Environment and Development Economics 16: 657–684 © Cambridge University Press 2011
doi:10.1017/S1355770X11000271

Is natural openness or trade policy good for the environment?

STEVEN YAMARIK
Department of Economics, California State University at Long Beach, SS/BA Building, Long Beach, CA 90840, USA. Tel: 562 985 4634. Email: syamarik@csulb.edu

SUCHARITA GHOSH
Department of Economics, University of Akron, USA. Email: sghosh@uakron.edu

Submitted February 3, 2010; revised March 2, 2011; accepted May 30, 2011; first published online 18 August 2011

ABSTRACT. In this paper, we estimate the individual effects of natural openness and trade policy on air pollution. Natural openness is the component of the trade share (imports and exports as a percentage of GDP) attributable to population, geography and factor endowment differences. We find that natural openness reduces air pollution, while trade policy has a limited impact. The implication is that 'natural' geographic and endowment differences play a more important role than deliberate trade policy decisions in explaining the trade and environment link.

1. Introduction

Since 1990, there has been a heated debate over the impact of trade liberalization on the environment. Anti-globalists argue that international trade will lead pollution-intensive industries to relocate to developing countries with less stringent environmental regulations (the *pollution haven* effect). In addition, opponents of globalization speculate that nations would compete further by lowering environmental standards in a regulatory race to the bottom. Pro-globalists contend that international trade could bring about an improvement in the environment as pollution-intensive industries move to capital-abundant developed countries with stricter environmental regulations (the *factor endowment* effect). Proponents also argue that trade

The authors would like to thank the three anonymous referees and participants at the 2008 Midwest International Economics meeting for their helpful comments and suggestions. They would also like to thank Jeffrey Frankel and Andrew Rose for use of their data. All remaining errors are, of course, the authors' own.

can improve environmental outcomes by encouraging greater efficiency, diffusing abatement technologies and raising environmental awareness.[1]

Empirical research has found a positive link between trade openness and environmental quality. In early studies, Shafik and Bandyopadhyay (1992) and Lucas *et al.* (1992) show that more open economies experienced lower levels of ambient sulfur dioxide (SO_2) and toxic emissions in the 1980s. Antweiler *et al.* (2001) and Harbaugh *et al.* (2002) find that openness reduces SO_2 concentrations. Likewise, Cole and Elliott (2003), Cole (2004), and Kellenberg (2008) show that trade openness decreases concentrations of other air pollutants (i.e., nitrogen oxides and particulate matter (PM)). In an important paper, Frankel and Rose (2005) control for the endogeneity of trade and income and also find that openness reduces air pollution.[2]

The most common measure of trade openness is the trade share: imports and exports as a percentage of GDP.[3] The trade share, however, is an outcome measure that combines aspects of 'natural openness' as determined by geography and factor endowments with trade policy (Berg and Krueger, 2003; Wei, 2000; Wacziarg, 2001). As a result, the exact interpretation of the negative coefficient for the trade share is unclear. Is it that more naturally open economies import cleaner production techniques, greener corporate practices and stricter environmental policies? Or is it that more liberal trade policies carry with them cleaner production techniques, greener corporate practices and stricter environmental policies?[4]

There are reasons to believe that natural openness and trade policy could have different quantitative and possibly qualitative impacts on the environment. First, from a theoretical point of view, we argue that the trade costs associated with trade policy are more likely to be 'iceberg costs', while the costs associated with natural openness are more likely to be per-unit transportation costs and fixed market-entry costs.[5] As such, trade policy is predicted to affect the volume of trade, while natural openness is predicted to have an impact on both the volume of trade and the number

[1] Copeland and Taylor (2004) provide an overview of the main arguments on the trade and the environment debate.

[2] In a recent paper, Managi *et al.* (2009) extend this literature by testing for differences between OECD and developing countries, allowing a dynamic adjustment process, and addressing endogeneity issues. They found that trade openness reduces air pollution in the developed nations, but generally increases air pollution in the developing nations.

[3] Throughout the paper, we use 'trade share' to refer exclusively to imports and exports as a share of GDP so as not to confuse this measure with 'natural openness' and 'policy-induced openness'.

[4] In one of the earliest cross-country studies, Grossman and Krueger (1993: 17) estimate a negative and significant coefficient for trade openness in a regression on SO_2 concentrations. They remarked that: 'We have no good explanation for this finding'.

[5] An 'iceberg cost' is an exogenous trade cost that is fixed and proportional to the value shipped. A per-unit trade cost is a cost imposed on the weight of a product and thus the delivered price equals the origin price plus a shipping charge which can depend upon weight and also value (Hummels, 2010).

https://doi.org/10.1017/S1355770X11000271 Published online by Cambridge University Press

and variety of exporting firms. Second, from an empirical standpoint, the majority of the trade share and the trade costs that underlie it can be attributed to natural openness. In a review of trade costs, Anderson and van Wincoop (2004) report that the bulk of trade costs are non-policy: transportation costs, border-related trade costs and distribution costs. Similarly, Wei (2000) find that population and geography differences explain half of the variation in the trade share, while trade policy measures add very little explanatory power. Third, from a strategic point of view, there is an incentive for governments to substitute environmental policy for trade policy when undergoing trade liberalization (Copeland, 2000; Ederington, 2001). As a result, environmental protection may be less when openness is being driven by trade policy as opposed to natural openness.

In this paper, we examine the relative roles played by natural openness and trade policy in explaining the trade and environment link. We first decompose the trade share into natural openness and trade policy. We create a measure of natural openness by regressing the log trade share on size, geography, language and relative factor endowments and then taking the exponent of the fitted value of the regression. For trade policy, we use four different types: the component of the trade share attributable to observed trade policy (policy-induced openness), the trade policy measures themselves (trade policy indicators), a combination of trade policy indicators (trade policy indices), and deviations of observed prices from some hypothetical free trade level (price deviations).

We then estimate the individual effects of natural openness and trade policy on three air pollutants: nitrogen dioxide (NO_2), SO_2 and PM. We follow the empirical strategy of Frankel and Rose, which controls for the endogeneity of income and trade. Initially, we find that natural openness reduces all three air pollutants, while policy-induced openness lowers NO_2 and SO_2 concentrations. However, when we use other trade policy measures and control for domestic environmental regulations, we find that natural openness continues to lower air pollution, while trade policy has a limited effect. Our results therefore suggest that 'natural' geographic and endowment differences play a more important role than deliberate trade policy decisions in explaining the trade and environment link.

The remainder of the paper is organized as follows. We discuss the relationship between openness, trade policy and the environment in section 2. We present our empirical methodology in section 3. We discuss our results in section 4 and conclude in section 5.

2. Openness, trade policy and the environment

2.1. Trade openness and the environment

Trade openness can have both indirect and direct effects on the environment. The most prominent indirect effect of trade openness is through economic growth. Trade can encourage investment flows, technology transfer and greater competition (Wacziarg, 2001). The resulting gains in factor accumulation and efficiency will increase the level of per capita income. However, the impact of higher per capita income on environmental outcomes depends upon the magnitudes of the scale, technique and composition effects (Copeland and Taylor, 2004). The scale effect states that greater output requires more inputs, and as a consequence, generates more pollution. The technique effect is the adoption of cleaner production methods that results from increased demand for environmental regulations as growth increases. The composition effect is the change in the structure of production resulting from economic growth, which can either raise or lower pollution emissions.

Previous studies by Grossman and Krueger (1993) and others have found an inverted U-shaped relationship between per capita income and environmental degradation – the so-called *environmental Kuznets curve* – for many forms of pollution. At low levels of income, the demand for environmental quality is low relative to that of increased consumption. As a result, the scale (and composition) effect dominates the technique effect so that pollution increases with income. At higher levels of income, the demand for environmental quality rises so that greater consumption is willing to be sacrificed. Therefore, the technique effect becomes larger than the scale effect so that pollution decreases with income.

Trade openness can also have direct effects operating through scale, composition and technique effects (Copeland and Taylor, 2004). Trade leads to larger production due to comparative advantage and economies of scale. As a result, the larger scale of production generates a higher level of pollution emission. This is the trade-induced scale effect which is positive. The trade-induced composition effect can be either positive or negative, depending upon a country's relative factor endowments and the stringency of its environmental regulations. The *factor endowment* hypothesis argues that greater openness will lead countries with relatively high capital–labor ratios (the 'North') to increase their production of capital-intensive goods, and countries with relatively low capital–labor ratios (the 'South') to increase their production of labor-intensive goods. Since capital-intensive goods are more pollution intensive, trade liberalization would lead to greater environmental degradation in the North and less environmental damage in the South. However, the *pollution haven* hypothesis argues that countries with weak environmental regulations have a comparative advantage in pollution-intensive production. As a result, increased openness will lead dirty industries to locate in countries with weaker environmental regulations and cleaner industries to locate in countries with stronger environmental regulations. Since countries with lower income levels tend to have weaker environmental regulations (Dasgupta *et al.*, 2001), this hypothesis predicts that the South will specialize in dirty production, while the North will specialize in clean production.

