at $7665 per capita.

[Table 2 about here.]

Our central interest is in μ, the coefficient on openness. The coefficient on openness is negative for all three kinds of air pollution – insignificantly so for PM, moderately significant for NO2, and highly significant for SO2. Apparently any adverse "race to the bottom" effect on air pollution is outweighed by positive "gains from trade" effects. When we use the spline for income, the same results emerge for openness [Table A2].

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.

[Table 3 about here.]

The IV results are generally similar to the OLS results, though with somewhat diminished significance levels in some cases. The EKC is still there for all three pollutants: SO2, NO2, and PM. In the IV results of Table 3, the coefficient on openness is negative for all three pollution measures. As in the OLS results, statistical significance is high for SO2, moderate for NO2, and altogether lacking for PM. (When the income relationship is estimated with a spline instead of a quadratic form, in Table A3, the effect on pollution again turns down for all three measures. The general pattern of coefficients on openness is the same as in the OLS estimates.)

3.3 Results for Other Environmental Measures

Air pollution is only one kind of measure of environmental quality. We also tried these tests with some others: carbon dioxide, deforestation, energy depletion, and access to clean water. As noted, the measurement difficulties tend to be much greater than with air pollution. The OLS results are reported in Tables 4 (for the case of quadratic EKC) and (for the spline). In most cases, the effects of polity, area, and quadratic income go in the same direction as with the air pollution indicators. The Kuznets curve shows up with high statistical significance for deforestation, energy depletion, and rural water access. Beneficial effects of openness show up only for energy depletion and water access, and are of borderline statistical significance. (In the case of water access, a positive coefficient indicates a beneficial environmental effect, the reverse of the other six indicators.)

[Tables 4 and 5 about here]

The case that would give an environmentalist the greatest concern is CO2. The coefficient on quadratic income is positive and highly significant. In the spline version as well, growth continues to have a positive, indeed increasing, effect through all three segments in the case of CO2. This confirms findings of other researchers, as well as a priori reasoning: CO2 is a purely global externality, so that there is no reason to expect individual countries to address it on their own, no matter what their level of income.

Furthermore, the coefficient on openness is apparently positive, and of moderate significance in the OLS case. This result could be viewed as one piece of evidence supporting the idea that global warming cannot be addressed without an international treaty, or at least has not been.[21]

The IV results are reported in Tables 5 (for the case of quadratic EKC) and A4 (for the spline). While some results, such as the Kuznets curve, differ very little from OLS, in some other cases the use of instrumental variables makes a difference. Encouragingly, the apparently detrimental effect of openness on carbon dioxide emissions loses all significance, awhile the apparently beneficial effect on energy depletion becomes significant (at the 10% level). On the other hand, the beneficial effect on water access (which was not quite significant under OLS) disappears.

Thus the results continue to be generally 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 perhaps to exacerbate the problem, though significance disappears under IV -- is CO_2. This is the one gas on our list that is a purely global externality, where countries cannot expect to be able to address it by national regulation on their own, and indeed where fears of adverse effects on competitiveness are most acute.

[21] Of course, we cannot rule out that emissions of CO_2 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.

3.4 Do Some Countries Have a "Comparative Advantage" in Pollution?

To summarize the results regarding openness so far, trade, if anything, appears often to have a beneficial effect on measures of environmental quality, for given levels of income. The cases where the effect is statistically significant, particularly SO2 and NO2, are cases where the effect is beneficial. We interpret the absence of a general upward effect of openness on environment degradation as evidence against the "race to the bottom" hypothesis.[22]

Putting aside now the effects on the overall level of environmental quality worldwide, one might also 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. One version of 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.[23] This hypothesis can be readily tested by adding to the environment equation the product of openness and

---

[22] Good economic practice forbids interpreting the absence of statistically significant rejections of the null hypothesis as proof that the null hypothesis is true. The test can have low power. Still, this is not one of those contexts where one would necessarily expect low power on a priori grounds (as one would, for example, when testing the hypothesis that a financial spot price follows a random walk -- Frankel, 1990). Many observers claim to see in the world around them evidence that trade is bad for the environment. Thus our inability to find it in when looking across countries has some meaning.

[23] 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. Levinson and Taylor (2001) find that those US industries experiencing the largest rise in environmental control costs have also experienced the largest increases in net imports.

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 in most cases not significant. The exceptions are PM and to some extent SO2; under either OLS or IV estimation, openness interacted with income appears to have a positive effect on these types of pollution. But this is the opposite of the sign predicted by the pollution haven hypothesis, which says that it is poor countries for whom trade leads to exploitation of the environment, with rich countries supposedly specializing in clean products.

[Table 6 about here]

A second version of the pollution haven 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 become pollution havens and import clean goods from those that are more densely populated. We tested this by adding the product of openness and land area per capita. Again, signs were divided between negative and positive, and coefficients were usually not at all significant. The only two cases where the coefficient on the interactive term was moderately significant -- IV for PM and OLS for CO2 -- again showed the wrong sign, counterintuitively suggesting that to the extent countries are open to trade, those that are sparsely populated have lower emissions than they otherwise would, not higher. In any case, there is no evidence for the pollution haven effect.

[*Table 7 about here.]*

A third possible source of "comparative advantage" derives from traditional trade theory. If some countries have a comparative advantage in capital intensive sectors such as mining or heavy manufacturing and other countries in labor intensive sectors, and if the former sectors are more polluting than the latter, then trade may lead to an increase in pollution among the capital-endowed countries and a decrease among the labor-endowed countries. Note that this version of the comparative advantage hypothesis is likely to imply that trade leads to lower pollution in poor countries, the opposite of the prediction of the first version considered above. (Rich countries usually have higher capital/labor ratios than poor countries, though not always.) We tested this version by including interactive terms defined as openness times the country's capital/labor ratio. The signs were negative as often as positive. Standard errors were large. In only one case out of 14 did the interactive term appear statistically significant: in the OLS estimate for CO2, the coefficient was positive and significant. This one case would suggest that international trade encourages capital-intensive countries to emit more carbon, and labor-intensive countries to emit less. The finding vanishes under IV estimation.

[Table 8 about here.]

To summarize this section, there is no evidence of that some countries use trade to exploit a comparative advantage in exporting pollution and others in importing it. This applies equally to versions that hypothesize countries deliberately setting pollution regulation so as to respond to their environmental comparative advantage, and to the version that says capital intensive countries will naturally pollute more as a side effect of trading according to comparative advantage. The only cases where the coefficient on the interactive term appears significant are of the wrong sign.

4. Conclusions

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 beneficial effect on some measures of environmental quality, though not all. This is particularly true of measures of air pollution, such as SO2. Even among other measures of environmental quality, one can at least say that there is no evidence that trade has the detrimental overall effect on the environment that the race-to-the-bottom theory would lead one to expect. There is also no evidence for the pollution haven hypothesis, which claims that to the extent countries engage in trade, some will specialize in dirtier environments and others in clean. 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.

4.1 A Sample Calculation

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 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 A2 implies that, in a poor country, this economic growth in turn induces energy depletion of 8.5*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 to read much into this calculation of the net effect. The difference is not statistically significant. Furthermore, the estimated 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.

