RIETI Discussion Paper Series 08-E-013

Does Trade Liberalization Reduce Pollution Emissions?

MANAGI Shunsuke
Yokohama National University

HIBIKI Akira
National Institute for Environmental Studies, Japan

TSURUMI Tetsuya
Yokohama National University

Research Institute of Economy, Trade & Industry, IAA

The Research Institute of Economy, Trade and Industry
http://www.rieti.go.jp/en/

Does Trade Liberalization Reduce Pollution Emissions?

Shunsuke Managi[1]*, Akira Hibiki[2] and Tetsuya Tsurumi[1]

[1] Faculty of Business Administration, Yokohama National University
79-4, Tokiwadai, Hodogaya-ku, Yokohama 240-8501 Japan
Tel. 81- 45-339-3751/ Fax: 81- 45-339-3707
*Corresponding author (managi@ynu.ac.jp)

[2] Social Environmental Systems Division, National Institute for Environmental Studies, Japan

RHH: MANAGI, HIBIKI & TSURUMI: TRADE AND ENVIRONMENT

*** Note: This is a revised version that replaces the original paper published May 2008***

Abstract

The literature on trade openness, economic development, and the environment is largely inconclusive about the environmental consequences of trade. This study treats trade and income as endogenous and estimates the overall impact of trade openness on environmental quality using the instrumental variables technique. We find the impact is large in the long term, after the dynamic adjustment process, although it is small in the short term. Trade is found to benefit the environment in OECD countries. It has detrimental effects, however, on sulfur dioxide (SO_2) and carbon dioxide (CO_2) emissions in non-OECD countries, although it does lower biochemical oxygen demand (BOD) emissions in these countries. Finally, trade openness influences emissions through the environmental regulation effect and capital labor effect. We find that the former effect is likely to be larger than the latter effect for all pollutants.

JEL. F18; O13; L60; L50

Keywords: Trade Openness; Composition Effect; Scale Effect, Technique Effect; Environment; Comparative Advantage; Environmental Regulations Effect.

1. Introduction

The environmental effect of trade openness has been one of the most important questions in trade policy for the past 10 years (see Copeland and Taylor, 2005; Taylor, 2004). Empirical studies on the relationship between international trade openness and environmental quality have been accumulating (see, e.g., Antweiler *et al*., 2001; Harbaugh *et al*., 2002; Cole and Elliott, 2003; Frankel and Rose, 2005). However, there are very few empirical studies on the determinants of emissions based on the theoretical framework.

Antweiler *et al*. (2001) first provide the theoretical framework to empirically explore the determinants of emissions and to successfully decompose them into scale, technique, and composition effects. The scale effect refers to the effect of an increase in production (e.g., GDP) on emissions. The technique effect indicates the negative impact of income on emission intensity. This refers to the effect of more stringent environmental regulations, which promote the employment of more environmentally-friendly production methods and which are put in place as additional income increases the demand for a better environment. The composition effect explains how emissions are affected by the composition of output (*i.e.*, the structure of the industry), which is determined by the degree of trade openness as well as by the comparative advantage of the country. This effect could be positive or negative, depending on the country's resource abundance and the strength of its environmental policy. These are called the capital–labor effect (KLE) and the environmental regulation effect (ERE), respectively[1].

[1] Countries where the capital-labor ratio is relatively high are expected to have a comparative advantage in capital-intensive goods (i.e., pollution goods) and thus, to produce more emissions. Trade openness would strengthen the effects of this comparative advantage and of any

Since trade openness could increase production and income, it affects emissions through the scale effect and the technique effect (Antweiler et al., 2001). Hereafter, we call these effects the trade-induced scale effect and the trade-induced technique effect. Antweiler *et al*. (2001) estimate how trade openness (increase in trade intensity) and GDP (or per capita income) affect pollution by using data on sulfur dioxide (SO_2) concentrations. They find that SO_2 concentrations increase as GDP rises (i.e., positive scale effect), decrease as per capita income rises (i.e., negative technique effect), and decrease as trade openness rises (i.e., negative composition effect). Similarly, Cole and Elliott (2003) analyze country-level emissions per capita of sulfur dioxide (SO_2), carbon dioxide (CO_2), nitrogen oxides (NO_x), and biochemical oxygen demand (BOD)) and estimate the net of the scale effect and the technique effect, and the composition effect[2].

---

between-country differences in environmental policy on the industrial structure. Therefore, more openness would increase the production share of the goods in which these countries have a comparative advantage (i.e., capital-intensive goods). On the other hand, trade openness would reduce the comparative advantage of capital-intensive goods in countries that have relatively strict environmental policies (i.e., higher income countries) while increasing the comparative advantage of such goods in countries with less stringent environmental regulations (*i.e.*, laxity is a source of comparative advantage). As a result, the production of capital-intensive goods under more (or less) stringent regulations decreases (increases), and the emissions decrease (increase). This is called the ERE, or, in other words, the pollution haven effect. The net effect of the composition effect as a result of trade openness could therefore be positive or negative, depending on the relative sizes of the KLE and the ERE (see Cole and Elliott, 2003).

[2] In Cole and Elliott (2003, 2006), the scale effect and the technique effect are not separated because real GDP per capita is used as a proxy for both production and per capita income level. Therefore, the net of the scale effect and the technique effect is estimated and named the scale-technique effect. In this study, we estimate the scale-technique effect following Cole and Elliott (2003, 2006). Hence, we call the net of the trade-induced scale effect and the trade-induced technique effect as the trade-induced scale-technique effect.

However, these previous studies do not consider the endogeneity problem and, therefore, do not treat the effect of trade openness on production or income explicitly. Therefore, the effects of trade openness on emissions via income and production changes (i.e., the trade-induced scale and technique effects) cannot be compared to the composition effect induced by trade. As a result, we cannot infer the overall environmental consequences of trade as a summation of these effects. For instance, in the case of Cole and Elliott's (2003) finding on SO_2 emissions, in which an increase in income reduces emissions (i.e., negative net scale and technique effects) while trade openness increases emissions (i.e., positive composition effects), we are not able to judge whether the overall sign of the effect of trade on emissions is positive or negative.

Furthermore, we need to note that an increase in income (or production) associated with trade openness might affect the composition effect. For example, the composition effect resulting from the ERE might be larger under more stringent policies. However, since the endogeneity of income is not considered in these previous studies, estimates of the composition effect induced by trade do not include this effect.

We also apply a dynamic model to consider an adjustment process. This is because it is important to clarify the short- and long-term effects of trade on the environment. Since the former studies do not consider the dynamic adjustment process, we must consider their results primarily to be short-term effects. This may explain why the effects of trade on the environment that they calculate are rather small.

In this study, we explore the short-term and the long-term overall effects of trade openness on emissions as well as decomposed effects, such as the trade-induced scale-technique effects and the trade-induced composition effects by extending the previous studies in the following ways: (1) we add the income equation to consider the effect of trade openness on real GDP per capita explicitly, and (2) we employ a dynamic model.

2. Model

2.1 Empirical Strategy

Antweiler *et al*. (2001) analyze SO_2 concentrations in 43 countries from 1971 to 1996. They find positive scale effects, negative technique effects, and negative trade-induced composition effects. Thus, since the technique effects dominate the scale effects on average, they conclude that trade openness is associated with reduced pollution. Similarly, Cole and Elliott (2003) and Cole (2006) analyze country-level emissions (SO_2, CO_2, NO_x, and BOD) and energy consumption per capita, and they estimate the scale-technique effects and composition effects. Their findings generally support those of Antweiler *et al*. (2001) for SO_2. The results suggest that greater openness reduces BOD emissions per capita but is likely to increase NO_x and CO_2 emissions and energy use.

These studies analyze how trade openness and income affect the environment. However, we are not able to find a causal relationship if we treat trade openness as exogenous[3]. Therefore, in addition to addressing the endogeneity of income, the endogeneity of trade needs to be modeled to analyze the consequences of trade for the environment (Copeland and Taylor, 2005; Frankel and Rose, 2005).

Frankel and Rose (2005) consider trade openness and income endogenously. They address the potential simultaneity of trade, environmental quality, and income by

[3] See Frankel and Romer (1999) and Noguer and Siscart (2005) for recent studies that treat trade as endogenous and that estimate the impact of trade on income using instrumental variables.

applying instrumental variables estimations using a gravity model of bilateral trade and endogenous growth from neoclassical growth equations. It should be noted that they do not derive these estimations from a theoretical model like Antweiler et al. (2001) and thus that they do not consider the decomposed effects. They estimate an environmental quality equation, a trade equation, and an income equation to test a causal relationship between trade and environmental outcomes. Using cross section data from 41 countries in 1990 and looking at the sign of the openness variable, they support the optimistic view that trade reduces sulfur dioxide emissions[4].

In this study, we use a larger and more globally representative sample, especially including more developing countries, of many local and global emissions than are reflected in previous studies. Panel data used in this study are the SO_2 and CO_2 emissions of 88 countries from 1973 to 2000 and the BOD emissions of 83 countries from 1980 to 2000.

In econometric models, serial correlation must be considered because the environmental and output dependent variables have relatively monotonic trends. However, previous studies of international trade and the environment do not control for this factor when analyzing panel data. It should be noted that a dynamic generalized method of moments (GMM) estimation of panel data applied to a dynamic model is useful both to correct for serial correlation and to analyze both short- and long-term effects of trade openness on the environment.

---

[4] Some of the variables used in Frankel and Rose (2005) are excluded from our estimated results in this paper because they are not statistically significant or because we are not able to explain the intuition behind the results regarding those variables. Instead, we follow the choice of variables from Cole and Elliott (2003). See also Chintrakarn and Millimet (2006) for another application where they analyze the causal effect of domestic state-level trade flows on toxic emissions in the US.

Improving the previous studies in several ways can produce a broader view of environmental consequences, and, therefore, we might come to different conclusions about the linkage between international trade and environmental quality.

2.2 Model

This study considers the endogeneity of trade openness and income and then estimates an environmental quality equation. Here, we only discuss the environmental quality equation. Equations of income and trade openness are discussed in Appendix A.