The trade-induced technique effect is predicted to have a positive impact on the environment. Frankel (2008) identifies three mechanisms for this beneficial link. First, increased competition from international trade can spur managerial and technological innovations beneficial to the environment. Second, multinationals can bring clean state-of-the-art production techniques from high-standard countries of origin (Esty and Gentry, 1997). Third, trade can raise public awareness of cleaner practices and policies from abroad. As a result, there could be a 'race to the top' for environmental standards.

2.2. Trade openness and trade costs

One can view trade openness as a reduction in trade costs. Trade costs are the cost of getting a good to the final user other than the costs of production. These include the transportation (freight and time) costs, information costs, local distribution (wholesale and retail) costs, legal and regulatory costs, and policy barriers (tariffs and non-tariff barriers).

In the trade literature, trade costs have traditionally been represented as iceberg costs. Iceberg costs are marginal costs that are proportional to the value shipped, with the value added of transportation services treated as pure waste, or 'melt' (Samuelson, 1954). In new trade theory models with increasing returns and love for variety, iceberg costs are used to explain the home market effect where industries tend to concentrate in the markets with the largest number of consumers (Krugman, 1980). Trade liberalization in the form of a lower iceberg cost raises the volume of trade, but has no impact on the overall production of the firm and the number of products produced (Hummels, 1999).

More recently, trade costs are being modeled more broadly to include per-unit transportation costs and fixed market-entry costs (Hummels, 2010). The inclusion of these non-iceberg trade costs into new trade theory models generates richer dynamics where some firms export (Venables, 1994; Medin, 2002), higher quality goods are exported abroad (Hummels and Skiba, 2004), and firms in developing countries pay higher transportation costs than developed countries (Hummels *et al.*, 2009). As a result, trade liberalization not only raises the volume of trade, but also increases the number and variety of exporting firms (Hummels, 1999).

On the empirical side, there is mounting evidence that transportation costs are per-unit, trade policy costs are iceberg and export entry costs are fixed. For example, Hummels and Skiba (2004) estimate a trade cost function and find that export prices depend positively upon per unit weight and negatively upon *ad valorem* tariff rates. Bernard and Jensen (2004) and Eaton *et al.* (2004) find that fixed export entry costs are a critical determinant in the firm-level decision to export. By applying a structural model, Das *et al.* (2007) estimate that these export entry costs are quite significant: $300,000–500,000 per firm.

2.3. Natural openness, trade policy and the environment

There are theoretical, empirical and strategic reasons to believe that natural openness and trade policy can have different impacts on the environment. The above discussion on the nature of trade costs provides the basis for our theoretical predictions. Trade policy liberalization is likely to increase the volume of exports and thus reinforce the existing trade patterns. As a result, one would expect trade policy to lead to trade-induced composition effects, whether it is positive or negative. Natural openness, on other hand, is more likely to be realized through reductions in per-unit transportation costs and fixed entry costs. As such, natural openness will increase the number and variety of exporting firms. Therefore, one would expect natural openness to lead to both trade-induced composition effects and trade-induced techniques effects.

From an empirical standpoint, the majority of the trade share and the trade costs that underlie it can be attributed to natural openness. Anderson and van Wincoop (2004) report that the bulk of trade costs are non-policy: transportation costs, border-related trade costs and distribution costs. In terms of an *ad valorem* tax equivalent, transportation costs have been estimated to represent 21 per cent; border-related trade costs are 44 per cent, and 55 per cent are local distributional costs with half of the border-related trade costs attributable to non-policy factors.[6] Similarly, Wei (2000) and our results in table 1 find that half of the variation in the trade share can be explained by population, geography and language. However, trade policy measures explain less than 10 per cent of the variation in the trade share.

From a strategic point of view, governments can use either trade policy or environmental policy to improve the terms of trade for their domestic industries. If both policies are available, Copeland (2000) shows that policy makers will use tariffs to protect domestic industries, but impose a domestic tax to internalize production externalities. However, if nations commit themselves to no tariffs, then policy makers will lower the domestic tax to protect the domestic industries and thus worsen the environment. Ederington (2001) also finds that policy makers will reduce environmental protection if bound to a multilateral trade agreement. As a result, environmental protection will be less when openness is being driven by trade policy as opposed to natural openness.

2.4. Trade policy measures

We consider four different types of trade policy measures: policy-induced openness, trade policy indicators, trade policy indices, and deviations from observed prices.[7]

The policy-induced openness measure is computed by isolating the variation in the trade share attributable to trade policy indicators (Wacziarg, 2001). In particular, the trade share is regressed on several geographic, endowment and trade policy measures. The sum of the predicted effects of the policy measures is policy-induced openness.

Trade policy indicators are direct incidence-based measures such as average tariff rates, collected duty revenue, non-tariff barriers, coverage rates and black market premiums. These indicators describe a country's policy position on trade and factor flows with the rest of the world. The main

[6] The exact breakdown of the 44 per cent border-related trade costs is: an 8 per cent policy barrier, a 7 per cent language barrier, a 14 per cent currency barrier (from the use of different currencies), a 6 per cent information cost barrier, and a 3 per cent security barrier.

[7] Our taxonomy is based on the discussions of Wolf (1993), Edwards (1998), Wacziarg (2001) and Berg and Krueger (2003). Leamer (1988), Wolf (1993), and Wei (2000) also consider 'residual openness' to measure trade policy. Residual openness is the estimated deviation of observed trade volumes from their predicted trade volume based on geography and factor endowments (natural openness). However, we do not use residual openness due to the bias introduced by omitted variables, correlation between geography and trade policy, and measurement error.

Table 1. *Explaining the trade share*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ln(*population*)	−0.166***	−0.176***	−0.175***	−0.182***	−0.188***	−0.192***	−0.174***	−0.172***
	(−3.41)	(−3.35)	(−3.45)	(−3.37)	(−3.30)	(−4.06)	(−3.10)	(−2.92)
ln(*surface area*)	−0.045	−0.050	−0.056	−0.056	−0.034	−0.044	−0.064	−0.068
	(−1.12)	(−1.11)	(−1.19)	(−1.16)	(−0.68)	(−0.92)	(−1.27)	(−1.33)
ln(*remoteness*)	−0.255**	−0.214	−0.093	−0.089	−0.189	−0.145	−0.033	−0.031
	(−2.01)	(−1.49)	(−0.57)	(−0.54)	(−1.08)	(−0.87)	(−0.19)	(−0.18)
Landlocked	0.039	0.060	0.126	0.103	0.091	0.071	−0.049	−0.023
	(0.35)	(0.52)	(1.14)	(0.92)	(0.75)	(0.51)	(−0.42)	(−0.20)
Island	−0.088	−0.117	−0.182	−0.204	−0.143	−0.157	−0.119	−0.112
	(−0.67)	(−0.96)	(−1.37)	(−1.53)	(−1.06)	(−1.19)	(−0.98)	(−0.90)
Coastal length/surface area	1.546***	0.988	0.607	0.372	0.873	0.934	−0.456	−0.312
	(3.21)	(1.50)	(0.67)	(0.40)	(0.74)	(0.84)	(−0.50)	(−0.34)
English language	0.132	0.170	0.188*	0.18	0.157	0.142	0.131	0.112
	(1.11)	(1.43)	(1.66)	(1.59)	(1.24)	(1.15)	(1.05)	(0.83)
French language	−0.126	−0.101	−0.055	−0.075	−0.068	−0.072	−0.104	−0.118
	(−1.17)	(−0.95)	(−0.53)	(−0.72)	(−0.59)	(−0.45)	(−1.04)	(−1.08)
Spanish language	0.004	−0.067	−0.139	−0.133	−0.123	−0.166	−0.183	−0.195
	(0.03)	(−0.45)	(−0.85)	(−0.83)	(−0.71)	(−1.10)	(−1.18)	(−1.24)
Relative ln(K/L)		−0.013	−0.004	−0.004	−0.016	−0.017	−0.001	0.006
		(−1.04)	(−0.36)	(−0.42)	(−1.23)	(−1.28)	(−0.02)	(0.49)
Relative (*secondary school in 15+ year–old pop*)		−1.313*	−1.756***	−1.847***	−1.423*	−1.446	−2.344***	−2.269***
		(−1.84)	(−2.59)	(−2.66)	(−1.97)	(−1.57)	(−3.85)	(−3.64)

(*continued*)