4.2 Summary of Conclusions

The results regarding the effects of trade and growth on air pollution, measured here by SO2, NO2 and Particulate Matter, are generally good. We confirmed the pattern of the environmental Kuznets curve, whereby growth eventually has a beneficial effect on pollution, after the initial adverse relationship at low levels of income. Trade accelerates the growth process. However the primary emphasis of the paper was on the effect of openness for a given level of income. Here we found little or no evidence of the *race to the bottom* hypothesis. To the contrary, a higher ratio of trade to income, for a given level of income, seems if anything to reduce air pollution. The new contribution of the paper is to address the likely endogeneity of trade, by means of instrumental variables drawn from the gravity model. The relationship holds up, suggesting that the observed correlation between trade and environmental quality is not attributable to other factors.

The results are more mixed when one tries broader measures of environmental quality. In particular, the optimistic story does not hold for the case of CO_2. 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. In this case, trade and growth alone won't do it. International cooperation is also needed to address this sort of global environmental problem.

* * *

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Table 1: Income equations

. *
. * Income equation with controls, OLS, and IV (gravity)
. *

Number of obs = 106
F(7, 98) = 378.1
R-squared = 0.940

lreal gdp/cap	Coef.	Robust Std. Err.	t	P>|t|
openness	.003	.001	4.51	0.000
lpop	.065	.021	3.17	0.002
lrgdpchi	.711	.052	13.56	0.000
invrat	.016	.006	2.75	0.007
popg	-.055	.050	-1.10	0.273
sch1	.002	.002	1.04	0.299
sch2	.007	.002	3.37	0.001
_cons	1.019	.446	2.29	0.024

Number of obs = 102
F(7, 94) = 329.25
R-squared = 0.9382

lrgdpch	Coef.	Robust Std. Err.	t	P>|t|
openness	.004	.001	4.28	0.000
lpop	.078	.024	3.28	0.001
lrgdpchi	.726	.057	12.71	0.000
invrat	.013	.006	2.17	0.032
popg	-.047	.058	-0.82	0.416
sch1	.001	.002	0.83	0.407
sch2	.007	.003	2.82	0.006
_cons	.750	.496	1.51	0.135

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

Table 2:
Air pollution equations - OLS (with quadratic income)

[comment PA4 Aug. 2002]

. *
. *
. * NO2
. *

OLS regression

Number of obs = 36
R-squared = 0.1572
Root MSE = 40.427

NO2	Coef.	Robust Std. Err.	t	P>|t|
inc	408.7414	121.7852	3.36	0.002
incsq	-22.84893	6.898182	-3.31	0.002
openness	-.2943246	.1666625	-1.77	0.088
polity	-3.202309	1.473066	-2.17	0.038
lareapc	-5.940883	5.930511	-1.00	0.324
_cons	-1697.314	517.8064	-3.28	0.003

. * Income Peak 7665.0902

```
. *
. * Sulfur Dioxide
. *
OLS regression                Number of obs =      41
                              F(  5,    35) =   11.99
                              R-squared     =  0.6763
                              Root MSE      =  23.106
-----------------------------------------------------
             |               Robust
         SO2 |      Coef.   Std. Err.      t    P>|t|
-------------+---------------------------------------
         inc |   287.2499   118.8063     2.42   0.021
       incsq |    -16.584   6.781331    -2.45   0.020
    openness |  -.3063532   .0794114    -3.86   0.000
      polity |  -6.579158   2.048908    -3.21   0.003
     lareapc |  -2.921048   1.393917    -2.10   0.043
       _cons |  -1123.359   500.5334    -2.24   0.031
-----------------------------------------------------
 * Income Peak  5770.1305
```

```
. *
. * Suspended Particles
. *
OLS regression              Number of obs =      38
                            F(  5,    32) =   13.03
R-squared     =  0.6227     Root MSE      =  59.799
-----------------------------------------------------
             |               Robust
         PM  |      Coef.   Std. Err.      t    P>|t|
-------------+---------------------------------------
         inc |   566.6506   336.1893     1.69   0.102
       incsq |  -35.56644   19.05568    -1.87   0.071
    openness |  -.3741319   .3365302    -1.11   0.275
      polity |  -6.696519   3.416111    -1.96   0.059
     lareapc |  -13.02382   6.292223    -2.07   0.047
       _cons |  -1998.683   1464.379    -1.36   0.182
------------------------------------------------------
. * Income Peak   2881.5566
```

Table 3:
Air pollution equations - IV (with quadratic income)

[Source note: pa4c]

```
. *
. * NO2
. *
IV (2SLS)    Number of obs =  35          F(  5,29) = 2.61
              R-squared     =  0.1847      Root MSE  =  38.992
-----------------------------------------------------
             |               Robust
         NO2 |      Coef.   Std. Err.      t    P>|t|
-------------+---------------------------------------
         inc |   460.8478   198.5226     2.32   0.027
       incsq |  -25.63361   10.88135    -2.36   0.025
     pwtopen |  -.3257459   .1889883    -1.72   0.095
      polity |  -3.772668   1.374741    -2.74   0.010
     lareapc |  -6.141273    6.42893    -0.96   0.347
       _cons |  -1934.291   868.1319    -2.23   0.034
--------------------------------------------------
Instrumented:  inc incsq pwtopen
Instruments:   polity lareapc elhsfs incf incfsq
--------------------------------------------------
. * Income Peak       8015.4835
```

```
. *
. * Sulfur Dioxide
. *
IV (2SLS)      Number of obs =  40     F(5,34) = 7.17
R-squared     =  0.6677                Root MSE = 23.749
-----------------------------------------------------
             |               Robust
        SO2  |      Coef.   Std. Err.      t    P>|t|
-------------+-------------------------------------
         inc |   296.2443   139.5389     2.12   0.041
       incsq |  -17.14944   7.740589    -2.22   0.034
     pwtopen |  -.2270678   .0952128    -2.38   0.023
      polity |  -6.409379   2.272604    -2.82   0.008
     lareapc |  -1.541768   1.959461    -0.79   0.437
       _cons |  -1169.049   607.1931    -1.93   0.063
-----------------------------------------------------
Instrumented:  inc incsq pwtopen
Instruments:   polity lareapc elhsfs incf incfsq
-----------------------------------------------------
. * Income Peak    5637.1921
```

```
. *
. * Suspended Particles
. *
IV (2SLS)      Number of obs = 37     F( 5, 31) =  10.31
               R-squared =  0.6311    Root MSE =  59.278
-----------------------------------------------------
             |               Robust
         PM  |      Coef.   Std. Err.      t    P>|t|
-------------+---------------------------------------
         inc |   681.1777   411.7603     1.65   0.108
       incsq |  -41.95689   23.24485    -1.80   0.081
     pwtopen |  -.3063286   .4091727    -0.75   0.460
      polity |  -7.779254   4.072516    -1.91   0.065
     lareapc |  -12.62894   6.838168    -1.85   0.074
       _cons |  -2506.845   1794.301    -1.40   0.172
-----------------------------------------------------
Instrumented:  inc incsq pwtopen
Instruments:   polity lareapc elhsfs incf incfsq
```