2.2.1 Environmental Quality Equation

This study employs a specification similar to that of Cole and Elliott (2003) under which the determinants of emissions can be decomposed into scale-technique and composition effects. Contrary to the study by Cole and Elliott (2003), a lagged term of the dependent variable and international protocol dummies are included. The lagged variable is intended to control for the effect of the dynamic process.

$$\begin{aligned} \ln E_{it} &= c_1 + \alpha_1 \ln E_{it-1} + \alpha_2 S_{it} + \alpha_3 S_{it}{}^2 + \alpha_4 (K/L)_{it} + \alpha_5 (K/L)_{it}{}^2 + \alpha_6 (K/L)_{it} \cdot S_{it} \\ &+ \alpha_7 T_{it} + \alpha_8 (RK/L)_{it} \cdot T_{it} + \alpha_9 (RK/L)_{it}{}^2 T_{it} \\ &+ \alpha_{10} RS_{it} \cdot T_{it} + \alpha_{11} RS_{it}{}^2 T_{it} + \alpha_{12} (RK/L)_{it} \cdot RS_{it} \cdot T_{it} + \alpha_{13} H_{it} + \alpha_{14} O_{it} + \varepsilon_{1it} \end{aligned}$$

$$\varepsilon_{1it} = \eta_{1i} + \nu_{1it}, \qquad (1)$$

where E_{it} denotes emissions (SO_2, CO_2, and BOD) per capita of country *i* in year *t* (for example, kilograms of sulfur dioxide per capita), and *S* is GDP per capita. GDP per capita and its quadratic are intended to capture the scale-technique effect. *T* is defined as the ratio of aggregate exports and imports to GDP, which, as in the growth literature, proxies trade openness (or trade intensity) (see, e.g., Antweiler *et al.*, 2001; Frankel and Rose, 2005) [5]; *K/L* denotes a country's capital–labor ratio; *RK/L* denotes a country's

---

[5] This study focuses on trade exposure rather than trade liberalization. See Ederington *et al.* (2004) for the direct impact of liberalization on polluting activities. They study the effect of reductions in

relative capital–labor ratio; *RS* is relative GDP per capita[6]; and ε_1 is an error term and consists of an individual country effect η_1 and a random disturbance ν_1. To address the dynamics, the lagged dependent variable is included in (1) (see Arellano and Bond, 1991).

We are able to interpret each term following Antweiler et al. (2001) and Cole and Elliott (2003). The third term, S_{it}, and the fourth term, S_{it}^2, on the right hand side in (1) reflect the effects of income and production on emissions. From this, we expect to estimate the scale-technique effect (Cole and Elliott, 2003). The 14th and 15th terms are additional technique effects. These terms represent international environmental treaties for emission reductions. In the case of SO_2, two international environmental treaties are included in the regression. *H* denotes the Helsinki dummy, where 1 indicates that the country has ratified the Helsinki Protocol and 0 indicates otherwise, and *O* denotes the Oslo dummy, where 1 indicates ratification of the Oslo Protocol and 0 indicates otherwise[7]. We should note that the decision of a country to ratify these protocols cannot be treated as exogenous because this decision is likely to be affected by that country's economic conditions (see Beron *et al*., 2003; Murdoch *et al*., 2003). Similarly, the Kyoto Protocol and the Protocol on Water and Health are considered for the cases of CO_2 and BOD, respectively, where detailed explanations are provided later. Therefore, to address self-selection bias, the predicted probability of reaching the ratification stage

---

US tariffs schedules on the output of pollution intensive industries.

[6] To show a country's comparative advantage, a country's capital–labor ratio and per capita income levels are expressed relative to the world average for each year, following Cole and Elliott (2003).

[7] The 1985 Helsinki Protocol on the reduction of sulfur emissions and their trans-boundary fluxes by at least 30 percent entered into force in 1987. The 1994 Oslo Protocol on the further reduction of sulfur emissions is a successor to the Helsinki Protocol and entered into force in 1998.

is calculated using probit estimation and is used for these dummy variables for the countries participating in the negotiations of these treaties[8].

The fifth to 13th terms on the right hand side show the composition effects. A country's comparative advantage is a major factor influencing the composition effects. We consider factor endowment, stringency of environmental regulations, and trade openness as factors affecting the comparative advantage (as in Antweiler *et al.*, 2000; Cole and Elliott, 2003). A capital-abundant country will specialize in capital-intensive production, whereas a labor-abundant country has a comparative advantage in labor-intensive goods. Therefore, a country with a higher capital-labor ratio tends to have higher emissions because capital-intensive goods are associated with higher emissions (see Cole and Elliott, 2003). This effect is captured by the fifth to seventh and ninth to 13th terms.

At the same time, however, a country with relatively more stringent regulations has a smaller comparative advantage in capital (pollution) intensive goods because production would be constrained by these regulations. It is important to know that there is a strong correlation between a sector's capital intensity and its pollution intensity (see Cole and Elliott, 2003). Therefore, even if countries have a comparative advantage in capital (pollution) intensive goods (i.e., a higher capital-labor ratio), the comparative advantage is weakened and emissions would decrease in high-income countries. The seventh term in the equation reflects this effect.

In addition, an increase in trade encourages an increase in the production of capital-intensive goods in countries that have a comparative advantage in these goods

[8] The predicted probabilities are controlled for SO_2 and CO_2. The value for BOD emissions is not controlled because we are not able to obtain statistically significant results in the probit estimation.

and a decrease in the production of capital-intensive goods in countries that have a comparative disadvantage in capital-intensive goods (see the explanation of the KLE in footnote 1). This is captured by the ninth and tenth terms. An increase in trade might, however, encourage a shift in the production of capital-intensive goods from countries with more stringent environmental regulations (high income countries) to countries with less stringent environmental regulation (low income countries). This effect (see the explanation of the ERE in footnote 1) is captured by the 11^{th} to 13^{th} terms.

2.2.2 Income Equation

Following the endogenous growth literature (see, e.g., Mankiw *et al*., 1992; Frankel and Romer, 1999), we control for trade openness, capital–labor ratio, population, and human capital in the income equation. The income equation is:

$$\ln S_{it} = c_2 + \beta_1 \ln S_{it-1} + \beta_2 \ln T_{it} + \beta_3 \ln(K/L)_{it} + \beta_4 \ln P_{it-1} + \beta_5 \ln Sch_{it} + \varepsilon_{2it}$$

$$\varepsilon_{2it} = \eta_{2i} + \nu_{2it} . \qquad (2)$$

where P is the population, Sch proxies human capital investment based on school attendance years, and ε_2 is an error term and consists of an individual country effect η_2 and a random disturbance ν_2. The other variables have been defined previously.

2.2.3 Short-Term and Long-Term Effects and Trade-Induced Elasticity

Short-Term Effect

We can decompose the terms in equation (1) into two groups as follows. One is the scale-technique effect (Y_{it}) and the other is the composition effect (C_{it})[9].

[9] Although discussions based on the decomposition are provided, we note that the decomposed effects are imputed instead of observed. For example, one could consider the case in which a higher *K/L* also leads to higher energy inputs, and there may not be compositional effects. Hence *K/L* may capture a technique effect, as *S* does. Similarly, a higher *S* may also induce structural shifts due to non-homothetic demand (see Echevarria, 2008) that move demand to cleaner service–type sectors.

$$Y_{it} = \alpha_2 S_{it} + \alpha_3 [S_{it}]^2 + \alpha_{13} H_{it} + \alpha_{14} O_{it} \quad (3)$$

$$C_{it} = \alpha_4 (K/L)_{it} + \alpha_5 [(K/L)_{it}]^2 + \alpha_6 (K/L)_{it} \cdot S_{it}$$
$$+ \alpha_7 T_{it} + \alpha_8 (RK/L)_{it} \cdot T_{it} + \alpha_9 [(RK/L)_{it}]^2 T_{it} + \alpha_{10} RS_{it} \cdot T_{it} + \alpha_{11} [RS_{it}]^2 T_{it} + \alpha_{12} (RK/L)_{it} \cdot RS_{it} \cdot T_{it} \quad (4)$$

Equation 4 is divided into two parts: one with terms including T_{it}, which captures the effect of trade openness on the composition effect through the factor endowment and/or the environmental regulation effect, and another one without terms including T_{it}.

The first part of equation 4 is the direct effect of trade, and the latter is the indirect effect of trade. We name the former the *Direct Trade-Induced Composition Effect* (TC_{it}) and the latter the *Indirect Trade-Induced Composition Effect* (OC_{it}). This reflects the indirect effect of a trade-induced change in income on emissions. Once the environmental regulations in a country become more stringent following an increase in income, that country loses its comparative advantage in capital-intensive goods. Thus, TC_{it} and OC_{it} are expressed as follows:

$$TC_{it} = \alpha_7 T_{it} + \alpha_8 (RK/L)_{it} \cdot T_{it} + \alpha_9 [(RK/L)_{it}]^2 T_{it}$$
$$+ \alpha_{10} RS_{it} \cdot T_{it} + \alpha_{11} [RS_{it}]^2 T_{it} + \alpha_{12} (RK/L)_{it} \cdot RS_{it} \cdot T_{it} \quad (5)$$

$$OC_{it} = \alpha_4 (K/L)_{it} + \alpha_5 [(K/L)_{it}]^2 + \alpha_6 (K/L)_{it} \cdot S_{it} \quad (6)$$

Here, we consider the effect of a one- percent increase in trade intensity. σ_{ST}^{S} [10] is the trade elasticity of emissions driven by the scale-technique effect through changes in income. It is derived from (1) and given in (7). In the same way, σ_{TC}^{S} is the trade

---

Hence, S may have little relationship with regulation at all but may have a compositional effect.