Table 1. *Continued*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Relative ln(*area per capita*)		0.010	0.010	0.012	0.012	0.009	0.014	0.012
		(0.63)	(0.62)	(0.74)	(0.60)	(0.51)	(1.00)	(0.82)
Oil producer		0.334*	0.352***	0.441***	0.322*	0.313	0.494***	0.419***
		(2.16)	(2.58)	(3.15)	(1.83)	(1.42)	(4.26)	(3.18)
Import duties/Total imports			−0.876**	−0.792*				−0.474
			(−1.73)	(−1.75)				(−0.64)
Export duties/Total exports			−3.015***	−2.805***				−1.102
			(−4.37)	(−3.83)				(−1.42)
ln(*black market premium*)				−0.095*				0.060
				(−1.85)				(0.70)
Sachs–Warner Openness					0.029			
					(0.18)			
Heritage Foundation's Trade Freedom						0.094		
						(0.26)		
Fraser Institute's Freedom to Exchange							1.645***	1.821***
							(4.19)	(3.10)
R-squared	0.54	0.58	0.62	0.63	0.56	0.57	0.67	0.68
Adjusted R-squared	0.50	0.51	0.54	0.55	0.47	0.49	0.60	0.61
Observations	99	99	88	88	87	84	84	84

Notes: The dependent variable is the log of imports plus exports as a share of GDP. Robust t-statistics are in parentheses where ***, ** and * indicate significance at the 1, 5, and 10% level of confidence, respectively.

advantage of trade policy indicators is that they are obtained directly from observed data and can describe intermediate policy stances between closed and open economies.

Trade policy indices combine the information of several trade policy indicators into a single index. There are three popular trade indices: Sachs and Warner's Openness, the Heritage Foundation's Trade Freedom, and the Fraser Institute's Freedom to Trade. Each index uses predetermined criteria to weigh the impact of each policy indicator.[8]

The fourth type is deviations of observed prices from some hypothetical free trade level. The most famous example is the Dollar (1992) index of real exchange rate distortion. Dollar computed a price-deviation index by comparing the observed real exchange rate relative to the purchasing power parity rate purged of the effects of non-tradables.

Pritchett (1996), Edwards (1998) and especially Rodriguez and Rodrik (2001) provide critiques of the trade policy measures. In general, each type suffers from potential measurement errors, omitted variable bias, aggregation problems and extraneous information. Moreover, the degree of bias introduced by each type is unknown. Therefore, rather than relying on one measure of trade policy, we use examples from all four types in our analysis.[9]

3. Empirical methodology

3.1. Data

We use NO_2, SO_2 and PM concentrations to measure air pollution. The air pollution data are for 1995–2001 and are taken from the World Development Indicators.[10] NO_2 is formed by the oxidation of nitric oxide, which is produced by most combustion processes. SO_2 is created from burning coal or oil as a fuel and releasing sulfur. SO_2 emissions can be reduced by switching to cleaner coal or using flue gas desulfurization (commonly

[8] The Sachs and Warner Openness index is a 0 (closed) and 1 (open) variable where a country takes a value of zero if *any* of the following five criteria are met: (1) average tariff rates higher than 40 per cent; (2) non-tariff barriers coverage of more than 40 per cent of imports; (3) socialist economic system; (4) state monopoly of major exports; and (5) black market premium exceeding 20 per cent. See Sachs and Warner (1995) for details.
The Heritage Foundation's Trade Freedom is a continuous index from 1 (closed) to 5 (open) based on the trade-weighted average tariff rate and non-tariff barriers. See Johnson and Sheehy (1996) for details.
The Fraser Institute's Freedom to Trade Internationally is a continuous index from 1 (closed) to 10 (open) based on five categories: (1) tariff rates; (2) non-tariff barriers; (3) size of trade sector related to expected; (4) black market exchange rates; and (5) international capital market controls. See Gwartney *et al.* (1996) for details.

[9] Edwards (1998) and Rose (2004) also use multiple measures of trade policy in their empirical analysis of economic growth and the WTO.

[10] The World Bank (2010) publishes air pollution data for the most recent year available in their table 3.14. However, because the values are infrequently updated and change very little when updated, we use the average value for 1995–2001 as opposed to constructing a panel data set.

known as ‘scrubbers’). PM includes dust, dirt, soot, smoke and liquid droplets directly emitted in the air by sources such as cars, construction, diesel trucks, fires, factories, power plants and natural windblown dust.

We disaggregate the trade share into natural openness and trade policy. For natural openness, we regress the trade share on contemporaneous population, geographic variables and lagged relative factor endowments. We then use the predicted value to record natural openness. For trade policy, we use policy-induced openness, trade policy indicators, trade policy indices, and deviations from observed prices to measure trade policy. Policy-induced openness is the predicted value of the trade policy indicators in the trade share regression. The trade policy indicators are the ratio of import duties to import value, ratio of export duties to export value, and the log of the black market premium. The trade policy indices are the Sachs–Warner Openness, Heritage Trade Freedom and Fraser Freedom to Exchange. Each trade policy index is normalized to a 0 to 1 scale, where 0 corresponds to ‘closed’ and 1 to ‘open’. The deviation from observed prices is the Dollar index of real exchange rate deviation. The Dollar index is also normalized to a 0 to 1 scale. Natural openness and the trade policy measures are averaged over 1985–1995 to smooth out temporary fluctuations and maximize country coverage.

The real GDP per capita, real GDP per capita squared, polity and surface area per person values used in the final estimation are measured in 1995. We use average values of factor accumulation, lagged natural openness and lagged trade policy to instrument for real GDP per capita, natural openness and trade policy, respectively. Appendix A provides the details of the data sources and dates.

The air pollution, trade share and real GDP data are shown in appendix B. There are 45 potential countries in our sample: 24 developed and 21 developing nations. As a result, there is a good deal of cross-sectional variation in our air pollution, trade and development data. However, our cross-sectional data set is unable to exploit any potential time variation in the data which could be used to control for unobserved differences across nations.

3.2. Empirical design

The first step is to create our estimate of natural openness: the component of the trade share attributable to population, geography and relative factor endowments. We regress the trade share on size, geography, language and relative factor endowments:

$$\begin{aligned}\ln(\mathit{trade}/\mathit{GDP})_i = {} & \alpha_0 + \alpha_1 \ln(\mathit{pop})_i + \alpha_2 \ln(\mathit{area})_i + \alpha_3 \ln(\mathit{remoteness})_i \\ & + \alpha_4(\mathit{geography})_i + \alpha_5(\mathit{language})_i \\ & + \alpha_6(\mathit{relative\ factors})_i + e_i \qquad (1)\end{aligned}$$

The variables *pop* and *area* are total population and surface area and control for country size. The variable *remoteness* is the weighted sum of each country’s distance to all other countries in the world. We weigh each distance with initial real GDP of the other country to control for market size. The

https://doi.org/10.1017/S1355770X11000271 Published online by Cambridge University Press

three *geography* variables are dummies for landlocked and island and the ratio of a country's sea coast length to its land area. There are three *language* dummy variables for English, French and Spanish speaking nations. The three *relative factor* endowments are capital per worker, schooling per worker and surface area per capita.[11] We also include an oil dummy to control for the role of extractive industries. Natural openness is measured as the exponent of the fitted value of (1).

The second step is to compute policy-induced openness. We add trade policy indicators and indices to our trade share regression:

$$\begin{aligned}\ln(trade/GDP)_i = {} & \alpha_0 + \alpha_1 \ln(pop)_i + \alpha_2 \ln(area)_i + \alpha_3 \ln(remoteness)_i \\ & + \alpha_4 (geography)_i + \alpha_5 (language)_i + \alpha_6 (relative\ factors)_i \\ & + \alpha_7 (trade\ policies)_i + e_i \end{aligned} \tag{2}$$

The exponent of the estimated effect of policy – $\hat{\alpha}_7(trade\ policies)_i$ – is our measure of policy-induced openness. We have three trade policy indicators and three indices at our disposal. We therefore use the predicted values of those combinations that produce the 'best fit' in terms of predicted signs and highest adjusted R-squared.

The third step is to estimate the individual effects of natural openness and trade-policy openness on air pollution. We adopt the specification of Frankel and Rose (2005):

$$\begin{aligned}Pollution_i = {} & \varphi_0 + \varphi_1 \ln(Y/pop)_i + \varphi_2 [\ln(Y/pop)_i]^2 + \varphi_3 (Polity)_i \\ & + \varphi_4 \ln(area/pop)_i + \beta_1 (natural\ openness)_i \\ & + \beta_2 (trade\ policy\ openness)_i + e_i \end{aligned} \tag{3}$$

where *Y/pop* is real GDP per capita, *Polity* is a measure of democracy (−10 for 'strongly autocratic' to +10 for 'strongly democratic'), and *area/pop* is surface area per person. The EKC hypothesis predicts an inverted U-shaped relationship between real GDP per capita and pollution ($\varphi_1 > 0$ and $\varphi_2 < 0$). Barrett and Graddy (2000) and Frankel and Rose (2005) find that greater democracy improves the environment ($\varphi_3 < 0$), while Frankel and Rose (2005) show that greater congestion (more people per square mile) harms the environment ($\varphi_4 < 0$).