Table 4: Other environmental degradation equations-- OLS (with quadratic income)

```
. *
. * CO2 per capita
. *
OLS regression
Number of obs =     100       F(  5,    94) =   46.66
R-squared     =  0.7517       Root MSE      =  2.4205
-----------------------------------------------------
             |               Robust
     CO2/cap |      Coef.   Std. Err.      t    P>|t|
-------------+---------------------------------------
         inc |  -17.89567   4.397366    -4.07   0.000
       incsq |   1.332968   .2857756     4.66   0.000
    openness |   .0162143   .0082568     1.96   0.053
      polity |  -.0285954   .0225989    -1.27   0.209
     lareapc |   .1374593   .1571698     0.87   0.384
       _cons |   58.78729   16.46965     3.57   0.001
-----------------------------------------------------
. * Income Flat       822.80085
```

```
. *
. * Deforestation
. *
OLS regression
Number of obs =      96              F(5, 90) =  8.60
R-squared     =  0.2459              Root MSE =  1.1264
------------------------------------------------------
             |               Robust
       Defor |      Coef.   Std. Err.      t    P>|t|
-------------+----------------------------------------
         inc |   4.332887   1.323462     3.27   0.002
       incsq |  -.3102442   .0836911    -3.71   0.000
    openness |   .0019005   .0026914     0.71   0.482
      polity |   .0372964   .0302987     1.23   0.222
     lareapc |  -.1105794   .0752327    -1.47   0.145
       _cons |  -13.63388   5.205874    -2.62   0.010
-----------------------------------------------------
. * Income Peak       1078.177
```

```
. *
. * Energy Depletion
. *
OLS regression
Number of obs =      98       F(5, 92) = 3.89
R-squared     =  0.1673       Root MSE =  6.8129
-----------------------------------------------------
      Energy |               Robust
      Depltn |      Coef.   Std. Err.      t    P>|t|
-------------+----------------------------------------
         inc |   38.11421   9.068405     4.20   0.000
       incsq |  -2.221143   .5226622    -4.25   0.000
    openness |  -.0140725   .0086366    -1.63   0.107
      polity |  -.4502979   .1631437    -2.76   0.007
     lareapc |   .2913516   .4207371     0.69   0.490
       _cons |  -155.9837    38.3077    -4.07   0.000
-----------------------------------------------------------
. * Income Flat   5323.3903
```

```
. *
. * Rural access to clean water
. *
OLS regression
Number of obs =      57              F(  5,    51) =   29.48
R-squared     =  0.5977              Root MSE      =  18.154
-----------------------------------------------------
    Rural H20 |               Robust
     Access  |      Coef.   Std. Err.      t    P>|t|
-------------+----------------------------------------
         inc |  -79.80476   37.52545    -2.13   0.038
       incsq |   5.966993   2.261655     2.64   0.011
     pwtopen |   .1114468   .0779627     1.43   0.159
      polity |  -.3198072   .5366819    -0.60   0.554
     lareapc |  -9.462271   2.094926    -4.52   0.000
       _cons |    332.356   154.2255     2.16   0.036
----------------------------------------------------
. * Income Peak       802.06048
```

Table 5: Other environmental degradation equations -- IV (with quadratic income)

```
. *
. * CO2
. *
IV (2SLS)      Number of obs = 96     F(5, 90) =   51.90
               R-squared=  0.7712     Root MSE =  2.0875
-----------------------------------------------------
             |               Robust
     CO2/cap |      Coef.   Std. Err.      t    P>|t|
-------------+---------------------------------------
         inc |  -15.62027   3.790209    -4.12   0.000
       incsq |   1.210887   .2490011     4.86   0.000
     pwtopen |   .0001553   .0100028     0.02   0.988
      polity |   -.083874   .0354992    -2.36   0.020
     lareapc |   .0186855   .1594831     0.12   0.907
       _cons |   49.92776   14.25378     3.50   0.001
-----------------------------------------------------
Instrumented:  inc incsq pwtopen
Instruments:   polity lareapc elhsfs incf incfsq
--------------------------------------------------
. * Income Flat   632.65641
```

```
. * Deforestation
. *
IV (2SLS)      Number of obs =  92    F( 5, 86) = 11.55
R-squared     =  0.2559               Root MSE      =  1.1374
-----------------------------------------------------
             |               Robust
        Defor |      Coef.   Std. Err.      t    P>|t|
-------------+---------------------------------------
         inc |   5.353294   1.566078     3.42   0.001
       incsq |  -.3696913   .0973345    -3.80   0.000
     pwtopen |   .0010038   .0035137     0.29   0.776
      polity |   .0294181   .0260728     1.13   0.262
     lareapc |  -.0769178   .0827553    -0.93   0.355
       _cons |  -17.90421   6.134636    -2.92   0.004
-----------------------------------------------------
Instrumented:  inc incsq pwtopen
Instruments:   polity lareapc elhsfs incf incfsq
-----------------------------------------------------
. * Income Peak   1394.4029
```

```
. *
. * Energy Depletion
. *
IV (2SLS)     Number of obs = 93      F( 5, 87) = 4.30
              R-squared  =  0.1644    Root MSE=  6.9883
--------------------------------------------------------
      Energy |               Robust
      Depltn |      Coef.   Std. Err.      t    P>|t|
-------------+------------------------------------------
         inc |    43.3005   9.624654     4.50   0.000
       incsq |  -2.510521   .5576702    -4.50   0.000
     pwtopen |  -.0342903   .0195457    -1.75   0.083
      polity |  -.5218554   .1813587    -2.88   0.005
     lareapc |   .3640927   .5103971     0.71   0.478
       _cons |  -177.1147   39.62378    -4.47   0.000
 -------------------------------------------------------
Instrumented:  inc incsq pwtopen
Instruments:   polity lareapc elhsfs incf incfsq
--------------------------------------------------------
. * Income Peak   5562.526
```

```
. *
. * Rural access to clean water
. *
IV (2SLS)      Number of obs = 55      F(5, 49) = 33.57
R-squared     =  0.5760                Root MSE = 18.94
----------------------------------------------------------
             |               Robust
     ruralan |      Coef.   Std. Err.      t    P>|t|
-------------+-------------------------------------------
         inc |  -64.96357   47.91549    -1.36   0.181
       incsq |   5.164893   2.799938     1.84   0.071
     pwtopen |  -.0665827   .2654793    -0.25   0.803
      polity |  -.3386013   .5783459    -0.59   0.561
     lareapc |  -8.402257   2.526703    -3.33   0.002
       _cons |   273.6916   196.6735     1.39   0.170
---------------------------------------------------------
Instrumented:  inc incsq pwtopen
Instruments:   polity lareapc elhsfs incf incfsq
---------------------------------------------------------
. * Income Peak       538.59069
```

Table 6: Does openness lead poor countries to exploit a comparative advantage in pollution?

```
. *
. * Openness * income interaction
. *

OLS regression
Number of obs =     100              F(  7,    92) =   35.49
R-squared     =  0.7672              Root MSE      =  2.3692
-----------------------------------------------------
             |               Robust
     CO2/cap |      Coef.   Std. Err.      t    P>|t|
-------------+--------------------------------------
        inc1 |   .1203402   .6341995     0.19   0.850
        inc2 |    1.19975   1.086426     1.10   0.272
        inc3 |   5.776292   1.305655     4.42   0.000
     openness|  -.1192059   .0718369    -1.66   0.100
       open*y|   .0154795   .0088929     1.74   0.085
      polity |   .0016827   .0294482     0.06   0.955
     lareapc |   .3136713      .1861     1.69   0.095
       _cons |  -.6098371   4.700176    -0.13   0.897
------------------------------------------------------

IV (2SLS)
Number of obs =      96              F(  7,    88) =   21.04
R-squared     =  0.5724              Root MSE      =  2.8864
---------------------------------------------------------
             |               Robust
     CO2/Cap |      Coef.   Std. Err.      t    P>|t|
-------------+-----------------------------------------
        inc1 |   2.043932   2.034551     1.00   0.318
        inc2 |   7.065352    4.42335     1.60   0.114
        inc3 |   9.755345   4.996979     1.95   0.054
     openness|   .4100573   .5188282     0.79   0.431
       open*y|  -.0462038   .0584844    -0.79   0.432
      polity |  -.1315086   .1079307    -1.22   0.226
     lareapc |  -.3942336   .6656567    -0.59   0.555
       _cons |  -18.09126    18.3905    -0.98   0.328
--------------------------------------------------------
Instrumented:  inc1 inc2 inc3 pwtopen
Instruments:   open*ypolity lareapc elhsfs incf1 incf2 incf3
------------------------------------------------------
```