[10] The superscripts "*S*" and "*L*" refer to the short- and long-term effects, respectively.

elasticity of emissions driven by the direct composition effect. It is derived from (5) and given in (8). Finally, σ_{OC}^{S} [11] is the trade elasticity of emissions driven by the indirect composition effect through changes in income. It is derived from (6) and given in (9). It should be noted that we use the short-term trade elasticity of income, which is calculated from the income equation as β_2, to obtain these elasticities.

$$\sigma_{ST}^{S} = \left(\alpha_2 + 2\alpha_3 S_{it}\right)\beta_2 S_{it} \tag{7}$$

$$\begin{aligned}\sigma_{TC}^{S} &= \Big[\left(\alpha_{10} + 2\alpha_{11} RS_{it} + \alpha_{12}(RK/L)_i\right)\beta_2 RS_{it} \\ &+ \left(\alpha_7 + \alpha_8 (RK/L)_{it} + \alpha_9\left[(RK/L)_{it}\right]^2 + \alpha_{10} RS_{it} + \alpha_{11}\left[RS_{it}\right]^2 + \alpha_{12}(RK/L)_{it}\cdot RS_{it}\right)\Big] T_{it}\end{aligned} \tag{8}$$

$$\sigma_{OC}^{S} = \left(\alpha_6 (K/L)_{it}\right)\beta_2 S_{it} \tag{9}$$

As we can see from equation (5), the effect of an increase in trade intensity on emissions in (8) is divided into two effects: the direct effect of trade intensity and the indirect effect of trade intensity through changes in income. We define σ_{ITC}^{S} [12] and σ_{DTC}^{S} [13] as the elasticities that represent both of these effects.

$$\sigma_{ITC}^{S} = \left(\alpha_{10} + 2\alpha_{11} RS_{it} + \alpha_{12}(RK/L)_i\right)\beta_2 RS_{it} T_{it} \tag{10}$$

$$\sigma_{DTC}^{S} = \left(\alpha_7 + \alpha_8 (RK/L)_{it} + \alpha_9\left[(RK/L)_{it}\right]^2 + \alpha_{10} RS_{it} + \alpha_{11}\left[RS_{it}\right]^2 + \alpha_{12}(RK/L)_{it}\cdot RS_{it}\right) T_{it} \tag{11}$$

[11] This elasticity implies an indirect trade-induced composition effect, or, more precisely, a composition effect caused by trade-induced income changes that affect the stringency of the country's environmental regulations and that result in a change in the comparative advantage of capital-intensive goods.

[12] This is an indirect trade-induced composition effect. It is caused by a trade-induced income change that affects the ERE or the KLE.

[13] This is a direct trade-induced composition effect. It is caused by a trade intensity change that affects the ERE or the KLE.

From these elasticities, the total trade-induced composition effect, σ_C^S, is calculated as $\sigma_C^S = \sigma_{OC}^S + \sigma_{DTC}^S + \sigma_{ITC}^S$. However, the total trade-induced composition effect used by Cole and Elliott (2003) corresponds to σ_{DTC}^S. Hence, they ignore the influence of σ_{OC}^S and σ_{ITC}^S. This might overestimate or underestimate the composition effect. Finally, the short-term overall trade openness elasticity of emissions, σ_T^S, is calculated as follows:

$$\sigma_T^S = \sigma_{ST}^S + \sigma_{OC}^S + \sigma_{ITC}^S + \sigma_{DTC}^S \tag{12}$$

Long-Term Effect

In the same manner, each of the long-term effects of σ_{ST}^L, σ_{OC}^L, σ_{TC}^L, σ_{ITC}^L, and σ_{DTC}^L can be defined. Considering that the long-term elasticity of trade openness to income is calculated as $\beta_2/(1-\beta_1)$, these effects are calculated as follows:

$$\sigma_{ST}^L = \left(\alpha_2 + 2\alpha_3 S_i\right)\frac{\beta_2}{1-\beta_1}\frac{1}{1-\alpha_1}S_i \tag{13}$$

$$\sigma_{OC}^L = \left(\alpha_6 (K/L)_i\right)\frac{\beta_2}{1-\beta_1}\frac{1}{1-\alpha_1}S_i \tag{14}$$

$$\begin{aligned}\sigma_{TC}^L = \Big[& \left(\alpha_{10} + 2\alpha_{11}RS_i + \alpha_{12}(RK/L)_i\right)\frac{\beta_2}{1-\beta_1}RS_i \\ & + \left(\alpha_7 + \alpha_8(RK/L)_i + \alpha_9\left[(RK/L)_i\right]^2 + \alpha_{10}RS_i + \alpha_{11}\left[RS_i\right]^2 + \alpha_{12}(RK/L)_i \cdot RS_i\right)\Big]\frac{1}{1-\alpha_1}T_i\end{aligned} \tag{15}$$

$$\sigma_{ITC}^L = \left(\alpha_{10} + 2\alpha_{11}RS_i + \alpha_{12}(RK/L)_i\right)\frac{\beta_2}{1-\beta_1}\frac{1}{1-\alpha_1}RS_iT_i \tag{16}$$

$$\sigma_{DTC}^L = \left(\alpha_7 + \alpha_8(RK/L)_i + \alpha_9\left[(RK/L)_i\right]^2 + \alpha_{10}RS_i + \alpha_{11}\left[RS_i\right]^2 + \alpha_{12}(RK/L)_i \cdot RS_i\right)\frac{1}{1-\alpha_1}T_i \tag{17}$$

The long-term overall trade openness elasticity of emissions, σ_C^L, is calculated as follows:

$$\sigma_T^L = \sigma_{ST}^L + \sigma_{OC}^L + \sigma_{ITC}^L + \sigma_{DTC}^L \qquad (18)$$

3. Estimation Strategy and Data

3.1 Differenced GMM

Perman and Stern (2003) use the same data source for SO_2 emissions as we do, and they find that a co-integrating relation exists between SO_2 emissions per capita, income, and income squared for each country. This implies that long-run relationships exist among these variables and that the process of adjustment to the long-run equilibrium is slow. Since there is a possibility that other variables in our data also have long-run relationships, it is appropriate to adopt a model that takes the time factor into consideration in our study.

To address the dynamics, we adopt a differenced GMM, which is proposed by Arellano and Bond (1991). This method has the advantage that it controls for both the long-run relationship and any endogeneity problems by including appropriate instrumental variables. We include dependent variables before *t-2* and predicted values of both trade openness and income as instrumental variables.

3.2 Data

The data used in this study are obtained from different sources. We obtain SO_2 emissions data from *The Center for Air Pollution Impact and Trend Analysis* (CAPITA) and Stern (2005). This data set is superior to other data sets in terms of its spatial and temporal resolution and extent (Stern, 2005), and it covers more time and countries than the data Cole and Elliot applied. We also obtained updated CO_2 emissions data and BOD emissions data from the same source as Cole and Elliot (2003); these data are beneficial for drawing comparisons with Cole and Elliot. The CO_2 data is obtained from the *Carbon Dioxide Information Analysis Center* (CDIAC), and the BOD data is obtained from *World Development Indicators* (WDI).

As discussed in Cole and Elliot (2003), because emissions data are often estimated using engineering functions based on inputs, the engineering assumptions may not reflect the true gains from techniques precisely[14]. However, our estimates are able to adequately capture technique effects since each of these estimates considers country and year specific information. For example, in the case of SO_2, the sulfur release factor is determined by technology information obtained by country and year from the *International Energy Agency*. This information is combined with the sulfur content data for refined products and the net production and is used in the final emission calculations (Lefohn et al., 1999). The data for CO_2 is calculated using CO_2 emissions factors for individual fuels, which stem from country and year specific estimates of fuel use. Since CO_2 emissions factors cannot be reduced by end-of-pipe technology, they are time-invariant. However, regulations and technology improve fuel efficiency. Therefore, these emissions factors are generally updated over time to allow for changes in technology and regulations (Marland et al., 2000). On the other hand, the BOD emissions data is based on each country's actual monitoring data, which measures the amount of oxygen that bacteria in water consume in breaking down waste[15]. Hettige et al. (1998) first apply this data. They note that water pollution data are relatively reliable because the sampling techniques for measuring water pollution are more widely understood and much less expensive than those for air pollution. The World Bank's

[14] On the other hand, concentrations data tend to be affected by site-specific factors. For example, SO_2 gas is produced from not only anthropogenic sources such as the burning of fossil fuels but also from natural sources such as transboundary movement and volcanoes.

[15] This is a standard water-treatment test for the presence of organic pollutants.

Development Research Group updated the data through 2004 using the same methodology as Hettige et al. (1998).

SO_2 and BOD have local and trans-boundary impacts, whereas CO_2 is a greenhouse gas and has a global impact. See Cole and Elliot (2003) for a more detailed comparison of each emission. For data on SO_2 and CO_2, we have observations for 88 countries covering the period from 1973–2000. For data on BOD, we have observations for 83 countries for the period from 1980–2000[16]. We are able to obtain large sample sizes because annual data and data for a longer time span are available from several different data sources. For example, in case of SO_2, our SO_2 emissions data is annual and covers many countries, while Cole and Elliot (2003) obtain 5-year data from the *United Nations Environment Programme: Environmental Data Report 1993-1994*, which covers fewer countries.

Per capita income, which is defined as GDP per capita (measured in real dollars), and trade openness are taken from the *Penn World Table 6.1*. The capital-labor ratio is obtained from the *Extended Penn World Table*. Population and land area data come from the WDI. Data on school attainment (years) come from the education data set in Barro and Lee (2000), and distances between the country pairs in question (physical distance and dummy variables indicating common borders, linguistic links, and landlocked status) come from the *Center for International Prospective Studies*.

16 A list of countries used in this study for SO_2, CO_2, and BOD is presented in Appendix C.

4. Estimation Results

4.1. Parameter Estimates

Table 1 presents the results of the differenced GMM with instrumental variables estimation of the environmental quality equation for SO_2, CO_2, and BOD.[17] Before discussing the result, it should be noted that the estimation methodology (i.e., the differenced GMM estimation taking endogeneity into account) is found to be more important to our results than the data used (see Appendix F for detail). In other words, the differences between the results of Antweiler et al. (2001) and Cole and Elliot (2003) and our results seem mainly to stem from estimation methods rather than from data[18]. In the equations, the Sargan test for over-identifying restrictions and the hypothesis of no second-order autocorrelation imply that the instruments used in the GMM estimation are valid and that there is no serial correlation in the error term[19]. Table 2 and Table 3 report the short-term and long-term elasticities of trade openness on emissions, σ_{ST}, σ_C, σ_{OC}, σ_{ITC}, σ_{DTC} and σ_T, respectively. They are evaluated for sample averages of OECD countries and non-OECD countries using the estimated parameters. The values calculated with an average of all samples are also reported for reference. We obtained statistically significant results for all elasticities.

The lagged emissions terms for all specifications are statistically significant with a positive sign, but their values are less than one. These results imply that changes in

---

[17] For a robustness check, Appendix D provides results for different estimation techniques. The results for NOx are provided in Appendix E.

[18] The differences in estimation results between our study and the previous studies might be caused by changes in data and/or by differences in estimation methods. We intend to identify the sources of such differences. The identifications of discrepancies between our study and former studies are provided in Appendix F, which includes replications of Cole and Elliot (2003).