3.3. Two-stage least squares

There is potential endogeneity of real GDP per capita (and squared), natural openness and trade policy in (3). For real GDP, environmental degradation can reduce production possibilities and thus cause lower growth rates, especially in the developing world (Arrow *et al.*, 1995). For natural openness, the inclusion of contemporaneous population in (1) creates a feedback from environmental degradation to natural openness through the impact

[11] The relative factor endowments are calculated by squaring the difference between the factor endowment of country *i* and the world effective endowment. See Spilimbergo *et al.* (1999) for details.

https://doi.org/10.1017/S1355770X11000271 Published online by Cambridge University Press

of air pollution on mortality rates. For trade policy, the feedback potential operates through environmental policy. Kennedy (1994) and Barrett (1994) find that trade liberalization can reduce (or even raise) environmental regulation. Porter (1991) argues that environmental regulation can stimulate productivity and thus impact economic growth. By impacting environmental policy and productivity, trade policy can have a simultaneous impact on air pollution (dependent variable) and income (independent variable).

We therefore estimate equation (3) using two-stage least squares (2SLS). In the first stage, we estimate natural openness, trade policy, real GDP per capita and real GDP per capita squared as functions of lagged natural openness, lagged trade policy, fitted trade openness, fitted real GDP per capita, fitted real GDP per capita squared, and the exogenous variables. The fitted trade share variable is the aggregated predicted values of a geographic-based gravity model (Frankel and Romer, 1999). The fitted real GDP per capita terms are constructed from regressing real GDP per person on initial real GDP per capita, population, the trade share, investment, population growth, and primary and secondary enrollment (Frankel and Rose, 2005).

An instrumental variable must satisfy two requirements: it must be orthogonal to the error term (validity) and it must be correlated with the included endogenous variable (relevance). We use the Hansen J-statistic to test for the orthogonality of the instruments when there are more excluded instruments than endogenous variables (over-identification). Relevance is examined through the first-stage F-statistics and the Shea (1997) partial R-squares of the excluded instruments. However, the recent literature on weak instruments (c.f. Stock *et al.*, 2002) has shown that mere instrument relevance is insufficient. In particular, there is a possibility that each endogenous variable can be nearly explained by the same combination of instruments (i.e., 'weak').

With more than one endogenous variable, we use the Stock and Yogo (2005) weak instrument test to determine the strength of our instruments. The Stock and Yogo weak instrument test compares the Cragg–Donald statistic to critical values based upon the worst possible case of weak instruments.[12] If the instruments are weak, then the Cragg–Donald statistic takes a low value, the 2SLS estimates are biased, and the standard errors are underestimated (i.e., the null rejection rate based on t-tests at the nominal 5 per cent level could in fact be 10 per cent or more). However, if the instruments are strong, then the Cragg–Donald statistic exceeds the critical value and we can reject the fact that the 2SLS estimates have the potential to be biased of more than 10 per cent with a risk of rejecting the null wrongly of 5 per cent.

4. Empirical results

Table 1 reports the results for the trade share regressions. In column 1, we include the geographic and language variables. These variables explain

[12] The Cragg-Donald statistic is the minimum eigenvalue of the generalized F-statistic from the first-stage, reduced form regression.

54 per cent of the variation in the trade share. As expected, the coefficients for economic size are negative. As with Wei (2000), we also find that economies more distant from world markets have lower trade shares, while countries with longer coast lines (relative to surface area) have larger trade shares. The language variables are generally insignificant. In column 2, we add relative factor endowments. A positive coefficient implies that countries with different factor endowments trade more *à la* Heckscher–Ohlin, while a negative coefficient implies that countries with similar factor endowments trade more *à la* new trade theory. We find that countries with similar capital and skill endowments tend to trade more which suggests that these countries conduct more intra-industry trade. We measure natural openness as the exponent of the predicted value from column 2.

We next add trade policy indicators and indices to our trade share regression. In column 3, we include the ratios of import duties to imports and export duties to exports to quantify import and export tax rates. As expected, the coefficient for each trade tax is negative, indicating that countries with more restrictive trade policies have a lower trade share. We then add the black market premium to control for foreign exchange restrictions in column 4.[13] The coefficient for the black market premium also has its expected negative sign and is significant.

In the remaining columns, we include the different trade policy indices. These indices are combinations of tariff rates, non-tariff barriers, export monopolies, black market premium and capital controls. The coefficient for each trade policy index is positive, but only the coefficient for the Fraser Institute's Freedom to Exchange is economically and statistically significant. Lastly, in column 8, we add back the trade policy indicators to see if we can increase the predictive power. Although the trade policy indicators are insignificant, there is a slight increase in the adjusted R-squared so we use the sum of the predicted values for the trade policy variables in column 8 to construct our measure of policy-induced openness.[14]

Tables 2a and 2b report the summary statistics and correlation coefficients for our trade openness measures. The trade share is highly correlated with natural openness, but weakly correlated with each trade policy. This is not surprising given the strong predictive power of population and geography in table 1. There is also very little correlation between natural

[13] Sachs and Warner (1995) argue that a black market premium represents inconvertibility of the national currency and therefore rationing of foreign exchange to importers. This rationing will have an economically similar impact to a quota on imports. Rodriguez and Rodrik (2001) and Easterly (2005) contend that the black market premium may capture the distortionary effects of other government policies.

[14] Although not shown, we also added the non-tariff barrier coverage ratio on intermediate inputs and capital goods (Barro and Lee, 1994) and on all goods (Nogues *et al.*, 1986; Pritchett, 1996). Like Wacziarg (2001) and others, we found that non-tariff barriers had little to no impact on trade openness. The insignificance of NTB can be attributed to measurement problems, low country coverage, and non-compatibility of data between developing and industrialized nations (See Pritchett, 1996, footnote 18).

Table 2a. *Summary statistics of trade openness measures*

Variable	*Obs*	*Mean*	*S.D.*	*Min*	*Max*
Trade share	99	69.90	48.83	16.28	339.38
Natural openness	99	65.18	34.78	19.81	240.16
Policy-induced openness	88	730.22	97.66	283.33	831.31
Import duty ratio	88	0.10	0.08	0.00	0.47
Export duty ratio	88	0.02	0.05	0.00	0.34
Black market premium	99	0.33	0.65	−0.01	4.30
Sachs–Warner Openness	97	0.61	0.40	0.00	1.00
Heritage Trade Freedom	94	0.60	0.16	0.10	0.90
Fraser Freedom to Exchange	93	0.61	0.15	0.24	0.96
Dollar RER index	82	0.40	0.13	0.17	0.83

openness and each trade policy indicator. Within trade policy, there is a high correlation between policy-induced openness and the Fraser Freedom to Exchange index.

As a baseline, we estimate the impact of natural openness along with real GDP per capita, polity and area per person on air pollution. Table 3 presents the results where the ordinary least squares (OLS) estimates are shown on the left and the 2SLS estimates are displayed on the right.[15] We cannot test for over-identification (instrument validity) since the number of instruments equals the number of endogenous variables. In the first stage, the F-statistics are high (with two exceptions) and the Shea partial R-squared are far above zero. These test results suggest relevant instruments. In the weak instrument test, the Cragg–Donald statistic exceeds the critical value, which means that we reject the null of hypothesis that the relative bias of the 2SLS coefficient is more than 10 per cent of the OLS bias (with a risk of 5 per cent).

The signs and significance levels of the coefficient for natural openness support the hypothesis that a higher trade share stemming from geographical differences reduces air pollution. The coefficient for natural openness is negative and statistically significant at the 5 per cent level for all three air pollutants. Using sample means, the point estimates imply that the natural openness elasticity is −0.55 for NO_2, −0.56 for SO_2 and −0.12 for PM. Of particular interest, our natural openness elasticities are of similar magnitude to estimates of the trade intensity elasticity using trade intensity, GDP, income per capita, capital labor ratio and their interaction terms *à la* Antweiler *et al.* (2001).[16] In addition, the signs and significance levels for the remaining variables are as generally predicted: greater democracy

[15] An appendix that presents the first-stage regression results is available upon demand from the authors.