OLS regression   Number of obs = 96   F(7,88) = 7.34
R-squared = 0.2748   Root MS = 1.1171

Defor	Coef.	Robust Std. Err.	t	P>|t|
inc1	.7187417	.3805059	1.89	0.062
inc2	-.8738187	.4755121	-1.84	0.069
inc3	-.8390258	.3312262	-2.53	0.013
openness	.0269479	.0289467	0.93	0.354
open*y	-.0028786	.003156	-0.91	0.364
polity	.0288022	.0296454	0.97	0.334
lareapc	-.1420845	.0882805	-1.61	0.111
_cons	-3.668555	2.74146	-1.34	0.184

IV (2SLS)   Number of obs = 92   F(7, 84) = 3.08
R-squared = .   Root MSE = 1.759

Defor	Coef.	Robust Std. Err.	t	P>|t|
inc1	1.688401	2.551697	0.66	0.510
inc2	2.117906	6.235248	0.34	0.735
inc3	1.588058	6.302834	0.25	0.802
openness	.3527669	.7622332	0.46	0.645
open*y	-.0398898	.0867823	-0.46	0.647
polity	-.0146906	.1039573	-0.14	0.888
lareapc	-.4887307	.9524837	-0.51	0.609
_cons	-13.34922	23.862	-0.56	0.577

Instrumented: inc1 inc2 inc3 pwtopen
Instruments: open*ypolity lareapc elhsfs incf1 incf2 incf3

OLS regression   Number of obs = 98   F(7, 90)= 2.63
R-squared = 0.1662   Root MSE = 6.8927

Energy Depltn	Coef.	Robust Std. Err.	t	P>|t|
inc1	7.021516	2.448437	2.87	0.005
inc2	4.655401	2.866341	1.62	0.108
inc3	-2.80314	2.179854	-1.29	0.202
openness	.0344963	.1056991	0.33	0.745
open*y	-.0055399	.0119254	-0.46	0.643
polity	-.4541131	.1745755	-2.60	0.011
lareapc	.1912074	.4854832	0.39	0.695
_cons	-47.98723	17.31681	-2.77	0.007

IV (2SLS)   Number of obs = 93   F(7, 85) = 0.89
R-squared = .   Root MSE = 12.401

Energy Depltn	Coef.	Robust Std. Err.	t	P>|t|
inc1	16.00533	11.74501	1.36	0.177
inc2	23.49715	25.19547	0.93	0.354
inc3	16.92039	27.61245	0.61	0.542
openness	2.386805	3.186188	0.75	0.456
open*y	-.2729026	.3610807	-0.76	0.452
polity	-.7815838	.5146158	-1.52	0.133
lareapc	-2.451553	4.304506	-0.57	0.570
_cons	-130.7502	105.3609	-1.24	0.218

Instrumented: inc1 inc2 inc3 pwtopen
Instruments: open*ypolity lareapc elhsfs incf1 incf2 incf3

OLS regression   Number of obs = 36   F(7, 28) = 5.47
R-squared = 0.2087   Root MSE = 40.547

NO2	Coef.	Robust Std. Err.	t	P>|t|
inc1	-391.314	254.7488	-1.54	0.136
inc2	174.4945	69.97776	2.49	0.019
inc3	-14.98727	23.52335	-0.64	0.529
openness	.542728	4.57788	0.12	0.906
open*y	-.0906906	.4873519	-0.19	0.854
polity	-3.888602	.9682091	-4.02	0.000
lareapc	-5.861136	6.170607	-0.95	0.350
_cons	2864.241	1810.88	1.58	0.125

IV (2SLS)   Number of obs = 35   F(6, 27) = .
R-squared = 0.2267   Root MSE = 39.356

NO2	Coef.	Robust Std. Err.	t	P>|t|
inc1	-386.3218	276.3737	-1.40	0.174
inc2	185.1002	87.96971	2.10	0.045
inc3	-52.43732	36.52884	-1.44	0.163
openness	-6.530771	6.474132	-1.01	0.322
open*y	.657162	.6997684	0.94	0.356
polity	-4.878152	.7820215	-6.24	0.000
lareapc	-7.214065	5.840496	-1.24	0.227
_cons	2866.21	1958.397	1.46	0.155

Instrumented: inc1 inc2 inc3 pwtopen
Instruments: open*ypolity lareapc elhsfs incf1 incf2 incf3

OLS regression   Number of obs = 41   F(7, 33) = 84.38
R-squared = 0.7275   Root MSE = 21.834

SO2	Coef.	Robust Std. Err.	t	P>|t|
inc1	155.3254	94.3227	1.65	0.109
inc2	.5225823	20.25033	0.03	0.980
inc3	-46.77605	15.7941	-2.96	0.006
openness	-4.76608	2.187854	-2.18	0.037
open*y	.4837392	.2323481	2.08	0.045
polity	-6.15931	1.80856	-3.41	0.002
lareapc	-2.316554	1.626319	-1.42	0.164
_cons	-1009.304	665.3372	-1.52	0.139

IV (2SLS)   Number of obs = 40   F(7, 32) = 8.89
R-squared = 0.7297   Root MSE = 22.075

SO2	Coef.	Robust Std. Err.	t	P>|t|
inc1	191.0826	152.0559	1.26	0.218
inc2	-3.533549	46.19984	-0.08	0.940
inc3	-67.68094	32.24662	-2.10	0.044
openness	-7.805166	4.571801	-1.71	0.097
open*y	.8083979	.4891454	1.65	0.108
polity	-6.340865	1.855417	-3.42	0.002
lareapc	-2.270977	1.990991	-1.14	0.262
_cons	-1249.701	1085.205	-1.15	0.258

Instrumented: inc1 inc2 inc3 pwtopen
Instruments: open*ypolity lareapc elhsfs incf1 incf2 incf3

```
OLS regression
Number of obs =      38               F(  7,    30) =   14.75
R-squared     =  0.7438               Root MSE      =  50.896
----------------------------------------------------
             |               Robust
         PM  |      Coef.   Std. Err.      t    P>|t|
-------------+---------------------------------------
        inc1 |   302.4914   78.65209     3.85   0.001
        inc2 |  -143.3542   51.88573    -2.76   0.010
        inc3 |  -98.09078   33.43229    -2.93   0.006
     openness|  -7.812377   3.700031    -2.11   0.043
       open*y|   .8556435    .401887     2.13   0.042
      polity |  -7.781859   2.882361    -2.70   0.011
     lareapc |  -8.695255   4.412314    -1.97   0.058
       _cons |  -1859.638   571.4924    -3.25   0.003
--------------------------------------------------------
```

```
IV (2SLS) regression
Number of obs =      37               F(  7,    29) =   13.21
R-squared     =  0.7853               Root MSE      =  46.759
------------------------------------------------------
             |               Robust
         PM  |      Coef.   Std. Err.      t    P>|t|
-------------+-------------------------------------
        inc1 |   371.4085   110.7734     3.35   0.002
        inc2 |   -160.822   63.55778    -2.53   0.017
        inc3 |  -100.5136   45.36372    -2.22   0.035
     openness|  -9.303708   4.179282    -2.23   0.034
       open*y|    .995322   .4570525     2.18   0.038
      polity |  -8.643015   3.004949    -2.88   0.007
     lareapc |  -8.886813   4.505417    -1.97   0.058
       _cons |  -2334.084   801.3242    -2.91   0.007
----------------------------------------------------
Instrumented:  inc1 inc2 inc3 pwtopen
Instruments:   open*ypolity lareapc elhsfs incf1 incf2 incf3
```