[19] In the case of BOD, we are not able to pass AR(2) tests, though the t-value is small enough.

explanatory variables, such as trade openness, at a specific point in time would also influence emissions after the current period. This indicates that there is an adjustment process and that the short- and long-term effects of trade on emissions are different. Therefore, we need to use a dynamic model, although previous studies do not. Comparing Table 2 to Table 3, we find that the long-term elasticities are larger than the short-term elasticities.

In all of the specifications for SO_2, CO_2, and BOD, almost all of the variables, including the endogenous variables such as trade openness, per capita income, and their interaction terms, have statistically significant effects. It is important to note that our statistical results for SO_2, CO_2, and BOD are somewhat different from those of Cole and Elliott (2003). As is discussed in Appendix D, these discrepancies are caused by differences in the estimation methods. In the methods, we correct for serial correlation, use dynamic GMM, and use instrumental variables techniques.

The sign of S is positive with statistical significance in the SO_2 and CO_2 estimates but negative in the BOD estimates, while the sign of S^2 is negative with statistical significance in all three estimates. These results indicate that (i) the scale-technique effect is negative for BOD and (ii) a negative technique effect gradually dominates a positive scale effect for SO_2 and CO_2 as income increases because higher income leads to a greater demand for a better environment. To consider the effect of an increase of S on per capita SO_2, CO_2 and BOD emissions more precisely, we calculated the values of $\alpha_2 + 2\alpha_3 S$ and σ_{ST} using sample means of income in OECD and non-OECD countries. We find that both values are negative for SO_2 and CO_2 in OECD countries but positive in non-OECD countries[20]. In other words, an increase in either

[20] β_2 is estimated to be statistically significant with a positive sign, as is discussed in Appendix A.

production or income leads to an increase in emissions in non-OECD countries but to a decrease in emissions in OECD countries. Thus, in the average non-OECD country, the scale effect dominates the technique effect because of the overall lower demand for a better environment due to lower income, whereas in the average OECD country the technique effect dominates the scale effect.

We also find that both the average OECD country and the average non-OECD country have a negative value for BOD. Hence, the technique effect dominates the scale effect in both developed and developing countries. This might be because the social pressure against water pollution is likely to be stronger than that against air pollution. In addition, there is some evidence that developing countries use abatement technologies for SO_2 from developed countries less frequently than those for BOD, possibly because of higher costs (Cheremisinoff, 2001). Thus, a technique effect might be more likely to dominate a scale effect in the case of BOD.

It should be noted that the values of $\alpha_2 + 2\alpha_3 S$ and σ_{ST} for SO_2 are smaller than those for CO_2 for both OECD and non-OECD countries. This result may stem from a greater awareness of the negative effects of SO_2. It is usually hard to perceive the future damages caused by CO_2, unlike those of SO_2.

The sign of the cross product of *KL* and *S* is positive with statistical significance in all estimates, making σ_{OC} positive for all estimates. One reason for this result might be that technological changes resulting in stronger comparative advantages in capital-intensive goods occur as the production scale increases[21]. We find a positive

[21] An increase of income weakens the comparative advantages in capital-intensive products because of stricter environmental policies, but it also strengthens these advantages because of technological changes caused by a larger production scale. The sign of this interaction term suggests that the latter dominates the former. This is pointed out by the referee.

sign for *KL* and a negative sign for KL^2 for all estimates, with statistical significance in all cases except for *KL* in the SO_2 equation. These results suggest that increases in the capital-labor ratio lead to increases in per capita emissions with a diminishing marginal effect.

As the dummies for ratification of the Helsinki and Oslo Protocols are statistically significant with a negative sign, the countries participating in international environmental treaties are associated with lower SO_2 emissions relative to nonratifying countries. This indicates that these treaties were effective in reducing SO_2 emissions. In contrast, the dummies for Kyoto Protocol and Protocol on Water and Health are statistically insignificant, although their signs are negative[22]. Therefore, there is a possibility that these protocols were not effective at reducing emissions within our sample period. Note that we use predicted values from a probit estimation to account for possible self-selection bias; the estimation results are described in Appendix B.

4.2 Environmental regulation effect vs. Capital-labor effect

With trade intensity increased, a country that has a comparative advantage in capital-intensive products is likely to increase its emissions by specializing more in these products. Factor endowment, i.e., the KLE, can affect this comparative advantage. On the other hand, environmental policy can also affect this comparative advantage. In other words, a country which enforces relatively strict environmental policies is likely to have less of a comparative advantage in capital-intensive goods following an increase

[22] It is notable that we use signification data for the Kyoto Protocol and the Protocol on Water and Health in place of ratification data because few countries ratify them within the sample period. Therefore, there is a possibility that we cannot control for the effect of these protocols appropriately, and we report two specifications, one with the protocols and the other without them, for each emission. Note that we calculate all values, including elasticities, in this study using the specifications without these protocols.

in trade intensity, thereby decreasing its emissions as its relative production of these goods decreases , i.e. the ERE.

We are able to determine how an increase in trade intensity affects composition effects through both the KLE and the ERE by looking at the sign of the following equation, where KLE_ERE_{it}, is determined by the first-order partial derivatives of equation (1) with respect to *T*.

$$KLE\_ERE_{it} = \alpha_7 + \alpha_8 (RK/L)_{it} + \alpha_9 \left[(RK/L)_{it} \right]^2 + \alpha_{10} RS_{it} + \alpha_{11} \left[RS_{it} \right]^2 + \alpha_{12} (RK/L)_{it} \cdot RS_{it} \tag{19}$$

As Table 1 indicates, all of the parameter estimates included in the above equation are statistically significant. Hereafter, since it is difficult to interpret each of the parameter estimates, we try only to evaluate the value of the above equation using sample averages for both OECD and non-OECD countries by pollutant. It should be noted that σ_{DTC} corresponds to this equation, as is shown in equations (11) and (17). We obtain negative values for both KLE_ERE_{it}, and σ_{DTC}, as is shown in Tables 2 and 3, for OECD countries, but we obtain positive values for both KLE_ERE_{it}, and σ_{DTC} for non-OECD countries over all pollutants. This implies that an increase in trade intensity results in a decrease in emissions in OECD countries and an increase in emissions in non-OECD countries. Because the sample averages of *RS* and *RKL* are larger than 1 in OECD countries and are less than 1 in non-OECD countries, we see that developed countries have a comparative advantage in capital-intensive production and enforce relatively strict environmental policies. Meanwhile, developing countries have a comparative advantage in labor-intensive production and enforce relatively lax environmental policies. The negative sign of *KLE_ERE* in developed countries implies that the ERE dominates the KLE. On the other hand, the positive sign of *KLE_ERE* in developing countries implies that the ERE dominates the KLE. Thus, we find that the ERE dominates the KLE both in OECE and non-OECD countries.

Finally, we intend to explore whether the Environmental Kuznets Curve (EKC) hypothesis is supported[23]. For this reason, we take the first-order and second-order partial derivatives of equation (1) with respect to *S* as follows:

$$EKC_{it} = \alpha_2 + 2\alpha_3 S_{it} + \alpha_6 (K/L)_{it} + \frac{T_{it}}{S_t^W}\left(\alpha_{10} + 2\alpha_{11} RS_{it} + \alpha_{12}(RK/L)_{it}\right) \qquad (20)$$

$$EKC'_{it} = \frac{\partial EKC}{\partial S_{it}} = 2\alpha_3 + 2\alpha_{11}\frac{T_{it}}{(S_t^W)^2} \qquad (21)$$

We find that the values in (20) evaluated at the means of the OECD and non-OECD samples are negative and positive for SO_2 and CO_2, respectively, and negative for BOD. We also find that the values in (21) evaluated at the means of the OECD and non-OECD samples are negative for all emissions. This indicates that the EKC hypothesis is likely to be supported for SO_2 and CO_2 but not for BOD.

4.3 Overall Effect of Trade Openness on Emissions

As already discussed, the elasticities of the trade-induced scale-technique effect, σ_{ST}, for CO_2 and SO_2 are found to be negative for OECD countries but positive for non-OECD countries, while that for BOD is found to be negative both for OECD and non-OECD countries. The elasticity of the trade-induced composition effect, σ_C, is positive in both cases. From these estimations, following results can be summarized:

[23] The uses of per capita GDP and its quadratic to capture both scale and technique effects are consistent with some of the studies on the EKC. However, we note recent studies applying a cubic factor or a nonparametric method to test the EKC. Additionally, we may only estimate the compound effect of the three effects (Grossman and Krueger, 1995).

(1) The overall effect of trade openness on emissions, σ_T, is negative for all pollutants in OECD countries because the negative trade-induced scale-technique effect dominates the positive trade-induced composition effect.

(2) The overall effect of trade openness is positive for SO_2 and CO_2 but negative for BOD in non-OECD countries. This is mainly because the trade-induced scale-technique effect and the trade-induced composition effect are both positive in the cases of SO_2 and CO_2. On the other hand, since the technologies developed by OECD countries to reduce BOD emissions are available in non-OECD countries and these technologies have lower costs, the negative scale-technique effect dominates the positive trade-induced composition effect for BOD.

(3) Trade openness therefore reduces BOD emissions both in OECD and non-OECD countries, while it reduces SO_2 and CO_2 emissions in OECD countries and increases them in non-OECD countries.

(4) The short-term elasticities of the overall effect of trade openness on SO_2, CO_2, and BOD are –0.147, –0.054, and –0.058 for OECD countries, and 0.030, and 0.113, –0.004 for non-OECD countries, respectively. On the other hand, in the long term, they are –2.228, –0.186, and –0.224 for OECD countries and 0.920, 0.883, and –0.155 for non-OECD countries, respectively.

(5) Looking at the above estimations, we see that the short-term overall effects are small for all pollutants and for OECD and non-OECD countries. We also find that the magnitude of the long-term overall effects varies. In the cases of SO_2 in OECD countries and of SO_2 and CO_2 in non-OECD countries, the effects are large. In the case of SO_2 in OECD countries, the scale-technique effects are not offset by the composition effects in the long term, whereas in the case of SO_2 and CO_2 in

non-OECD countries, the composition effects are added to the scale-technique effects. In the other cases, the scale-technique effects are offset by the composition effects, and the overall long-term effects are small.