[16] For instance, Antweiler *et al.* (2001) estimate a trade intensity elasticity of −0.39 to −0.88 for SO_2 (table 1), while Cole and Elliot (2003) estimate −0.56 for NO_2 and −0.36 for SO_2 (table 6). However, Kellenberg (2008) splits his samples along income lines and estimates a trade intensity elasticity of −1.02 for NO_x and −1.41 for SO_2 for middle-income countries, but positive trade intensity elasticities for

Table 2b. *Correlation matrix of trade openness measures*

	Trade share	*Natural openness*	*Policy-ind. openness*	*Import duty ratio*	*Export duty ratio*	*Black mkt. Premium*	*Sachs–Warner*	*Heritage*	*Fraser*	*Dollar*
Trade share	1.00									
Natural openness	0.83	1.00								
Policy-induced openness	0.46	0.31	1.00							
Import duty	−0.27	−0.23	−0.56	1.00						
Export duty	−0.17	−0.10	−0.50	0.09	1.00					
Black market premium	−0.08	0.01	−0.37	0.24	0.12	1.00				
Sachs–Warner Openness	0.28	0.25	0.65	−0.68	−0.13	−0.41	1.00			
Heritage Trade Freedom	0.24	0.20	0.63	−0.75	−0.29	−0.21	0.64	1.00		
Fraser Freedom to Exchange	0.41	0.25	0.97	−0.65	−0.40	−0.51	0.74	0.66	1.00	
Dollar RER index	−0.10	−0.04	−0.28	0.10	0.26	0.11	−0.27	−0.30	−0.25	1.00

Table 3. *Natural openness and air pollution*

	OLS			*2SLS*		
	NO_2	SO_2	*PM*	NO_2	SO_2	*PM*
Natural openness	−0.46**	−0.32***	−0.22**	−0.49**	−0.32***	−0.21**
	(−2.35)	(−3.23)	(−2.67)	(−2.37)	(−3.11)	(−2.18)
ln(*real GDP per capita*)	332.33***	253.09*	142.43	531.16***	390.51*	68.56
	(2.93)	(1.97)	(1.34)	(2.88)	(1.86)	(0.60)
[ln(*real GDP per capita*)]^2	−17.11***	−13.80*	−8.22	−27.75***	−21.03*	−4.36
	(−2.79)	(−1.99)	(−1.46)	(−2.90)	(−1.90)	(−0.73)
Polity	−3.27**	−5.98***	−2.88**	−3.69**	−6.27***	−2.47**
	(−2.68)	(−2.73)	(−2.06)	(−2.76)	(−2.91)	(−1.97)
ln(*area per capita*)	−3.06	−0.69	−4.60**	−3.82	−1.15	−4.33**
	(−0.64)	(−0.36)	(−2.22)	(−0.81)	(−0.71)	(−2.45)
R-squared	0.15	0.64	0.54	0.13	0.63	0.53
Hansen *J*-test				–	–	–
Number of observations	35	40	45	35	40	45
Number of instruments				3	3	3
First-stage statistics						
F-statistic for *Natural openness*				116.5	133.5	153.4
F-statistic for *GDP*				57.5	50.6	60.0
F-statistic for *GDP*^{2}				56.7	51.9	63.1
Shea partial *R* for *Natural openness*				0.88	0.88	0.89
Shea partial *R* for *GDP*				0.86	0.76	0.78
Shea partial *R* for *GDP*^{2}				0.86	0.76	0.79
Weak instrument test						
Cragg–Donald statistic				29.7	22.8	31.2
Critical value				4.2	4.2	4.2

Notes: The dependent variable is listed on the top. Each equation is estimated using OLS and 2SLS. Robust *t*-statistics are in parentheses. ***, ** and * indicate significance at the 1, 5, and 10% level of confidence, respectively.

For 2SLS, the trade share, real GDP per capita and real GDP per capita squared are instrumented with fitted trade share, predicted real GDP per capita and predicted real GDP per capita squared. The Hansen *J*-test is the *p*-value of a test of exogeneity of the instruments. For the weak instrument test, a Cragg–Donald statistic in excess of the critical value indicates that a standard significance with nominal size of 5% has a maximal size of 10%.

low- and high-income countries. Similarly, Managi *et al.* (2009) split their sample between developing and OECD countries and estimate a short- and long-run trade intensity elasticity of −0.15 and −2.23 for OECD countries, but a positive short- and long-run trade intensity elasticity for developing countries.

Table 4. *Natural openness, policy-induced openness and air pollution*

	OLS			*2SLS*		
	NO_2	*SO_2*	*PM*	*NO_2*	*SO_2*	*PM*
Natural openness	−0.42**	−0.26***	−0.20**	−0.48**	−0.28***	−0.20**
	(−2.37)	(−4.34)	(−2.66)	(−2.62)	(−4.59)	(−2.31)
Policy-induced openness	−0.04	−0.04**	−0.02	−0.04*	−0.06**	−0.01
	(−1.54)	(−2.35)	(−1.09)	(−1.72)	(−2.60)	(−0.68)
ln(*real GDP per capita*)	270.07**	190.58*	124.83	454.24**	299.04**	51.36
	(2.14)	(1.98)	(1.08)	(2.38)	(1.96)	(1.42)
[ln(*real GDP per capita*)]^2	−12.87*	−9.58*	−6.90	−22.70**	−14.90*	−3.20
	(−1.78)	(−1.84)	(−1.11)	(−2.24)	(−1.88)	(−1.48)
Polity	−4.21***	−6.12***	−3.02**	−4.66***	−6.58***	−2.54**
	(−3.22)	(−2.89)	(−2.09)	(−3.26)	(−3.31)	(−2.00)
ln(*area per capita*)	−5.66	−3.85***	−6.02***	−6.25	−5.26**	−5.20***
	(−0.92)	(−3.46)	(−2.65)	(−1.16)	(−3.35)	(−2.63)
R-squared	0.20	0.71	0.56	0.18	0.69	0.54
Hansen J-test				(0.79)	(0.35)	(0.41)
Number of observations	35	40	45	35	40	45
Number of instruments				4	4	4
First-stage statistics						
F-statistic for *Natural openness*				105.7	121.2	141.2
F-statistic for *GDP*				29.5	30.4	38.0
F-statistic for *GDP*^{2}				29.3	31.5	39.9
Shea partial R for *Natural openness*				0.89	0.90	0.90
Shea partial R for *GDP*				0.84	0.76	0.78
Shea partial R for *GDP*^{2}				0.83	0.77	0.79
Weak instrument test						
Cragg–Donald statistic				14.9	18.0	23.7
Critical value				10.0	10.0	10.0

Notes: The dependent variable is listed on the top. Each equation is estimated using OLS and 2SLS. Robust t-statistics are in parentheses. ***, ** and * indicate significance at the 1, 5, and 10% level of confidence, respectively.

For 2SLS, natural openness, real GDP per capita and real GDP per capita squared are instrumented with lagged natural openness, fitted trade share, predicted real GDP per capita and predicted real GDP per capita squared. The Hansen J-test is the p-value of a test of exogeneity of the instruments. For the weak instrument test, a Cragg–Donald statistic in excess of the critical value indicates that a standard significance with nominal size of 5% has a maximal size of 10%.

decreases all three air pollutants, there is an estimated EKC for NO_2 and SO_2, and greater congestion in the form of a higher area per capita increases PM concentrations.

The remainder of the paper estimates the individual impacts of natural openness and trade policy. Table 4 begins by including policy-induced openness. The Hansen J-test fails to reject the null of exogeneity, indicating

Table 5. *Natural openness, trade policy indicators and air pollution*

	2SLS			*2SLS*		
	NO_2	*SO_2*	*PM*	*NO_2*	*SO_2*	*PM*
Natural openness	−0.61***	−0.38***	−0.20***	−0.49**	−0.29***	−0.21**
	(−2.62)	(−4.29)	(−2.90)	(−2.38)	(−3.75)	(−2.41)
Import duties/Total imports	1.78	1.69**	1.52*			
	(1.24)	(2.25)	(1.93)			
Export duties/Total exports	−3.41	−30.30***	−3.52**			
	(−0.56)	(−4.46)	(−2.19)			
ln(*black market premium*)				7.00	27.04*	−20.91
				(0.37)	(1.82)	(−1.52)
ln(*real GDP per capita*)	754.17**	664.32***	12.39	518.96***	218.63**	156.97
	(2.55)	(3.82)	(0.12)	(2.65)	(2.02)	(1.33)
[ln(*real GDP per capita*)]^2	−38.58**	−35.20***	−0.93	−27.06***	−11.89**	−9.08
	(−2.57)	(−3.90)	(−0.17)	(−2.65)	(−2.02)	(−1.44)
Polity	−5.53***	−6.44***	−2.61*	−3.65***	−4.63***	−3.53***
	(−2.27)	(−5.17)	(−1.94)	(−2.79)	(−3.94)	(−2.56)
ln(*area per capita*)	−4.64	−2.92*	−4.28***	−3.92	−1.91	−3.51**
	(−0.97)	(−1.80)	(−3.21)	(−0.85)	(−1.27)	(−1.95)
R-squared	0.11	0.75	0.63	0.13	0.78	0.53
Hansen J-test	(0.95)	(0.89)	(0.12)	(0.66)	(0.38)	(0.71)
Number of observations	35	40	45	35	40	45

Notes: The dependent variable is listed on the top. Each equation is estimated using 2SLS. Robust t-statistics are in parentheses. ***, ** and * indicate significance at the 1, 5, and 10% level of confidence, respectively. Natural openness, import duty share, export duty share, black market premium, real GDP per capita and real GDP per capita squared are instrumented with lagged natural openness, lagged import duty share, lagged export duty share, lagged black market premium, fitted trade share, predicted real GDP per capita and predicted real GDP per capita squared. The Hansen J-test is the p-value of a test of exogeneity of the instruments.

instrument validity. As before, the highly significant first-stage F-statistics and high Shea partial R-squared indicate that the instruments are correlated with the endogenous variables. In addition, the Cragg–Donald statistics are above the critical value and thus the instruments are strong.