Table 7: Does openness lead sparsely populated countries to exploit a comparative advantage in pollution?

```
. *
. * Add openness/area interaction
. *
```

```
OLS regression
Number of obs =     100               F(  7,    92) =   38.09
R-squared     =  0.7611               Root MSE      =    2.40
----------------------------------------------------
             |               Robust
     co2perc |      Coef.   Std. Err.      t    P>|t|
-------------+------------------------------------
        inc1 |   1.299684   .4221266     3.08   0.003
        inc2 |     2.1362   .8239958     2.59   0.011
        inc3 |   6.890616   1.235773     5.58   0.000
     openness|   .0447978   .0203516     2.20   0.030
    open*land|  -.0035943   .0018404    -1.95   0.054
      polity |  -.0290418   .0220731    -1.32   0.192
     lareapc |   .3705155   .1920085     1.93   0.057
       _cons |  -9.724961   3.156701    -3.08   0.003
------------------------------------------------------
```

IV (2SLS) Number of obs = 96 F(7, 88) = 35.67
R-squared = 0.7596 Root MSE = 2.1642

CO2/cap	Coef.	Robust Std. Err.	t	P>|t|
inc1	.4465435	.5833635	0.77	0.446
inc2	3.821037	1.083521	3.53	0.001
inc3	6.337574	1.370789	4.62	0.000
openness	-.0135278	.0371035	-0.36	0.716
open*land	.0017062	.0037488	0.46	0.650
polity	-.0751272	.0375316	-2.00	0.048
lareapc	-.0640638	.258771	-0.25	0.805
_cons	-3.265222	4.090651	-0.80	0.427

Instrumented: inc1 inc2 inc3 pwtopen
Instruments: openl polity lareapc elhsfs incf1 incf2 incf3

OLS regression Number of obs = 96 F(7, 88) = 6.75
R-squared = 0.2673 Root MSE = 1.1228

defp	Coef.	Robust Std. Err.	t	P>|t|
inc1	.5432714	.3500954	1.55	0.124
inc2	-1.069021	.4629858	-2.31	0.023
inc3	-1.028875	.3355678	-3.07	0.003
openness	.0007328	.0067485	0.11	0.914
open*land	.0001749	.0008616	0.20	0.840
polity	.0331086	.030571	1.08	0.282
lareapc	-.1245322	.087913	-1.42	0.160
_cons	-2.258488	2.42957	-0.93	0.355

IV (2SLS) Number of obs = 92 F(7, 84) = 7.79
R-squared = 0.2693 Root MSE = 1.1405

defp	Coef.	Robust Std. Err.	t	P>|t|
inc1	.2748065	.545598	0.50	0.616
inc2	-.6915597	.607778	-1.14	0.258
inc3	-1.228064	.4950552	-2.48	0.015
openness	-.0112997	.0162695	-0.69	0.489
open*land	.0017305	.0019063	0.91	0.367
polity	.0331557	.029215	1.13	0.260
lareapc	-.1848112	.1722153	-1.07	0.286
_cons	-.6470294	3.796892	-0.17	0.865

Instrumented: inc1 inc2 inc3 pwtopen
Instruments: openl polity lareapc elhsfs incf1 incf2 incf3

OLS regression Number of obs = 98 F(7, 90) = 2.75
R-squared = 0.1747 Root MSE = 6.8574

enrdam	Coef.	Robust Std. Err.	t	P>|t|
inc1	6.301647	2.235743	2.82	0.006
inc2	4.319096	2.871935	1.50	0.136
inc3	-3.037144	1.845817	-1.65	0.103
openness	-.0609797	.048293	-1.26	0.210
open*land	.0057844	.0058749	0.98	0.327
polity	-.4448992	.1690579	-2.63	0.010
lareapc	-.1398897	.6781088	-0.21	0.837
_cons	-42.73908	15.97659	-2.68	0.009

```
IV (2SLS) regression
Number of obs =      93               F(  7,    85) =    2.50
R-squared     =  0.1073               Root MSE      =  7.3078
-------------------------------------------------------
             |               Robust
      enrdam |      Coef.   Std. Err.      t    P>|t|
-------------+------------------------------------------
        inc1 |   5.113796   3.127727     1.63   0.106
        inc2 |   5.070123   3.631556     1.40   0.166
        inc3 |  -2.709335   2.382761    -1.14   0.259
     openness|  -.2138088   .1571853    -1.36   0.177
   open*land |   .0234133   .0177814     1.32   0.191
      polity |  -.4554991   .2008395    -2.27   0.026
     lareapc |  -1.156387   1.374061    -0.84   0.402
       _cons |  -34.88446   21.95798    -1.59   0.116
---------------------------------------------------------------
Instrumented:  inc1 inc2 inc3 pwtopen
Instruments:   openl polity lareapc elhsfs incf1 incf2 incf3
----------------------------------------------------------
```

```
OLS regression
Number of obs =      36               F(  7,    28) =    8.77
R-squared     =  0.2111               Root MSE      =  40.486
----------------------------------------------------------
             |               Robust
        no2m |      Coef.   Std. Err.      t    P>|t|
-------------+------------------------------------------
        inc1 |  -395.9399   238.3117    -1.66   0.108
        inc2 |   175.4628   63.49874     2.76   0.010
        inc3 |  -19.44896   14.25501    -1.36   0.183
     openness|  -.4422456   .2767019    -1.60   0.121
   open*land |   .0198979   .0477338     0.42   0.680
      polity |  -4.114193    .974946    -4.22   0.000
     lareapc |  -6.368941    5.84243    -1.09   0.285
       _cons |   2899.056   1701.499     1.70   0.099
----------------------------------------------------------
```

```
IV (2SLS) regression
Number of obs =      35               F(  6,    27) =       .
R-squared     =       .               Root MSE      =  53.433
---------------------------------------------------------
             |               Robust
        no2m |      Coef.   Std. Err.      t    P>|t|
-------------+-----------------------------------------
        inc1 |   664.5396   3716.559     0.18   0.859
        inc2 |  -90.05426   984.4065    -0.09   0.928
        inc3 |  -11.22919   38.91062    -0.29   0.775
     openness|   1.864164   5.839316     0.32   0.752
   open*land |  -.2966072   .7611961    -0.39   0.700
      polity |   1.173267   17.99566     0.07   0.948
     lareapc |   1.640181   22.13381     0.07   0.941
       _cons |  -4685.086   26608.97    -0.18   0.862
-------------------------------------------------------------
Instrumented:  inc1 inc2 inc3 pwtopen
Instruments:   openl polity lareapc elhsfs incf1 incf2 incf3
----------------------------------------------------------
```

OLS regression   Number of obs = 41   F(7, 33) = 54.09
R-squared = 0.6907   Root MSE = 23.261

sulfdm	Coef.	Robust Std. Err.	t	P>|t|
inc1	56.99028	65.26708	0.87	0.389
inc2	28.68848	16.23312	1.77	0.086
inc3	-19.58229	8.962396	-2.18	0.036
openness	-.0816878	.1551855	-0.53	0.602
open*land	-.029564	.0223639	-1.32	0.195
polity	-6.315455	2.065723	-3.06	0.004
lareapc	-1.961573	1.817273	-1.08	0.288
_cons	-321.8509	464.3563	-0.69	0.493