(6) As previously presented, we find that the sign of σ_T^S is negative in OECD countries and positive in non-OECD countries for SO_2 and CO_2. This suggests that there might be some turnover level of income at which this sign changes from positive to negative as the level of income increases. We would like to determine the average turnover incomes of OECD and non-OECD countries respectively using their average *K/L*, *RK/L*, and *T*. The average turnover income for SO_2 is $24,616 for OECD countries and $14,045 for non-OECD countries, while that for CO2 is $29,678 for OECD countries and $24,732 for non-OECD countries. We find that the average turnover income for OECD countries is larger than that for non-OECD countries. OECD countries have a comparative advantage in the production of capital-intensive goods due to a larger *K/L* compared with non-OECD countries. Hence, OECD countries need a higher income for the technique effect to cancel out the scale effect. We also find that the turnover income for CO_2 is larger than that for SO_2 due to much weaker public awareness about global warming[24].

5. Conclusions

Economists have been analyzing for decades how trade intensity affects environmental quality. However, both the theoretical and the empirical literature on trade, economic development, and the environment are largely inconclusive about the

[24] For BOD emissions, we are not able to calculate the turnover income since the elasticities of overall income are always negative.

overall impact of trade on the environment. Openness to international trade is expected to have both positive and negative effects (Grossman and Krueger, 1993; Copeland and Taylor; 2005). Previous studies have been unable to estimate the overall impact of trade openness on the environment.

This study treats trade and income as endogenous and estimates the overall impact of trade openness on the environment using the instrumental variables technique. This study has analyzed the causal effects of trade openness on SO_2, CO_2, and BOD emissions by using extensive annual data for OECD and non-OECD countries. We find that whether trade has a beneficial effect on the environment on average or not varies depending on the pollutant and the country. A 1% increase in trade openness causes an increase of 0.920% and 0.883% in SO_2 and CO_2 emissions, respectively, and a decrease of 0.155% in BOD emissions in non-OECD countries in the long term. On the other hand, the long-term effects for OECD countries are –2.228%, –0186%, and –0.224% for SO_2, CO_2 and BOD, respectively.

Our results also show that there is a sharp contrast between OECD and non-OECD countries with regard to SO_2 and CO_2. Both in the short and long terms, trade reduces emissions of these pollutants only in OECD countries. On the other hand, we find that trade has a beneficial effect on BOD emissions all over the world in both the short and long terms. We also find that there is a distinct difference between short-term elasticities and long-term elasticities, implying that it is important to take dynamics into consideration. Finally, trade openness influences emissions through the environmental regulation effect and capital labor effect. We find that the former effect is likely to be larger than the latter effect for all pollutants.

Reference

Antweiler, W., B. Copeland, and S. Taylor. 2001. Is Free Trade Good for the Environment? *American Economic Review*, 91 (4): 877–908.

Arellano, M., and S. Bond. 1991. Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations. *Review of Economic Studies*, 58: 277–297.

Barro, E.J. and J.W. Lee. 2000. International Data on Educational Attainment: Updates and Implications, *CID Working Paper No. 42. Center for International Development*, Harvard University, MA.

Beron, K. J., J. C. Murdoch, and W.P.M. Vijverberg, 2003. Why Cooperate? Public Goods, Economic Power, and the Montreal Protocol, *Review of Economics and Statistics*, 85(2): 286–297.

Cheremisinoff, N. P. 2001. Handbook of Pollution Prevention Practices (Environmental Science and Pollution Control Series) Marcel Dekker Inc, Cambridge.

Chintrakarn, P. and D.L. Millimet. 2006. The Environmental Consequences of Trade: Evidence from Subnational Trade Flows, *Journal of Environmental Economics and Management*, 52(1): 430–453.

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.

Cole, M.A. 2006. Does Trade Liberalization Increase National Energy Use?. *Economics Letters*, 92 (1): 108–112.

Copeland, B. and M.S. Taylor. 2005. *Trade and the Environment: Theory and Evidence*, Princeton Series in International Economics. Princeton and Oxford: Princeton

University Press.

Dollar, D. and A. Kraay, 2003. Institutions, Trade, and Growth. *Journal of Monetary Economics*, 50 (1): 133–162.

Echevarria. C. 2008. International trade and the sectoral composition of production, *Review of Economic Dynamics*, 11: 192–206.

Ederington, J, A. Levinsohn and J. Minier, 2004. Trade Liberalization and Pollution Havens, *Advances in Economic Analysis and Policy* 4(2) Article 6.

Frankel, J., and D. Romer, 1999. Does Trade Cause Growth? *American Economic Review*, 89(3): 379–399.

Frankel, J. and A. Rose. 2005. In 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 *The U.S.-Mexico Free Trade Agreement*, P. Garber, ed. Cambridge, MA: MIT Press.

Grossman, G.M, and A.B.Krueger. 1995. Economic Growth and the Environment, *Quarterly Journal of Economic,s* 110: 353–377.

Harbaugh, W., A. Levinson, and D. Wilson. 2002. Reexamining Empirical Evidence for an Environmental Kuznets Curve, *Review of Economics and Statistics,* 84 (3): 541–551.

Hettige, Hemamala, Mani, Muthukumara and Wheeler, David. 1998. Industrial Pollution in Economic Development: Kuznets Revisited. , The World Bank, Washington, DC.

Lefohn A.S., Husar J.D., and Husar R.B. 1999. Estimating Historical Anthropogenic Global Sulfur Emission Patterns for the Period 1850–1990. *Atmospheric*

Environment. 33(21): 3435–3444.

Mankiw, N.G., D. Romer, and D. Weil, 1992. A Contribution to the Empirics of Economic Growth, *Quarterly Journal of Economics*, 152: 407–437.

Marland, G., T.A. Boden, and R.J. Andres. 2000. Global, regional, and national fossil fuel CO_2 emissions, in: Trends: A Compendium of Data on Global Change, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, TN, USA

Murdoch, J. C., T. Sandler, and W. P. M. Vijverberg. 2003. The Participation Decision versus the Level of Participation in an Environmental Treaty: A Spatial Probit Analysis, *Journal of Public Economics,* 87(2): 337–362.

Noguer, M. and M. Siscart. 2005. Trade Raises Income: A Precise and Robust Result. *Journal of International Economics*, 65(2). 447–460.

Perman, R. and D. I. Stern. 2003. Evidence from Panel Unit Root and Cointegration Tests that the Environmental Kuznets Curve does not Exist, *Australian Journal of Agricultural and Resource Economics*, 47: 325–347.

Rodriguez, F., and D. Rodrik. 2001. Trade Policy and Economic Growth: a Septic's Guide to Cross-National Evidence. In: Bernanke, B.S., Rogoff, K. (Eds.), *NBER Macroeconomics Annual 2000*. MIT Press, Cambridge, 261–325.

Stern, D. I. 2005. Global sulfur emissions from 1850 to 2000, *Chemosphere,* 58: 163–175.

Taylor, M. 2004. Unbundling the Pollution Haven Hypothesis, Advances in Economic Analysis & Policy. 4 (2), Article 8.

Table 1. The determinants of SO_2, CO_2, and BOD Emissions per capita (Differenced GMM)

Variable	SO_2 (Protocol)	SO_2	CO_2 (Protocol)	CO_2	BOD (Protocol)	BOD
$\ln E_{it-1}$	0.67*** (70.81)	0.68*** (90.02)	0.60*** (31.72)	0.60*** (28.38)	0.57*** (26.73)	0.58*** (21.52)
S	1.10*** (7.82)	1.11*** (7.77)	0.82*** (6.95)	0.84*** (6.21)	–0.79*** (–4.91)	–0.95*** (–6.96)
S^2	–0.907*** (–8.33)	–0.96*** (–15.62)	–0.43*** (–5.47)	–0.42*** (–4.63)	–0.20** (–2.02)	–0.14* (–1.94)
K/L	0.013 (0.32)	0.028 (0.70)	0.079** (2.13)	0.078** (2.17)	0.17*** (4.91)	0.22*** (7.24)
$(K/L)^2$	–0.031*** (–3.66)	–0.033*** (–5.56)	–0.014*** (–3.52)	–0.013*** (–3.63)	–0.043*** (–10.57)	–0.045*** (–9.81)
$(K/L)S$	0.27*** (5.22)	0.28*** (8.94)	0.095*** (3.16)	0.089*** (2.72)	0.21*** (6.10)	0.20*** (6.76)
T	0.0014*** (4.33)	0.0018*** (7.96)	0.0024*** (14.41)	0.0026*** (20.93)	0.00050 (1.43)	0.00050* (1.90)
Trelative(K/L)	–0.0013* (–1.66)	–0.0016** (–2.37)	–0.0014*** (–2.65)	–0.0014** (–2.55)	–0.0039*** (–5.77)	–0.0048*** (–6.41)
Trelative$(K/L)^2$	0.0011*** (4.19)	0.0011*** (6.12)	0.00066*** (5.92)	0.00064*** (6.42)	0.0017*** (6.32)	0.0019*** (5.99)
Trelative$S$	–0.0010* (–1.79)	–0.0011** (–2.27)	–0.00059* (–1.83)	–0.00065* (–1.76)	0.0018*** (4.24)	0.0023*** (5.45)
TrelativeS^2	0.00074*** (8.01)	0.00075*** (12.18)	0.00037*** (4.60)	0.00036*** (4.21)	0.00023** (2.11)	0.00017*** (3.13)
Trel(K/L)rel$S$	–0.0015*** (–6.07)	–0.0015*** (–11.00)	–0.00077*** (–4.49)	–0.00074*** (–4.48)	–0.0013*** (–5.14)	–0.0013*** (–6.07)
Helsinki Protocol	–0.097*** (–4.01)	–	–	–	–	–
Oslo Protocol	–0.040*** (–2.93)	–	–	–	–	–
Kyoto Protocol	–	–	–0.0025 (–0.60)	–	–	–
Protocol on Water and Health	–	–	–	–	–0.010 (–1.20)	–
Constant	–0.0067*** (–11.22)	–0.0067*** (–9.06)	0.0012*** (3.14)	0.0010*** (3.27)	–0.0014** (–2.55)	–0.0010 (–1.41)
Observations	2152	2152	2152	2152	1159	1159
Number of countries	88	88	88	88	83	83
Sargan test	76.29	75.99	76.27	79.84	70.39	67.46
AR(1)	–4.41***	–4.44***	–3.45***	–3.52***	–3.27***	–3.38***
AR(2)	–0.01	–0.02	–0.94	–0.94	1.74*	1.75*

Note: Values in parentheses are t–values. * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level. Trade openness, per capita GDP, and its square term are instrumented for using predicted openness, predicted per capita GDP, and predicted its square term, respectively.