The results show that natural openness reduces all three pollutants, while policy-induced openness decreases NO_2 and SO_2. The coefficients for natural openness imply a natural openness elasticity of −0.50 for NO_2 and SO_2 and −0.11 for PM. Similarly, the coefficients for policy-induced openness imply a trade policy elasticity of −0.35 for NO_2 and −0.91 for SO_2, but an insignificant trade policy elasticity for PM.

Table 5 uses trade policy indicators to measure trade policy. Once again, natural openness reduces all three air pollutants with elasticities of −0.50 and −0.11. The impact of trade policy, however, is uneven. On the one

https://doi.org/10.1017/S1355770X11000271 Published online by Cambridge University Press

Table 6a. *Natural openness, trade policy indices and air pollution*

	2SLS			*2SLS*		
	NO_2	SO_2	*PM*	NO_2	SO_2	*PM*
Natural openness	−0.49**	−0.30***	−0.22**	−0.49**	−0.29***	−0.18**
	(−2.34)	(−2.76)	(−2.52)	(−2.40)	(−2.77)	(−1.98)
Sachs−Warner Openness	−11.96	−96.93*	23.47			
	(−0.19)	(−1.90)	(0.96)			
Heritage Trade Freedom				6.55	−56.33	−36.75
				(0.11)	(−0.70)	(−0.29)
R-squared	0.13	0.67	0.45	0.13	0.61	0.56
Hansen J-test	(0.68)	(0.33)	(0.46)	(0.66)	(0.27)	(0.38)
Number of observations	35	40	45	35	40	45

Table 6b. *Natural openness, trade policy indices and air pollution*

	2SLS			*2SLS*		
	NO_2	SO_2	*PM*	NO_2	SO_2	*PM*
Natural openness	−0.83**	−0.45***	−0.35**	−0.52***	−0.31***	−0.20**
	(−3.02)	(−3.18)	(−2.37)	(−2.61)	(−4.29)	(−2.27)
Dollar: RER distortion	−169.01	−59.84	−36.65			
	(−1.04)	(−0.73)	(−0.43)			
Fraser Freedom to Exchange				−154.63*	−235.91***	−14.26
				(−1.65)	(−3.87)	(−0.29)
R-squared	0.20	0.61	0.52	0.18	0.72	0.54
Hansen J-test	(0.70)	(0.44)	(0.44)	(0.63)	(0.40)	(0.34)
Number of observations	27	32	37	35	40	45

Notes: The dependent variable is listed on the top. Each equation is estimated using 2SLS. Robust t-statistics are in parentheses. ***, ** and * indicate significance at the 1, 5, and 10% level of confidence, respectively. Natural openness, trade policy, real GDP per capita and real GDP per capita squared are instrumented with lagged natural openness, lagged trade policy, fitted trade share, predicted real GDP per capita and predicted real GDP per capita squared. The Hansen J-test is the p-value of a test of exogeneity of the instruments.

hand, higher import duty rates raise SO_2 and PM emissions, while a higher black market premium increases SO_2 concentrations. On the other hand, higher export duty rates reduce SO_2 and PM emission, while a higher black market premium lowers PM concentrations.

Tables 6a and 6b include the three trade policy indices (Sachs–Warner, Heritage and Fraser) and the price deviation measure (Dollar RER deviation) one at a time. Regardless of which trade policy measure is used, natural openness is found to reduce concentrations of all three air pollutions. With regards to trade policy, trade liberalization in the Sachs–Warner

Table 7a. *Natural openness, trade policy, environmental policy, and air pollution*

	2SLS			2SLS		
	NO_2	SO_2	PM	NO_2	SO_2	PM
Natural openness	−0.53**	−0.34***	−0.18*	−0.66*	−0.16**	−0.08
	(−2.08)	(−2.92)	(−1.65)	(−1.72)	(−2.14)	(−1.38)
Fraser Freedom to Exchange	−147.93	−220.36***	−30.11	−40.61	−31.63	−14.56
	(−1.53)	(−3.89)	(−0.65)	(−0.37)	(−0.59)	(−0.33)
Domestic Environmental Policy Stringency index	−44.61	−50.04	40.34			
	(−0.91)	(−1.46)	(1.28)			
Environmental tax				6.71*	2.18**	0.69
				(1.78)	(2.51)	(0.57)
R-squared	0.19	0.73	0.56	0.20	0.82	0.62
Hansen J-test	(0.79)	(0.50)	(0.26)	(0.48)	(0.37)	(0.38)
Number of observations	34	39	44	27	28	28

Table 7b. *Natural openness, trade policy, pollution abatement policy, and air pollution*

	2SLS			2SLS		
	NO_2	SO_2	PM	NO_2	SO_2	NO_2
Natural openness	−0.54	−0.12**	−0.06	−0.51**	−0.31***	−0.60***
	(−1.54)	(−2.04)	(−1.25)	(−2.30)	(−5.14)	(−2.07)
Fraser Freedom to Exchange	−84.46	−34.03	−51.72	−153.58	−101.62	−100.07
	(−0.80)	(−0.80)	(−1.62)	(−1.10)	(−1.51)	(−0.75)
Pollution abatement and control expenditures	7.74	−14.82**	3.42			
	(0.39)	(−2.25)	(0.59)			
NO_X regulation				0.41		
				(0.02)		
SO_2 regulation					9.65	
					(0.65)	
NO_X strict regulation						23.65
						(0.96)
R-squared	0.04	0.82	0.70	0.15	0.40	0.17
Hansen J-test	(0.83)	(0.30)	(0.11)	(0.49)	(0.27)	(0.17)
Number of observations	25	26	26	32	34	32

Notes: The dependent variable is listed on the top. Each equation is estimated using 2SLS. Robust t-statistics are in parentheses. ***, ** and * indicate significance at the 1, 5, and 10% level of confidence, respectively. Natural openness, trade policy, real GDP per capita and real GDP per capita squared are instrumented with lagged natural openness, lagged trade policy, fitted trade share, predicted real GDP per capita and predicted real GDP per capita squared. The Hansen J-test is the p-value of a test of exogeneity of the instruments.

https://doi.org/10.1017/S1355770X11000271 Published online by Cambridge University Press

and Fraser indices lower SO_2 levels, while trade liberalization in the Fraser index lowers NO_2 concentrations. Neither the Heritage Trade Freedom index nor the Dollar RER index had a significant impact on any pollutant. Although some of the mixed results can be partially attributed to measurement error in the trade policy variables, the overall message in tables 5 and 6 is that trade policy has very little impact on air pollution.

Domestic environmental policies play a critical role in determining environmental outcomes and also in linking trade to the environment. Therefore, some of the estimated impact of natural trade and/or the lack of impact of trade policy could be a byproduct of domestic environmental policy. To test for this possibility, we add a measure of domestic environmental policy or pollution abatement policy. The environmental policy measures are *Domestic Environmental Stringency index* (CIESIN and YCELP, 2010) and *Environmental tax* (OECD, 2008). The pollution abatement policies are *Pollution abatement and control expenditures* (OECD, 2008) and restrictions on coal-fired power plants (Lovely and Popp, 2011). Note that the *Environmental tax* and *Pollution abatement and control expenditures* data are available only for OECD countries and thus reduce our sample size. These environmental policy measures have been used before and are described in appendix A.

Tables 7a and 7b show the results for natural openness, trade policy and environmental policy. In controlling for differences in environmental policy in general and pollution abatement policies in particular, natural openness continues to lead to decreases in all three air pollutants. The coefficient for natural openness is negative in each regression and significant at 10 per cent in most instances. Moreover, the fall in significance of natural openness with *Environmental tax* and *Pollution abatement and control expenditures* can be at least partially attributed to the reduction in the sample size.

5. Conclusions

In this paper, we examined the individual effects of natural openness and trade policy on air pollution. We posited that natural openness is more likely to have beneficial effects than trade policy due to differences in theoretical trade costs, empirical importance and strategic link to environmental policy. We then found that natural openness reduces air pollution, while trade-policy openness has a limited impact on the environment.