IV (2SLS)   Number of obs = 40   F(7, 32) = 5.57
R-squared = 0.5249   Root MSE = 29.269

sulfdm	Coef.	Robust Std. Err.	t	P>|t|
inc1	94.05603	193.2025	0.49	0.630
inc2	28.72237	56.78161	0.51	0.616
inc3	-33.42498	16.23829	-2.06	0.048
openness	.8672607	1.079806	0.80	0.428
open*land	-.1448065	.1298384	-1.12	0.273
polity	-5.218058	2.762123	-1.89	0.068
lareapc	4.502931	7.009555	0.64	0.525
_cons	-588.0936	1395.034	-0.42	0.676

Instrumented: inc1 inc2 inc3 pwtopen
Instruments: openl polity lareapc elhsfs incf1 incf2 incf3

OLS regression   Number of obs = 38   F(7, 30) = 11.42
R-squared = 0.7156   Root MSE = 53.623

suspm	Coef.	Robust Std. Err.	t	P>|t|
inc1	340.8696	105.7901	3.22	0.003
inc2	-115.8087	54.30535	-2.13	0.041
inc3	-47.30731	22.7261	-2.08	0.046
openness	.2975468	1.153204	0.26	0.798
open*land	-.0493102	.0938695	-0.53	0.603
polity	-7.66129	3.572705	-2.14	0.040
lareapc	-9.036961	5.648587	-1.60	0.120
_cons	-2187.683	761.71	-2.87	0.007

IV (2SLS) Number of obs = 37   F(7, 29) = 8.45
R-squared = 0.7191   Root MSE = 53.486

suspm	Coef.	Robust Std. Err.	t	P>|t|
inc1	515.1731	127.7988	4.03	0.000
inc2	-169.1569	76.93958	-2.20	0.036
inc3	-35.95014	26.73539	-1.34	0.189
openness	2.503075	1.489398	1.68	0.104
open*land	-.2609476	.1356765	-1.92	0.064
polity	-9.57346	3.991047	-2.40	0.023
lareapc	-2.147277	6.519563	-0.33	0.744
_cons	-3419.099	905.9681	-3.77	0.001

Instrumented: inc1 inc2 inc3 pwtopen
Instruments: openl polity lareapc elhsfs incf1 incf2 incf3