Table 2. Short Term Trade Elasticity (Differenced GMM)

Elasticity			SO_2		CO_2		BOD	
OECD	σ^S_{ST}		–0.176***		–0.058***		–0.144*	
	σ^S_C	σ^S_{OC}	0.029*	0.146***	0.003*	0.046***	0.086*	0.130***
		σ^S_{ITC}		0.000*		0.000*		0.000***
		σ^S_{DTC}		–0.117*		–0.043*		–0.044*
	σ^S_T		–0.147**		–0.054*		–0.058*	
Non-OECD	σ^S_{ST}		0.006***		0.012***		–0.034*	
	σ^S_C	σ^S_{OC}	0.023*	0.008***	0.111*	0.003***	0.030*	0.010***
		σ^S_{ITC}		0.000*		0.000*		0.000***
		σ^S_{DTC}		0.015*		0.098*		0.020*
	σ^S_T		0.030**		0.113*		–0.004*	
All data	σ^S_{ST}		–0.016***		0.008***		–0.067*	
	σ^S_C	σ^S_{OC}	–0.026*	0.031***	0.047*	0.010***	0.019*	0.037***
		σ^S_{ITC}		0.000*		0.000*		0.000***
		σ^S_{DTC}		–0.057*		0.037*		–0.018*
	σ^S_T		–0.042**		0.055*		–0.048*	

Note: * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.

Table 3. Long Term Trade Elasticity (Differenced GMM)

Elasticity			SO_2		CO_2		BOD	
OECD	σ_{ST}^{L}		–10.908***		–2.388***		–1.239*	
	σ_{C}^{L}	σ_{OC}^{L}	8.679**	9.012***	2.202*	2.301***	1.014*	1.114***
		σ_{ITC}^{L}		0.028**		0.008*		0.002***
		σ_{DTC}^{L}		–0.361**		–0.107*		–0.102*
	σ_{T}^{L}		–2.228**		–0.186*		–0.224*	
Non-OECD	σ_{ST}^{L}		0.378***		0.513***		–0.289*	
	σ_{C}^{L}	σ_{OC}^{L}	0.543*	0.495***	0.369*	0.126***	0.135*	0.089***
		σ_{ITC}^{L}		–0.000*		–0.000*		0.001***
		σ_{DTC}^{L}		0.048*		0.243*		0.045*
	σ_{T}^{L}		0.920**		0.883*		–0.155*	
All data	σ_{ST}^{L}		–0.979***		0.348***		–0.572*	
	σ_{C}^{L}	σ_{OC}^{L}	1.937*	1.891***	0.575*	0.483***	0.273*	0.314***
		σ_{ITC}^{L}		0.001**		–0.000*		0.001***
		σ_{DTC}^{L}		–0.176*		0.092*		–0.042*
	σ_{T}^{L}		0.736**		0.923*		–0.299*	

Note: * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.

Appendix for Referee (Supplementary files)

Appendix A. Model of Income and Trade Openness

A.1 Income Equation

Table A-1 presents the results of the GMM estimation using instrumental variables for the income equation (2) using the same sample as in equation (1)[25]. In the equation, the Sargan test for over-identifying restrictions and the hypothesis of no second-order autocorrelation imply that the instruments used in the GMM estimation are valid and that there is no serial correlation in the error term. The lagged GDP per capita terms for all specifications are significant with a positive sign. This indicates that there is an adjustment process and that we should use a dynamic model even though the previous studies did not. Trade intensity has a statistically significant positive effect for all specifications. This indicates that trade openness contributes to the increase in GDP per capita. This is consistent with the literature (Frankel and Romer, 1999; Dollar and Kraay, 2003; Noguer and Siscart, 2005)[26].

[25] The results for both gravity and income are in line with the general findings in the literature.

[26] However, this relationship is the subject of a large and somewhat controversial literature (for example, see Rodriguez and Rodrik, 2001). We estimate several different specifications to obtain the trade elasticities and confirm that use of these elasticities would not alter our overall elasticities' signs in (12) and (18).

Table A-1. Income Equation

Sample used for	SO_2 & CO_2	BOD
$\ln S_{it-1}$	0.95*** (366.31)	0.73*** (872.58)
$\ln T$	0.05*** (30.92)	0.06*** (79.86)
$\ln(K/L)$	–0.05*** (–31.76)	–0.01*** (–10.92)
$\ln P$	–0.01* (–1.90)	–0.01*** (–12.11)
$\ln Sch$	–0.001** (–2.92)	–0.04*** (–30.31)
Constant	0.0004*** (4.06)	0.01*** (80.23)
Observations	2152	1159
Number of countries	88	83
Sargan test	86.32	79.47
AR(1)	–4.64***	–3.27***
AR(2)	–1.53	0.29

Note: Values in parentheses are t–values. * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level. Trade openness is instrumented for using predicted openness.

A.2 Trade Openness Equation

The endogeneity of trade is a familiar problem from the empirical literature on income and openness (e.g., Noguer and Siscart, 2005). Thus, instrumental variables estimations are used in this study, following Frankel and Rose (2005). The gravity model of bilateral trade offers good instrumental variables for trade because these are exogenous yet highly correlated with trade. We use indicators of country size (population, and land area) and distances between the pairs of countries in question (physical distance and dummy variables indicating common borders, linguistic links, and landlocked status). The equation is:

$$\begin{aligned}\ln(Trade_{ij}/GDP_i) &= c_3 + \gamma_1 \ln Dis_{ij} + \gamma_2 \ln P_j + \gamma_3 Lan_{ij} + \gamma_4 Bor_{ij} \\ &+ \gamma_5 \ln(Area_i \cdot Area_j) + \gamma_6 Landlocked_{ij} + \varepsilon_{3ij}\end{aligned} \qquad \text{(A-1)}$$

where $Trade_{ij}$ is the bilateral trade flows from country i to country j, GDP_i is the Gross Domestic Product of country i, Dis_{ij} is the distance between country i and country j, P_j

is the population of country *j*, Lan_{ij} is a common language dummy that takes a value of 1 if two countries have the same language and 0 otherwise, Bor_{ij} is a common border dummy that takes a value of 1 if countries *i* and *j* share a border and 0 otherwise, *Area* is land area, and *Landlocked* is a dummy that takes a value of 1 if one country is landlocked, 2 if both countries are landlocked, and 0 otherwise, and ε_3 is an error term.

The result is presented in Table A-2. We construct IV for openness as follows. A first-stage regression of the gravity equation is computed. Then, we take the exponential of the fitted values of bilateral trade and sum across bilateral trading partners as follows:

$$\sum_j Exp\left[Fitted\ \ln(Trade_{ij} / GDP_i)\right] \quad \text{(A-2)}$$

This fitted openness variable is added as an additional IV for the GMM.

Table A-2. Gravity Equation

$\ln(Trade_{ij}/GDP_i)$	Parameter estimates
$\ln(Distance_{ij})$	–0.92*** (–43.77)
$\ln(Population_j)$	0.85*** (88.92)
$Language_{ij}$	0.59*** (13.44)
$Border_{ij}$	0.57*** (5.71)
$\ln(Area_iArea_j)$	–0.22*** (–40.81)
$Landlocked_{ij}$	–0.41*** (–11.54)
Constant	–2.45*** (–12.43)
Observations	29147
R squared	0.25

Note: Values in parentheses are t–values. * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.

Appendix B. The Effect of Ratifying Multinational Environmental Agreements

We apply the probit model to the decisions of individual countries to ratify international environmental agreements following Beron *et al*. (2003) and Murdoch et al. (2003). Let the dependent variable y_i = 1 for countries that ratify the international environmental accord and y_i = 0 for nonratifying countries. The unknown parameters can be estimated with a standard probit model. In modeling the Helsinki and Oslo Protocols, we define y_i to equal 1 for countries that ratified the relevant protocol, whereas for the Kyoto Protocol and the Protocol on Water and Health[27], we define y_i to equal 1 for countries that signed the relevant protocol because there are few countries that ratified these protocols within our data period[28].

We consider two factors that influence these decisions. These factors are environmental quality as a normal good and the cost of compliance with the protocol. A country that ratifies or signs the protocol can be seen as a member of a group of nations that is voluntarily providing a public good. This is because additional demand for environmental quality comes with higher level of wealth. We use a country's average GNP per capita, lagged five years, to test this relationship; a positive sign is expected in the probit model.

Countries that ratify or sign these protocols are required to achieve some emissions level. Lagged emissions levels should therefore influence the cost of complying with the protocol. That is, we assume countries with higher emission levels

---

27 The Protocol on Water and Health to the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes is the first international agreement adopted specifically to attain an adequate supply of safe drinking water and adequate sanitation for people and to effectively protect water used for drinking.

28 The Kyoto Protocol on reducing the emissions of carbon dioxide was adopted on 11 December 1997, and 84 countries signed in 1998 or 1999, whereas the Protocol on Water and Health was adopted in 1999, and 36 countries signed in 1999 or 2000.

incur greater costs than countries with lower levels, implying that the net benefits from ratifying or signing a protocol are lower for high-emission countries. Therefore, we expect lagged emissions (as a proxy for compliance cost) to be negatively related to the ratification or signification decision.

Although there are several more variables included in the literature, we limit ourselves to two variables owing to multicollinearity and limited degrees of freedom. We use data from 20, 19, 172, and 16 nations for the Helsinki Protocol, Oslo Protocol, Kyoto Protocol, and Protocol on Water and Health, respectively. Samples used in the estimations of the Helsinki Protocol, Oslo Protocol, and Protocol on Water and Health are taken from the participant countries in the UN Economic Commission for Europe. Around 60%, 70%, and 65% of the countries participated in each protocol, respectively. Samples used in the estimation of the Kyoto Protocol are taken from the participant countries in the United Nations Framework Convention on Climate Change, where around 46% of the countries signed the protocol. The probit estimation results are presented in Table B.

For the Helsinki Protocol, Oslo Protocol, and Kyoto Protocol, we obtained statistically significant results that are almost in line with the expected sign. The only exception is the sign of lagged emissions for the Kyoto Protocol. On the other hand, we are not able to obtain a statistically significant result for the Protocol on Water and Health. Predicted probabilities are calculated and are then imputed to the original Helsinki, Oslo, and Kyoto Protocol variables.