There are two important limitations of our study. First, our small sample size reduces the power of our statistical tests and raises the possibly of influential outliers. Second, the use of our reduced-form equation (3) prevents us from acquiring individual estimates of trade-induced scale, composition and technique effects.

Nevertheless, our results indicate that 'natural' geographic and endowment differences play a more important role than deliberate trade policy decisions in explaining the trade and environment link. With regards to trade costs, our results suggest that reductions in transportation, distribution and export entry costs and not trade policy itself are behind the environmental benefits of trade openness. We do not interpret this to mean that the liberalization of trade policy has no impact or should be abandoned. However, our results do suggest that some of the virtuous benefits of trade on the environment have already been realized by countries exploiting their natural geographic advantages in trade.

References

Anderson, J.E. and E. van Wincoop (2004), 'Trade costs', *Journal of Economic Literature* **42**(3): 691–751.

Antweiler, W., B.R. Copeland, and M.S. Taylor (2001), 'Is free trade good for the environment?' *American Economic Review* **91**(4): 877–908.

Arrow, K., B. Bolin, R. Costanza, P. Dasgupta, C. Folke, C.S. Holling, B.-O. Jansson, S. Levin, K.-G. Mäler, C. Perrings, and D. Pimentel (1995), 'Economic growth, carrying capacity, and the environment', *Science* **268**(5210): 520–521.

Barrett, S. (1994), 'Strategic environmental policy and international trade', *Journal of Public Economics* **54**(3): 325–338.

Barrett, S. and K. Graddy (2000), 'Freedom, growth, and the environment', *Environment and Development Economics* **5**(4): 433–456.

Barro, R.J. and J.-W. Lee (1994), 'Sources of economic growth', *Carnegie-Rochester Conference Series on Public Policy* **40**(1): 1–46.

Berg, A. and A. Krueger (2003), 'Trade, growth, and poverty: a selective survey', IMF Working Paper WP/03/30, International Monetary Fund, Washington, DC.

Bernard, A. and J.B. Jensen (2004), 'Why some firms export', *Review of Economics and Statistics* **86**(2): 561–569.

CIESIN (Center for International Earth Science Information Network) and YCELP (Yale University Centre for Environmental Law and Policy) (2010), *Environmental Performance Index*, [Available at] http://sedac.ciesin.columbia.edu/es/epi/index.html.

Cole, M.A. (2004), 'Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages', *Ecological Economics* **48**(1): 71–81.

Cole, M.A. and R.J.R. Elliott (2003), 'Determining the trade-environment composition effect: the role of capital, labor and environmental regulations', *Journal of Environmental Economics and Management* **46**(3): 363–383.

Copeland, M.S. (2000), 'Trade and environment: policy linkages', *Environment and Development Economics* **5**(4): 405–432.

Copeland, B.R. and M.S. Taylor (2004), 'Trade, growth and the environment', *Journal of Economic Literature* **42**(1): 7–71.

Das, S., M.J. Roberts, and J.R. Tybout (2007), 'Market entry costs, producer heterogeneity, and export dynamics', *Econometrica* **75**(3): 837–873.

Dasgupta, S., A. Mody, S. Roy, and D. Wheeler (2001), 'Environmental regulation and development: a cross-country empirical analysis', *Oxford Development Studies* **29**(2): 173–187.

Dollar, D. (1992), 'Outward-oriented developing economies really do grow more rapidly: evidence from 95 LDCs (1976–1985)', *Economic Development and Cultural Change* **40**(3): 523–544.

Easterly, W. (2005), 'National policies and economic growth: a reappraisal', in P. Aghion and S. Durlauf (eds), *Handbook of Economic Growth*, Amsterdam: Elsevier, pp. 1015–1059.

Easterly, W. and R. Levine (2001), 'It's not factor accumulation: stylized facts and growth models', *World Bank Economic Review* **15**(2): 177–219.

Eaton, J., S. Kortum, and F. Kramarz (2004), 'Dissecting trade: firms, industries, and export destinations', *American Economic Review Papers and Proceedings* **94**(2): 150–154.

Ederington, J. (2001), 'International coordination of trade and domestic policies', *American Economic Review* **91**(5): 1580–1593.
Edwards, S. (1998), 'Openness, productivity and growth: what do we really know?', *The Economic Journal* **108**(447): 383–398.
Esty, D.C. and B.S. Gentry (1997), 'Foreign investment, globalization, and the environment', in T. Jones (ed.), *Globalization and Environment: Preliminary Perspectives*, Paris: OECD, pp. 141–197.
Frankel, J.A. (2008), 'Global environmental policy and global trade policy', John F. Kennedy School of Government Faculty Research Working Paper Series No. RWP08-058, Harvard University, Cambridge, MA.
Frankel, J.A. and D. Romer (1999), 'Does trade cause growth?', *American Economic Review* **89**(3): 379–399.
Frankel, J.A. and A.K. Rose (2005), 'Is trade good or bad for the environment? Sorting out the causality', *Review of Economics and Statistics* **87**(1): 85–91.
Grossman, G.M. and A.B. Krueger (1993), 'Environmental impacts of a North American Free Trade Agreement', in P.M. Garber (ed.), *The U.S.–Mexico Free Trade Agreement*, Cambridge, MA: MIT Press, pp. 13–56.
Gwartney, J., R. Lawson, and W. Block (1996), *Economic Freedom of the World: 1975–1995*, Vancouver: Fraser Institute.
Harbaugh, W.T., A. Levinson, and D.M. Wilson (2002), 'Reexamining the empirical evidence for an environmental Kuznets curve', *Review of Economics and Statistics* **84**(3): 541–551.
Hummels, D. (1999), 'Toward a geography of trade costs', Global Trade Analysis Project Working Paper No. 17, Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University, West Lafayette, IN.
Hummels, D. (2010), 'Transportation costs and adjustments to trade', in B. Hoekman and G. Porto (eds), *Trade Adjustment Costs in Developing Countries: Impacts, Determinants and Policy Responses*, London: Centre for Economic Policy Research, pp. 255–264.
Hummels, D. and A. Skiba (2004), 'Shipping the good apples out? An empirical confirmation of the Alchian–Allen conjecture', Journal of Political Economy **112**(6): 1384–1402.
Hummels, D., Lugovskyy, V. and A. Skiba (2009), 'The trade reducing effects of market power in international shipping', *Journal of Development Economics* **89**(1): 84–97.
Johnson, B.T. and T.P. Sheehy (1996), *1996 Index of Economic Freedom*, Washington, DC: Heritage Foundation.
Kellenberg, D.K. (2008), 'A reexamination of the role of income for the trade and environment debate', *Ecological Economics* **68**(1–2): 106–115.
Kennedy, P.W. (1994), 'Equilibrium pollution taxes in open economies with imperfect competition', *Journal of Environmental Economics and Management* **27**(1): 49–63.
Krugman, P.R. (1980), 'Scale economies, product differentiation, and the pattern of trade', *American Economic Review* **70**(5): 950–959.
Leamer, E. (1988), 'Measures of openness', in R. Baldwin (ed.), *Trade Policy Issues and Empirical Analysis*, Chicago: University of Chicago Press, pp. 145–204.
Lovely, M. and D. Popp (2011), 'Trade, technology, and the environment: does access to technology promote environmental regulation?', *Journal of Environmental Economics and Management* **61**(1): 16–35.
Lucas, R.E.B., D. Wheeler, and H. Hettige (1992), 'Economic development, environmental regulation and the international migration of toxic industrial pollution: 1960–88', World Bank Policy Research Discussion Paper WPS 1062, World Bank, Washington, DC.

Managi, S., A. Hibiki, and T. Tsurumi (2009), 'Does trade openness improve environmental quality?', *Journal of Environmental Economics and Management* **58**(3): 346–363.

Medin, H. (2002), 'Firms' export decisions – fixed trade costs and the size of the export market', *Journal of International Economics* **61**(1): 225–241.

Nogues, J., A. Olechowski, and A. Winters (1986), 'The extent of non-tariff barriers to industrial countries' imports', *World Bank Economic Review* **1**(1): 181–199.

OECD (2008), *Environmental Data Compendium 2006–2008*, Danvers, MA: OECD Publishing.

Porter, M. (1991), 'America's green strategy', *Scientific American* **264**(4): 168.

Pritchett, L. (1996), 'Measuring outward orientation in LDCs: can it be done?' *Journal of Development Economics* **49**(2): 307–335.

Rodriguez, F. and D. Rodrik (2001), 'Trade policy and economic growth: a skeptic's guide to the cross-national evidence', in B. Bernanke and K. Rogoff (eds), *Macroeconomics Annual 2000*, Cambridge MA: MIT Press for NBER, pp. 261–324.