Table 8: Does openness lead capital-intensive countries to exploit a comparative advantage in pollution?

```
. *
. * NO2
. *
OLS regression
Number of obs =      26               F(  6,    19) =    2.24
R-squared     =  0.2168               Root MSE      =  46.319
-----------------------------------------------------------
             |               Robust
         NO2 |      Coef.   Std. Err.      t    P>|t|
-------------+---------------------------------------------
         inc |   432.0514   188.0021     2.30   0.033
       incsq |  -23.70455   11.29099    -2.10   0.049
     pwtopen |  -.4917429   .4001593    -1.23   0.234
     open*K/L|  -1.23e-06   .0000113    -0.11   0.915
      polity |  -3.065802   3.641632    -0.84   0.410
     lareapc |  -9.516824   9.431383    -1.01   0.326
       _cons |  -1815.632   789.0531    -2.30   0.033
----------------------------------------------------------
. * Income Peak       9074.8222
```

```
IV (2SLS) regression
Number of obs =      26               F(  6,    19) =    8.33
R-squared     =  0.0982               Root MSE      =  49.705
---------------------------------------------------------
             |               Robust
         NO2 |      Coef.   Std. Err.      t    P>|t|
-------------+--------------------------------------------
         inc |   1076.193   389.2501     2.76   0.012
       incsq |  -62.06279   22.22047    -2.79   0.012
     pwtopen |  -.7970774   .3684829    -2.16   0.043
     open*K/L |   .0000108   .0000111     0.97   0.346
      polity |   .0504734   4.395518     0.01   0.991
     lareapc |  -8.710154    8.96786    -0.97   0.344
       _cons |  -4519.066   1711.041    -2.64   0.016
------------------------------------------------------
Instrumented:  inc incsq pwtopen
Instruments:   open*K/L polity lareapc elhsfs incf incfsq
-------------------------------------------------------
. * Income Peak       5826.6553
```

```
. *
. * Sulfur Dioxide
. *
OLS regression
Number of obs =      28               F(  6,    21) =    2.54
R-squared     =  0.4770               Root MSE      =  16.629
--------------------------------------------------------
             |               Robust
        SO2  |      Coef.   Std. Err.      t    P>|t|
-------------+--------------------------------------------
         inc |   299.3936   161.0884     1.86   0.077
       incsq |  -17.97758   9.737551    -1.85   0.079
     pwtopen |  -.3902438   .2305415    -1.69   0.105
    open*K/L |   4.71e-06   4.80e-06     0.98   0.338
      polity |  -1.415668   2.514041    -0.56   0.579
     lareapc |  -2.761184   1.840972    -1.50   0.149
       _cons |  -1170.302   662.7881    -1.77   0.092
---------------------------------------------------------
. * Income Peak       4133.4263
```

```
IV (2SLS) regression
Number of obs =      28              F(  6,    21) =   26.97
R-squared     =  0.3433              Root MSE      =  18.634
--------------------------------------------------------
             |               Robust
         SO2 |      Coef.   Std. Err.      t    P>|t|
-------------+------------------------------------------
         inc |   2.800528   475.6836     0.01   0.995
       incsq |  -.1549534   28.23113    -0.01   0.996
     pwtopen |   .0118908   .4524283     0.03   0.979
     open*K/L |  -4.81e-06    .000011    -0.44   0.668
      polity |  -2.659234   4.263488    -0.62   0.540
     lareapc |  -3.025493   1.621803    -1.87   0.076
       _cons |   49.87181   2009.666     0.02   0.980
--------------------------------------------------------
Instrumented:  inc incsq pwtopen
Instruments:   open*K/L polity lareapc elhsfs incf incfsq
---------------------------------------------------------
. * Income Peak  8405.8248
```

```
. *
. * Suspended Particles
. *
OLS regression
Number of obs =      28              F(  6,    21) =    3.84
R-squared     =  0.5705              Root MSE      =  57.516
---------------------------------------------------------
             |               Robust
          PM |      Coef.   Std. Err.      t    P>|t|
---------------------------------------------------------
         inc |   622.5589   528.4975     1.18   0.252
       incsq |  -39.71682   30.38049    -1.31   0.205
     pwtopen |  -.6369995   .6897447    -0.92   0.366
    open*K/L |   8.58e-06   .0000132     0.65   0.522
      polity |   -3.28841   7.639993    -0.43   0.671
     lareapc |   -12.7323    6.16094    -2.07   0.051
       _cons |  -2190.734   2241.871    -0.98   0.340
-------------------------------------------------------
. * Income Peak        2533.7881
```

```
IV (2SLS) regression
Number of obs =      28              F(  6,    21) =   17.51
R-squared     =  0.4480              Root MSE      =  65.199
------------------------------------------------------------------------------
             |               Robust
          PM |      Coef.   Std. Err.      t    P>|t|
-------------+------------------------------------------
         inc |  -187.8074    444.269    -0.42   0.677
       incsq |     8.4942   26.82096     0.32   0.755
     pwtopen |   .1409716   .5973184     0.24   0.816
    open*K/L |  -.0000149    .000014    -1.06   0.301
      polity |   .6310163   8.962102     0.07   0.945
     lareapc |  -12.78864   6.434292    -1.99   0.060
       _cons |   1130.471   1887.815     0.60   0.556
----------------------------------------------------------
Instrumented:  inc incsq pwtopen
Instruments:   open*K/L polity lareapc elhsfs incf incfsq
--------------------------------------------------------
. * Income Peak               63261.672
```

```
. *
. * CO2
. *
OLS regression
Number of obs = 49            F(  6,    42) =   38.01
R-squared     =  0.8080              Root MSE      =  2.3645
--------------------------------------------------------
             |               Robust
     co2perc |      Coef.   Std. Err.      t    P>|t|
-------------------------------------------------------
         inc |  -6.264538   7.094734    -0.88   0.382
       incsq |   .5238537   .4452012     1.18   0.246
     pwtopen |   -.001938   .0190309    -0.10   0.919
     open*K/L|   1.43e-06   6.88e-07     2.07   0.044
      polity |  -.0283246   .0568391    -0.50   0.621
     lareapc |   .5101885   .3180515     1.60   0.116
       _cons |   16.93333   27.42624     0.62   0.540
------------------------------------------------------
. * Income Peak  395.15627


IV (2SLS)
Number of obs =      48              F(  6,    41) =   35.66
R-squared     =  0.7870              Root MSE      =   2.047
-------------------------------------------------------
             |               Robust
        CO2  |      Coef.   Std. Err.      t    P>|t|
-------------------------------------------------------
         inc |  -15.41636   25.83755    -0.60   0.554
       incsq |   1.188027   1.533037     0.77   0.443
     pwtopen |    .012921   .0152394     0.85   0.401
    open*K/L |  -4.14e-07   6.18e-07    -0.67   0.507
      polity |  -.0531901   .2083393    -0.26   0.800
     lareapc |   .4163982   .2816945     1.48   0.147
       _cons |   47.77544   106.7887     0.45   0.657
------------------------------------------------------
Instrumented:  inc incsq pwtopen
Instruments:   open*K/L polity lareapc elhsfs incf incfsq
-----------------------------------------------------
. * Income Peak       657.35105



. *
. * Deforestation
. *
Regression
Number of obs =      46              F(  6,    39) =    5.17
R-squared     =  0.3171              Root MSE      =  1.3794
-------------------------------------------------------
             |               Robust
       Defor |      Coef.   Std. Err.      t    P>|t|
-------------+-----------------------------------------
         inc |  -.0148999   3.304742    -0.00   0.996
       incsq |  -.0532192   .1963267    -0.27   0.788
     pwtopen |   .0131713   .0169437     0.78   0.442
    open*K/L |  -1.90e-07   3.47e-07    -0.55   0.588
      polity |   .0644818   .0631231     1.02   0.313
     lareapc |  -.0001307   .1216412    -0.00   0.999
       _cons |    3.58308     13.641     0.26   0.794
------------------------------------------------------
. * Income Peak               .8693708
```

```
IV (2SLS)
Number of obs =      46              F(  6,    39) =    0.55
R-squared     =       .              Root MSE      =  2.9065
------------------------------------------------------------------
             |               Robust
       Defor |      Coef.   Std. Err.      t    P>|t|
-------------+----------------------------------------
         inc |  -55.94889   51.26357    -1.09   0.282
       incsq |   3.333191   3.060755     1.09   0.283
     pwtopen |   .0186028   .0216911     0.86   0.396
    open*K/L |  -1.89e-06   1.53e-06    -1.23   0.225
      polity |   .4319458   .4338433     1.00   0.326
     lareapc |  -.1944629   .4228314    -0.46   0.648
       _cons |   230.9296   211.1499     1.09   0.281
------------------------------------------------------
Instrumented:  inc incsq pwtopen
Instruments:   open*K/L polity lareapc elhsfs incf incfsq
------------------------------------------------------------------
. * Income Peak       4414.692
```

```
. *
. * Energy Depletion
. *
Regression
Number of obs =      47              F(  6,    40) =    1.19
R-squared     =  0.0465              Root MSE      =  8.4263
------------------------------------------------------------------
      energy |               Robust
      depltn |      Coef.   Std. Err.      t    P>|t|
-------------+----------------------------------------
         inc |    26.7365   19.83491     1.35   0.185
       incsq |  -1.694921   1.200254    -1.41   0.166
     pwtopen |   -.021903   .0187968    -1.17   0.251
    open*K/L |   8.53e-07   6.69e-07     1.27   0.210
      polity |  -.1618165   .2847076    -0.57   0.573
     lareapc |   .2471363   .7446471     0.33   0.742
       _cons |  -99.94707   82.27169    -1.21   0.232
------------------------------------------------------
. * Income Peak       2663.0946
```

```
IV (2SLS)
F(  6,    40) =    0.36              Prob > F      =  0.8979
R-squared     =       .               Root MSE      =  13.093
------------------------------------------------------------------
      energy |               Robust
      depltn |      Coef.   Std. Err.      t    P>|t|
-------------+----------------------------------------------------
         inc |  -190.8061   182.2415    -1.05   0.301
       incsq |   11.40254   10.85826     1.05   0.300
     pwtopen |  -.0151443   .0914005    -0.17   0.869
     open*K/L|  -4.34e-06   4.77e-06    -0.91   0.368
      polity |   1.300636    1.53464     0.85   0.402
     lareapc |   -.757164   1.753917    -0.43   0.668
       _cons |   789.5366   750.7969     1.05   0.299
------------------------------------------------------------------
Instrumented:  inc incsq pwtopen
Instruments:   open*K/L polity lareapc elhsfs incf incfsq
------------------------------------------------------------------
. * Income Peak       4301.968
```

```
. *
. * Rural access to clean water
. *
OLS regression
Number of obs =      27               F(  6,    20) =   10.37
R-squared     =  0.7044               Root MSE      =  19.013
-----------------------------------------------------
    rural H20|              Robust
      access |   Coef.   Std. Err.      t    P>|t|
-------------+----------------------------------------
         inc |  -105.6862   75.73808    -1.40   0.178
       incsq |   7.226187   4.629826     1.56   0.134
     pwtopen |   .0329863   .2089302     0.16   0.876
     open*K/L|   1.13e-06   5.66e-06     0.20   0.843
      polity |    1.20821   .9984656     1.21   0.240
     lareapc |  -9.759128   3.562662    -2.74   0.013
       _cons |   454.7026    304.658     1.49   0.151
----------------------------------------------------
. * Income Peak   1499.2562


IV (2SLS)
Number of obs =      27                F(  6,    20) =    1.79
R-squared     =       .                Root MSE      =  85.333
---------------------------------------------------------
   rural H20 |              Robust
      access |      Coef.   Std. Err.      t    P>|t|
-------------+----------------------------------------
         inc |    -1846.6   2286.727    -0.81   0.429
       incsq |    115.325   141.9123     0.81   0.426
     pwtopen |   .8095648   1.094208     0.74   0.468
     open*K/L|  -.0000733   .0000994    -0.74   0.470
      polity |   12.21201   15.95724     0.77   0.453
     lareapc |  -1.595393   18.93578    -0.08   0.934
       _cons |    7309.41   9030.419     0.81   0.428
-------------------------------------------------------
Instrumented:  inc incsq pwtopen
Instruments:   open*K/L polity lareapc elhsfs incf incfsq
------------------------------------------------------
. * Income Peak  2999.1145
```