Table B. Probit Estimation

Variable	Helsinki	Oslo	Kyoto	Water and Health
Lagged per capita GNP	0.40**	0.20**	0.067***	–0.045
	(2.38)	(1.96)	(4.54)	(–0.70)
Lagged emissions	–0.0005*	–0.0004*	0.0009*	–0.60
	(–1.70)	(–1.78)	(1.86)	(–0.31)
Constant	–6.08**	–2.36	–0.87***	1.18
	(–2.10)	(–1.42)	(–6.38)	(1.11)
Observations	20	19	172	16
Log-Likelihood Value	–5.26	–7.02	–93.90	–9.95
Pseudo R-Squared	0.60	0.36	0.16	0.06

Note: Values in parentheses are t–values. * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.

Appendix C. Data and the List of the Countries Used for This Study

List of the countries used for this study is provided in Table C.

Table C. Lists of the Country in This Study

North America	*Uruguay*	*Belgium*	*Gambia*[a]
Canada	*Venezuela*	*Britain*	*Ghana*
USA	**Asia**	*Cyprus*	*Kenya*
Latin America	*Bangladesh*	*Denmark*	*Malawi*
Argentine	*China*	*Finland*	*Mali*[b]
Barbados	*Hong Kong*	*France*	*Mauritania*[b]
Bolivia	*India*	*Greece*	*Mauritius*
Brazil	*Indonesia*	*Hungary*	*Mozambique*
Chile	*Japan*	*Iceland*	*Niger*
Colombia	*Korea*	*Ireland*	*Rwanda*
Costa Rica	*Malaysia*	*Italy*	*Senegal*
Dominica	*Nepal*	*Netherlands*	*Sierra Leone*[b]
Ecuador	*Pakistan*	*Portugal*	*South Africa*
El Salvador	*Philippines*	*Romania*	*Togo*
Guatemala	*Singapore*	*Spain*	*Tunisia*
Guiana	*Sri Lanka*	*Sweden*	*Uganda*
Haiti[b]	*Thailand*	*Switzerland*	*Zambia*
Honduras	**Middle East**	**Africa**	*Zimbabwe*
Jamaica	*Iran*	*Benin*[b]	**Oceania**
Mexico	*Israel*	*Burundi*[b]	*Australia*
Nicaragua	*Jordan*	*Cameroon*	*Fiji*
Panama	*Syria*	*Central Africa*	*New Zealand*
Paraguay[b]	*Turkey*[a]	*Congo*	
Peru	**Europe**	*Egypt*	
Trinidad and Tobago	*Austria*	*Ethiopia*	

Note [a] Not included in SO_2 and CO_2 specification. [b] Not included in BOD specification

Simple scatter plots are portrayed in Figure C, where there are not rough correlation between emissions and trade.

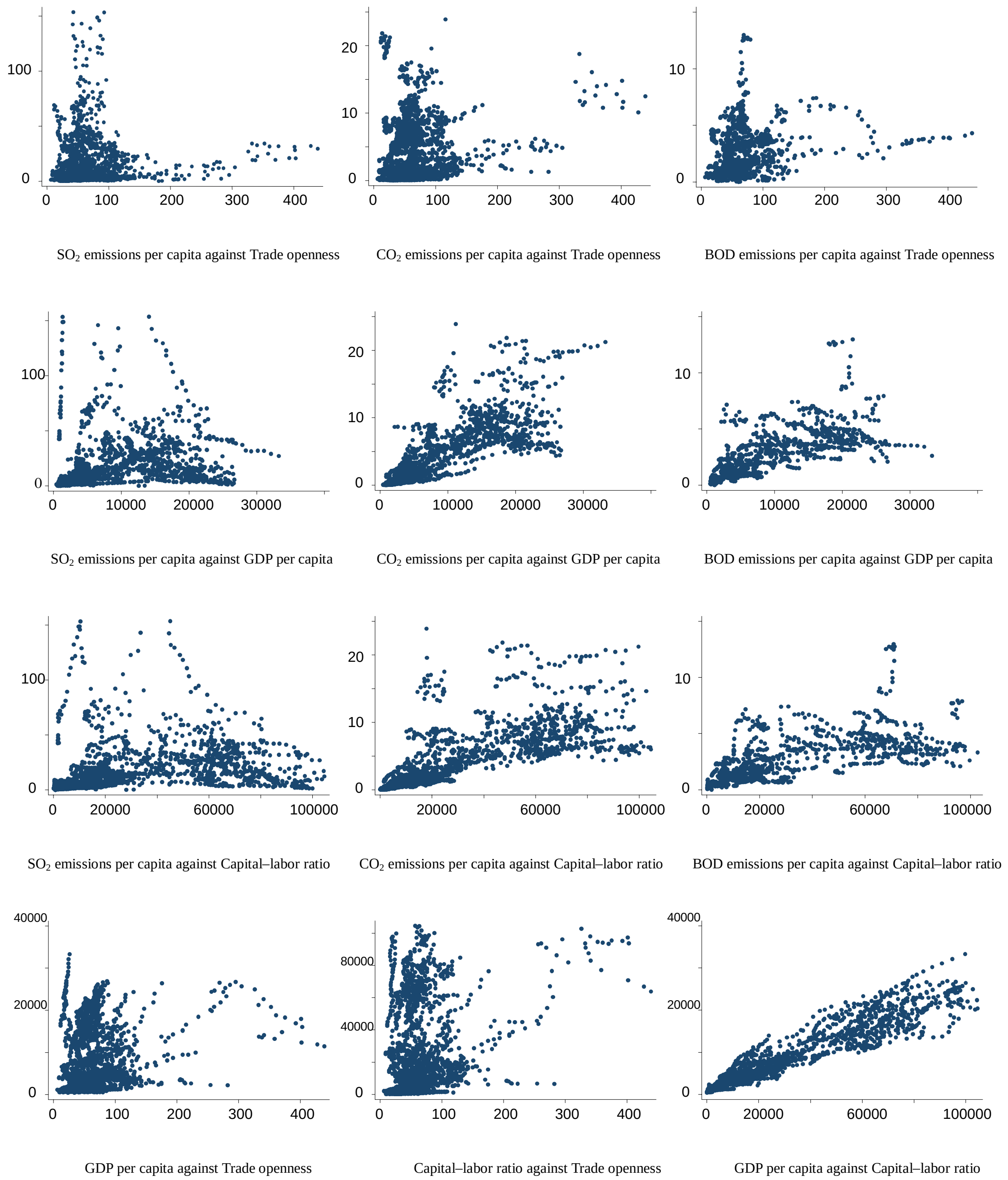

Fig. C. Simple scatter plots of data

Note: Vertical axis and horizontal axis are expressed as follows. In the case that the figure title is "A against B", vertical axis and horizontal axis corresponds to A and B, respectively. SO_2 emissions per capita, CO_2 emissions per capita and BOD emissions per capita are measured in kg, tons and kg, respectively. Trade openness, real GDP per capita and Capital–labor ratio are measured in %, $ and capital per worker, respectively.

Appendix D. The determinants of SO_2, CO_2, and BOD Emissions per capita (OLS, fixed effects, and differenced GMM)

Variable	SO_2 (OLS)	SO_2 (Fixed effects)	SO_2 (GMM)	CO_2 (OLS)	CO_2 (Fixed effects)	CO_2 (GMM)	BOD (OLS)	BOD (Fixed effects)	BOD (GMM)
$\ln E_{it-1}$	–	–	0.68***	–	–	0.60***	–	–	0.58***
			(90.02)			(28.38)			(21.52)
S	1.35***	1.074***	1.11***	2.99***	1.41***	0.84***	2.36***	–0.065	–0.95***
	(3.12)	(4.06)	(7.77)	(9.09)	(9.67)	(6.21)	(7.63)	(–0.30)	(–6.96)
S^2	0.54*	–0.77***	–0.96***	–0.055	–0.36***	–0.42***	–1.06***	–0.18	–0.14*
	(1.80)	(–4.60)	(–15.62)	(–0.24)	(–3.90)	(–4.63)	(–4.66)	(–1.24)	(–1.94)
K/L	0.92***	0.35***	0.028	0.74***	0.28***	0.078**	0.20**	0.45***	0.22***
	(8.57)	(5.57)	(0.70)	(9.08)	(7.98)	(2.17)	(2.56)	(8.63)	(7.24)
$(K/L)^2$	–0.044**	–0.029***	–0.033***	–0.048***	–0.015**	–0.013***	–0.065***	–0.042***	–0.045***
	(–2.17)	(–2.83)	(–5.56)	(–3.10)	(–2.59)	(–3.63)	(–3.92)	(–4.53)	(–9.81)
$(K/L)S$	–0.44***	0.079	0.28***	–0.26**	–0.022	0.089***	0.31***	0.086	0.20***
	(–2.99)	(1.04)	(8.94)	(–2.36)	(–0.54)	(2.72)	(2.68)	(1.25)	(6.76)
T	0.0092***	0.0026**	0.0018***	0.011***	0.0029***	0.0026***	0.0077***	0.0029**	0.00050*
	(6.85)	(2.52)	(7.96)	(10.84)	(4.97)	(20.93)	(6.23)	(2.53)	(1.90)
Trelative(K/L)	0.0038	0.0013	–0.0016**	–0.0024	–0.0010	–0.0014**	–0.0065***	–0.0077***	–0.0048***
	(1.10)	(0.76)	(–2.37)	(–0.90)	(–1.12)	(–2.55)	(–2.75)	(–6.22)	(–6.41)
Trelative$(K/L)^2$	–0.0019*	0.0010**	0.0011***	–0.0016**	0.00012	0.00064***	0.0014**	0.0017***	0.0019***
	(–1.89)	(2.13)	(6.12)	(–2.01)	(0.46)	(6.42)	(2.01)	(4.76)	(5.99)
Trelative$S$	–0.011***	–0.0037**	–0.0011**	–0.0046**	–0.00083	–0.00065*	0.0014	0.0034***	0.0023***
	(–4.65)	(–2.49)	(–2.27)	(–2.50)	(–1.00)	(–1.76)	(0.82)	(2.94)	(5.45)
TrelativeS^2	0.00031	0.0020***	0.00075***	–0.0010**	0.00023	0.00036***	–0.00024	–0.000077	0.00017***
	(0.52)	(5.90)	(12.18)	(–2.30)	(1.27)	(4.21)	(–0.60)	(–0.31)	(3.13)
Trel(K/L)rel$S$	0.0033**	–0.0025***	–0.0015***	0.0040***	–0.00017	–0.00074***	–0.00014	–0.00079	–0.0013***
	(2.48)	(–3.80)	(–11.00)	(3.98)	(–0.47)	(–4.48)	(–0.16)	(–1.64)	(–6.07)
Time trend	–0.020***	–0.017***	–	–0.0061***	0.0050***	–	–0.015***	–0.0076***	–
	(–7.06)	(–10.56)		(–2.78)	(5.78)		(–5.34)	(–4.31)	
Constant	40.84***	34.24***	–0.0067***	9.86**	–10.76***	0.0010***	28.36***	14.82***	–0.0010
	(7.09)	(11.03)	(–9.06)	(2.26)	(–6.30)	(3.27)	(5.11)	(4.29)	(–1.41)
Observations	2152	2152	2152	2152	2152	2152	1159	1159	1159
Number of countries	88	88	88	88	88	88	83	83	83
R squared	0.52	0.34	–	0.81	0.39	–	0.70	0.19	–
Sargan test	–	–	75.99	–	–	79.84	–	–	67.46
AR(1)	–	–	–4.44***	–	–	–3.52***	–	–	–3.38***
AR(2)	–	–	–0.02	–	–	–0.94	–	–	1.75*

Note: Values in parentheses are t–values. * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level. In differenced GMM, trade openness, per capita GDP, and its square term are instrumented for using predicted openness, predicted per capita GDP, and predicted its square term, respectively.