Rose, A.K. (2004), 'Do WTO members have more liberal trade policy?' *Journal of International Economics* **63**(2): 209–235.

Sachs, J.D. and A.M. Warner (1995), 'Economic reform and the process of global integration', *Brookings Papers on Economic Activity* **1995**(1): 1–118.

Samuelson, P.A. (1954), 'The transfer problem and transport costs II: analysis of effects of trade impediments', *Economic Journal* **64**(254): 264–289.

Shafik, N. and S. Bandyopadhyay (1992), 'Economic growth and environmental quality: time-series and cross-country evidence', World Bank Policy Research Discussion Paper WPS 904, World Bank, Washington, DC.

Shea, J. (1997), 'Instrument relevance in multivariate linear models: a simple measure', *Review of Economics and Statistics* **79**(2): 348–352.

Spilimbergo, A., J.L. Londoño, and M. Székely (1999), 'Income distribution, factor endowments, and trade openness', *Journal of Development Economics* **59**(1): 77–101.

Stock, J.H. and H. Yogo (2005), 'Testing for weak instruments in linear IV regression', in J.H. Stock and D.W.K. Andrews (eds), *Identification and Inference for Econometric Models: A Festschrift in Honor of Thomas Rothenberg*, Cambridge, UK: Cambridge University Press, pp. 80–108.

Stock, J.H., J.H. Wright, and M. Yogo (2002), 'A survey of weak instruments and weak identification in generalized method of moments', *Journal of Business and Economic Statistics* **20**(4): 518–529.

Venables, A.J. (1994), 'Integration and the export behavior of firms – trade costs, trade volume and welfare', *Weltwirtschaftliches Archiv* **130**(1): 118–132.

Wacziarg, R. (2001), 'Measuring the dynamic gains from trade', *World Bank Economic Review* **15**(3): 393–429.

Wacziarg, R. and Welch, K.H. (2008), 'Trade liberalization and growth: new evidence', *The World Bank Economic Review* **22**(2): 187–231.

Wei, S.-J. (2000), 'Natural openness and good governance', National Bureau of Economic Research Working Paper No. 7765, National Bureau of Economic Research, Cambridge, MA.

Wolf, H.C. (1993), 'Trade orientation: measurement and consequences', *Estudios de Economia* **20**(esp): 49–86.

World Bank (2010), *World Development Indicators*, Washington, DC: World Bank.

Appendix A

Variable	*Units*	*Years for RHS*	*Years for instruments*	*Source*
Air pollution variables				
Nitrogen dioxide (NO_2)	$\mu g/m^3$	1995–2001		WDI
Sulfur dioxide (SO_2)	ibid.	1995–2001		WDI
Particular matter (PM)	ibid.	1995–2001		WDI
Trade variables				
Trade share	percentage	1990–1995	1985	PWT
Import duties/Total imports	ibid.	1985–1995	1980–1985	WDI
Export duties/Total exports	ibid.	1985–1995	1980–1985	WDI
ln(*black market premium*)	ln(1 + bmp)	1985–1995	1980–1985	Global Development Network
Sachs–Warner Openness	(0,1)	1985–1995	1980–1985	Wacziarg and Welsch (2008)
Heritage Trade Freedom	0–1	1995–1998	N/A	Heritage Foundation
Fraser Freedom to Exchange	0–1	1985–1995	1980–1985	Fraser Institute
Dollar RER distortion index	0–1	1990	N/A	Rose (2004)
Economic variables				
Real GDP per capita	real US$ per person	1995	1970	PWT
Polity	–10 to +10	1995		Polity IV Project
Area per capita	km^2 per person	1995		CIA World Factbook and World Development Indicators
Population	millions		1970	WDI
Trade share	percentage		1970–1995	PWT
Investment/GDP	ibid.		1970–1995	PWT
Population growth	ibid.		1970–1995	WDI
Primary school enrollment	ibid.		1970–1995	Frankel and Rose (2005)

(*continued*)

Appendix A. *Continued*

Variable	*Units*	*Years for RHS*	*Years for instruments*	*Source*
Secondary school enrollment	ibid.		1970–1995	Frankel and Rose (2005)
Geography, language and endowment variables				
Population	millions	1990–1995	1970–1975	WDI
Remoteness	percentage	1970	1970	Constructed
Landlocked	(0,1)			CIA World Factbook
Island	(0,1)			CIA World Factbook
Coastal length/Surface area	km per km^2			Global Environment Outlook and CIA World Factbook
English language	(0,1)			CIA World Factbook
French language	(0,1)			CIA World Factbook
Spanish language	(0,1)			CIA World Factbook
K/L	real US$ per worker	1970	1970	Easterly and Levine (2001)
Secondary schooling attainment in 15+ year-old pop	percentage	1970	1970	Barro and Lee (1994)
Area per capita	km^2 per person	1970	1970	CIA World Factbook and World Development Indicators
Oil producer	(0,1)			CIA World Factbook
Environmental policy variables				
Domestic environmental policy	0–1	2001		CIESEN
Environmental tax (% of GDP)	percentage	1994–1995		OECD (2008)
Pollution abatement and control expenditures (% of GDP)	percentage	1990–1999		OECD (2008)

(*continued*)

https://doi.org/10.1017/S1355770X11000271 Published online by Cambridge University Press

Appendix A. *Continued*

Variable	*Units*	*Years for RHS*	*Years for instruments*	*Source*
NO_X *regulation*	(0,1)	1995		Lovely and Popp (2011)
SO_2 *regulation*	(0,1)	1995		Ibid.
NO_X *strict regulation*	(0,1)	1995		Ibid.

Notes: WDI, World Development Indicators; PWI, Penn World Tables 6.2.

Appendix B

Country	NO_2	SO_2	*PM*	*Trade share*	*Real GDP*
Argentina	97.0	–	97.0	15.8	4,706
Australia	24.5	11.0	44.7	34.6	14,445
Austria	42.0	14.0	47.0	76.1	12,695
Belgium	48.0	20.0	78.0	143.4	13,232
Brazil	83.0	86.0	112.5	15.4	4,042
Canada	40.7	13.7	33.0	52.6	17,173
Chile	81.0	29.0	–	60.0	4,338
China	68.8	112.6	368.9	23.7	1,324
Colombia	–	–	120.0	30.7	3,300
Denmark	54.0	7.0	61.0	65.3	13,909
Ecuador	–	23.0	151.0	54.5	2,755
Egypt	–	69.0	–	54.8	1,912
Finland	35.0	4.0	40.0	51.4	14,059
France	57.0	14.0	14.0	43.8	13,904
Germany	41.3	12.3	43.7	56.5	14,628
Ghana	–	–	137.0	37.0	902
Greece	64.0	34.0	178.0	54.6	6,768
Hungary	51.0	39.0	63.0	73.1	5,357
Iceland	42.0	5.0	24.0	71.6	13,362
India	24.6	23.3	277.2	16.4	1,264
Indonesia	–	–	271.0	46.1	1,974
Iran	–	209.0	248.0	17.4	3,392
Ireland	–	20.0	–	114.4	9,274
Italy	248.0	31.0	100.3	40.6	12,488
Japan	48.0	45.7	46.0	20.1	14,331
Kenya	–	–	69.0	51.8	911
Korea, South	57.7	61.7	83.3	68.9	6,673
Malaysia	–	24.0	85.0	124.1	5,124
Mexico	130.0	74.0	279.0	30.9	5,827
Netherlands	58.0	10.0	40.0	104.1	13,029
New Zealand	20.0	3.0	26.0	55.7	11,513
Norway	43.0	8.0	15.0	78.9	14,902

(*continued*)

https://doi.org/10.1017/S1355770X11000271 Published online by Cambridge University Press

Appendix B. *Continued*

Country	NO_2	SO_2	*PM*	*Trade share*	*Real GDP*
Philippines	–	33.0	200.0	53.8	1,763
Poland	51.3	40.0	–	38.8	3,820
Portugal	52.0	8.0	61.0	74.0	7,478
Singapore	30.0	20.0	–	348.7	11,710
South Africa	51.5	23.7	–	52.1	3,248
Spain	34.0	11.0	79.5	39.2	9,583
Sweden	29.0	5.0	9.0	63.4	14,762
Switzerland	39.0	11.0	31.0	73.6	16,505
Thailand	23.0	11.0	223.0	62.9	3,580
Turkey	46.0	87.5	57.0	43.2	3,741
United Kingdom	57.0	20.0	–	52.3	13,217
United States	70.0	16.3	–	19.7	18,054
Venezuela	57.0	33.0	53.0	47.9	6,055
Average	*57.1*	*33.1*	*104.5*	*61.2*	*8,378*

https://doi.org/10.1017/S1355770X11000271 Published online by Cambridge University Press