Appendix

Tables A2 and A4: Environmental degradation equations (with income spline)

. * Three-piece spline for real income per capita, split at the .33 and .66 percentiles.*

OLS regressions

. *
. * Estimation of pollution equation, a function of income, trade, democracy and size
. * [comment: p2a]

Number of obs = 100
F(6, 93) = 37.07
R-squared = 0.7526

emissions of co2 / cap	Coef.	Robust Std. Err.	t	P>|t|
inc1	1.037	.406	2.56	0.012
inc2	2.113	.827	2.55	0.012
inc3	7.049	1.282	5.50	0.000
openness	.016	.008	1.97	0.052
polity	-.025	.022	-1.13	0.263
lareapc	.161	.154	1.04	0.301
_cons	-8.099	3.03	-2.67	0.009

Number of obs = 96
F(6, 89) = 7.94
R-squared = 0.2670

annual deforestation	Coef.	Robust Std. Err.	t	P>|t|
inc1	.558	.338	1.65	0.102
inc2	-1.071	.460	-2.33	0.022
inc3	-1.035	.338	-3.06	0.003
openness	.002	.003	0.78	0.437
polity	.033	.030	1.08	0.281
lareapc	-.112	.076	-1.49	0.141
_cons	-2.356	2.37	-0.99	0.323

Number of obs = 98
F(6, 91) = 3.07
R-squared = 0.1653

energy depletion (%GDP)	Coef.	Robust Std. Err.	t	P>|t|
inc1	6.701	2.210	3.03	0.003
inc2	4.288	2.902	1.48	0.143
inc3	-3.197	1.842	-1.74	0.086
openness	-.013	.009	-1.53	0.130
polity	-.446	.167	-2.68	0.009
lareapc	.249	.419	0.59	0.554
_cons	-45.384	15.583	-2.91	0.005

Number of obs = 36
F(6, 29) = 7.13
R-squared = 0.2077

NO_2	Coef.	Robust Std. Err.	t	P>|t|
inc1	-373.491	209.562	-1.78	0.085
inc2	169.749	57.176	2.97	0.006
inc3	-19.707	14.786	-1.33	0.193
openness	-.302	.159	-1.91	0.066
polity	-3.854	.975	-3.96	0.000
lareapc	-5.897	6.055	-0.97	0.338
_cons	2740.844	1499.377	1.83	0.078

Number of obs = 41
F(6, 34) = 40.04
R-squared = 0.6789

SO_2	Coef.	Robust Std. Err.	t	P>|t|
inc1	46.351	68.589	0.68	0.504
inc2	29.202	17.0379	1.71	0.096
inc3	-16.540	8.827	-1.87	0.070
openness	-.303	.082	-3.72	0.001
polity	-6.561	2.081	-3.15	0.003
lareapc	-3.223	1.398	-2.30	0.027
_cons	-248.434	488.917	-0.51	0.615

```
. reg suspm inc1-inc3 openness polity lareapc, robust
```

Number of obs = 38
F(6, 31) = 13.45
R-squared = 0.7147

suspended PM	Coef.	Robust Std. Err.	t	P>|t|
inc1	332.443	100.885	3.30	0.002
inc2	-113.061	54.189	-2.09	0.045
inc3	-46.614	22.426	-2.08	0.046
openness	-.256	.323	-0.79	0.435
polity	-7.459	3.378	-2.21	0.035
lareapc	-10.514	4.576	-2.30	0.028
_cons	-2128.872	724.849	-2.94	0.006

Table A3 and A5: Environmental degradation equations (with income spline)

IV regressions

```
. *
. * Estimation of pollution equations, a function of income, trade, democracy and size
. *    [comment: p3d]
.
```

Number of obs = 96 F(6, 89) = 43.49
R-squared = 0.7695

emissions of CO_2 per cap	Coef.	Robust Std. Err.	t	P>|t|
inc1	.700	.479	1.46	0.147
inc2	3.754	1.043	3.60	0.001
inc3	6.322	1.318	4.80	0.000
openness	-.001	.010	-0.06	0.949
polity	-.080	.037	-2.19	0.031
lareapc	.033	.163	0.20	0.840
_cons	-4.876	3.184	-1.53	0.129

Instrumented: inc1 inc2 inc3 openness
Instruments: polity lareapc elhsfs incf1 incf2 incf3

Number of obs = 92
F(6, 85) = 10.69
R-squared = 0.2756

annual deforestation	Coef.	Robust Std. Err.	t	P>|t|
inc1	.545	.436	1.25	0.215
inc2	-.736	.593	-1.24	0.218
inc3	-1.262	.510	-2.48	0.015
openness	.001	.003	0.37	0.713
polity	.027	.027	1.00	0.320
lareapc	-.078	.084	-0.94	0.351
_cons	-2.367	3.035	-0.78	0.438

Instrumented: inc1 inc2 inc3 openness
Instruments: polity lareapc elhsfs incf1 incf2 incf3

Number of obs = 93 F(6, 86) = 3.57
R-squared = 0.1601

energy depletion	Coef.	Robust Std. Err.	t	P>|t|
inc1	8.526	3.132	2.72	0.008
inc2	4.257	3.654	1.16	0.247
inc3	-2.922	2.094	-1.40	0.166
openness	-.033	.020	-1.67	0.099
polity	-.521	.190	-2.74	0.007
lareapc	.314	.505	0.62	0.536
_cons	-57.089	20.293	-2.81	0.006

Instrumented: inc1 inc2 inc3 openness
Instruments: polity lareapc elhsfs incf1 incf2 incf3

Number of obs = 35   R-squared = 0.2120

NO_2	Coef.	Robust Std. Err.	t	P>|t|
inc1	-492.92	324.92	-1.52	0.140
inc2	207.14	100.29	2.07	0.048
inc3	-20.82	10.99	-1.89	0.069
openness	-.324	.186	-1.75	0.092
polity	-4.448	1.216	-3.66	0.001
lareapc	-5.792	6.445	-0.90	0.376
_cons	3593.957	2331.116	1.54	0.134

Instrumented: inc1 inc2 inc3 openness
Instruments: polity lareapc elhsfs incf1 incf2 incf3

Number of obs = 40   F(6,33)= 7.78   R-squared = 0.6618

SO_2	Coef.	Robust Std. Err.	t	P>|t|
inc1	-22.492	190.106	-0.12	0.907
inc2	39.992	58.752	0.68	0.501
inc3	-20.144	9.920	-2.03	0.050
openness	-.210	.089	-2.36	0.025
polity	-6.359	2.437	-2.61	0.014
lareapc	-1.420	2.230	-0.64	0.529
_cons	240.566	1373.882	0.18	0.862

Instrumented: inc1 inc2 inc3 openness
Instruments: polity lareapc elhsfs incf1 incf2 incf3

Number of obs = 37   F(6, 30) = 9.80   R-squared = 0.7024

suspended PM	Coef.	Robust Std. Err.	t	P>|t|
inc1	497.615	137.231	3.63	0.001
inc2	-172.283	79.002	-2.18	0.037
inc3	-33.763	27.233	-1.24	0.225
openness	.037	.293	0.13	0.900
polity	-8.524	3.950	-2.16	0.039
lareapc	-7.098	4.469	-1.59	0.123
_cons	-3325.855	973.424	-3.42	0.002

Instrumented: inc1 inc2 inc3 openness
Instruments: polity lareapc elhsfs incf1 incf2 incf3