Appendix E. The results for NOx

We obtain NOx emissions data from The Emission Database for Global Atmospheric Research (EDGAR) for 1990, 1995, and 2000, meaning that the data is available for only three years. The decision to ratify the Sofia Protocol[29] occurred in 1988 and the first year of data is from 1990, so we did not use a probit model. Instead, we use a simple dummy variable that takes a value of 1 if the country has already ratified the 1988 Sofia protocol and 0 otherwise. Table F-1 presents the estimated parameters of equation (1) using differenced GMM, while Table F-2 presents the trade-induced elasticities evaluated at the sample means. As is shown in Table F-2, the elasticities of the trade-induced scale-technique effect, σ_{ST}, are statistically significant with a positive sign in all cases. This result indicates that the scale effect dominates the technique effect. The elasticities of the trade-induced composition effects, σ_C, and of the overall effect, σ_T, are insignificant.

[29] This required the countries in the United Nations Economic Commission for Europe that signed the Protocol to stabilize emissions of NOx against 1987 levels by 1994, and some countries committed themselves to 30% reductions by 1998 (against levels of any year between 1980 and 1986).

Table E-1. The determinants of NOx Emissions per capita (Differenced GMM)

Variable	NOx (Protocol)	NOx
$\ln E_{it-1}$	–0.80 (–1.64)	–0.90* (–1.88)
S	2.73* (1.73)	2.79* (1.71)
S^2	3.05* (1.72)	3.47* (1.97)
K/L	0.18 (0.34)	0.24 (0.46)
$(K/L)^2$	0.19** (2.12)	0.21** (2.45)
(*K/L*)*S*	–1.73** (–2.04)	–1.95** (–2.36)
T	0.0073* (1.67)	0.0075* (1.76)
*T*relative(*K/L*)	0.018 (1.37)	0.015 (1.18)
$T\text{relative}(K/L)^2$	–0.0071 (–0.73)	–0.0096 (–1.06)
*T*relative*S*	–0.023** (–2.47)	–0.022** (–2.34)
$T\text{relative}S^2$	–0.0019 (–0.47)	–0.0033 (–0.88)
*T*rel(*K/L*)rel*S*	0.011 (0.85)	0.016 (1.29)
Sofia Protocol	0.18 (1.24)	–
Constant	0.29*** (5.27)	0.29*** (5.19)
Observations	69	69
Number of countries	69	69
Sargan test	5.40	5.69
AR(1)	–	–
AR(2)	–	–

Note: Values in parentheses are t–values. * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level. Trade openness, per capita GDP, and its square term are instrumented for using predicted openness, predicted per capita GDP, and predicted its square term, respectively.

Table E-2. Trade Elasticity (Differenced GMM)

Elasticity			Short Term NOx		Long Term NOx	
OECD	σ_{ST}		0.482*		1.951*	
	σ_C	σ_{OC}	–0.819	–0.404**	–2.172	–1.636**
		σ_{ITC}		–0.002*		–0.007*
		σ_{DTC}		–0.413		–0.217
	σ_T		–0.337		0.092	
Non-OECD	σ_{ST}		0.049*		0.200*	
	σ_C	σ_{OC}	–0.346	–0.022**	–0.098	–0.090**
		σ_{ITC}		–0.000*		–0.001*
		σ_{DTC}		–0.324		–0.170
	σ_T		–0.297		–0.061	
All data	σ_{ST}		0.130*		0.525*	
	σ_C	σ_{OC}	0.695	–0.085**	–0.505	–0.343**
		σ_{ITC}		–0.001**		–0.002*
		σ_{DTC}		–0.609		–0.320
	σ_T		–0.565		–0.141	

Note: * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.

Appendix F. *Why the Results are Different from Previous Studies?*

This paper is an improvement on papers by Antweiler et al. (2001) and Cole and Elliott (2003). By applying instrumental variables and using data from more years and countries, we find different results. Therefore, it is critical to understand where the differences come from.

First, we try to replicate the results of Antweiler et al. (2001) and Cole and Elliot (2003). We apply fixed effects estimation methods to the closest possible approximation to previous studies' data sets in terms of emissions data and country and year coverage.[30] We calculate the scale-technique effect[31] and σ_{DTC} and compare them with previous studies' trade-induced effects. We are able to obtain similar elasticities to those found in previous studies, as shown in Table F-1,[32] although some elasticities are not statistically significant.

Second, to clarify how important our instruments are, we also apply OLS estimation and differenced GMM estimation to the same data. We present σ_{ST} and σ_{DTC} as calculated using OLS estimation, fixed effects estimation, and differenced

---

[30] Although we tried to obtain the same data as previous studies, we were not able to obtain exactly the same data. To replicate Cole and Elliot (2003), we collected emissions data from the same data source as theirs. However, we did not obtain a complete set of years and countries. More specifically, we were able to collect data from 24 out of 26 countries for SO_2, 26 out of 32 countries for CO_2, and 25 out of 32 countries for BOD, and we were not able to obtain BOD data for 1975-1979. On the other hand, to replicate Antweiler et al. (2001), we used our emissions data for the countries and years in their paper, and we apply the same specification as ours because of data limitations. We are able to collect emissions data for SO_2 for 36 out of the 43 countries in Antweiler et al. (2001).

[31] Note that we calculate the scale-technique effect, not the trade-induced scale-technique effect.

[32] Exceptions are σ_{DTC} for SO_2 from Antweiler et al. (2001) and σ_{DTC} for BOD from Cole and Elliot (2003). These seem to be different because we were not able to obtain a complete data set to match those used in previous studies.

GMM estimation in sections (a), (b), and (c) of Table F-2 respectively. There may be other factors such as autocorrelation and heteroskedasticity that could bias the results of the OLS estimation. We obtained different results from the OLS and GMM estimates, which might imply that we need to take these factors into consideration. In addition, we obtain different elasticities using fixed effects and GMM, which also might imply that including instrumental variables has an impact on the results.

Third, to consider the effect of updating data, we perform a fixed effects estimation using the data in this study. Section (d) of Table F-2 shows the elasticities found using fixed effects as well as the elasticities found using OLS and differenced GMM estimation. These estimates come from our original data set[33]. We find that the change in data used has a small effect on the elasticities compared to the change in estimation methods. Therefore, we conclude that the differences between the results of Antweiler et al. (2001), Cole and Elliot (2003), and our study seem to stem mainly from differences in estimation methods rather than differences in data used. In other words, it is important to take endogeneity into consideration.

Table F-1. Replication of previous studies (Fixed effects)

Effect		SO_2	CO_2	BOD
Scale-technique effect (cf. trade-induced scale-technique effects)	Reproduced directly from Cole and Elliott (2003)	–1.7**	0.46***	–0.06***
	Our Replication of Cole and Elliot (2003)	–0.491	0.094***	–0.031
	Reproduced directly from Antweiler et al. (2001)	–0.332**		
	Our Replication of Antweiler et al. (2001)	–0.887***		
σ_{DTC}	Reproduced directly from Cole and Elliott (2003)	0.3***	0.049*	–0.05***
	Our Replication of Cole and Elliot (2003)	0.631*	0.151**	0.112*
	Reproduced directly from Antweiler et al. (2001)	–0.864***		
	Our Replication of Antweiler et al. (2001)	0.108*		

Note: * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level. Elasticities are evaluated at sample means.

[33] We present parameter estimates of OLS, fixed effects, and differenced GMM using the data in this study in Appendix D.

Table F-2. Comparison of σ_{ST} and σ_{DTC} using different data and estimation methods

(a)	OLS (Antweiler et al.)	SO_2			OLS (Cole and Elliot)	SO_2	CO_2	BOD
	σ_{ST}	–0.026***			σ_{ST}	0.539	0.180***	0.296***
	σ_{DTC}	–0.075			σ_{DTC}	0.493	0.068	0.257***
(b)	Fixed effects (Antweiler et al.)	SO_2			Fixed effects (Cole and Elliot)	SO_2	CO_2	BOD
	σ_{ST}	–0.019**			σ_{ST}	–0.026	0.005***	–0.002
	σ_{DTC}	0.108*			σ_{DTC}	0.631*	0.151**	0.112*
(c)	GMM (Antweiler et al.)	SO_2			GMM (Cole and Elliot)	SO_2	CO_2	BOD
	σ_{ST}	0.027***			σ_{ST}	0.326*	0.029	0.023
	σ_{DTC}	–0.015***			σ_{DTC}	–0.527*	0.090***	0.067
(d)	OLS (this study)	SO_2	CO_2	BOD	Fixed effects (this study)	SO_2	CO_2	BOD
	σ_{ST}	0.087***	0.137***	0.007***	σ_{ST}	–0.005***	0.040***	–0.007
	σ_{DTC}	–0.115***	0.171***	0.236***	σ_{DTC}	0.002*	0.058***	0.019**
	GMM (this study)	SO_2	CO_2	BOD				
	σ_{ST}	–0.016***	0.008***	–0.022*				
	σ_{DTC}	–0.057*	0.037*	–0.018*				

Note: * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level. Antweiler et al. stands for the data on Antweiler et al. (2001), Cole and Elliot stands for the data on Cole and Elliot (2003), and this study stands for updated data in this study. To calculateall σ_{ST} , we use β_2 , which we obtain from income equation using differenced GMM estimation.