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Strategic Interaction and Institutional Quality Determinants of Environmental Regulations across Select OECD Countries.

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Abstract: We provide a model of environmental regulation to control transboundary pollution while considering the role of neighboring country regulations and measures of institutional quality in own and neighboring country. We apply a Spatial Durbin model to identify the determinants of the environmental regulations of several OECD countries. We do not find evidence of strategic interaction as the environmental regulations of a neighbor do not significantly impact the own country environmental regulations. However, the higher the quality of government institutions in a country, the more stringent the implementation of regulations. Additionally, government institutional quality significantly positively impacts the stringency of regulations in neighboring countries.

JEL classification: H2, Q5

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1. Introduction

The regulatory setting and the policies enforced by own and neighboring jurisdictions may affect the level and effectiveness of the regulatory stringency adopted by a government when implementing environmental policies. Some theoretical models point to suboptimal environmental standards when decentralized governments set regulations (Barrett 1994, Kennedy 1994, Kunce and Shogren 2002, Oates and Portney 2003). Policy makers may set lax environmental regulations or fail to enforce them in the hopes of providing a more attractive business setting or if they free-ride on the benefits from strict environmental regulations from a neighboring region in the case of a transboundary pollutant. Empirical estimates have shown some support for this strategic interaction across counties, states and, to a lesser extent, countries.

A different strand of literature focuses on the role government institutions, such as government stability or the ability to execute impartial legislation, play in determining economic policy. Government institutions may affect the economic policies chosen (Acemoglu et al. 2003) which could be an underlying factor in determining the existence of strategic interaction.

The objective of this work is to examine if institutional factors within a country affect the *implemented* environmental regulations stringency by a government and also the *implemented* environmental regulations stringency by neighboring countries. First, we test if the levels of *implemented* environmental regulations in select countries from the Organization for Economic Cooperation and Development (OECD) depend on the *implemented* environmental regulations of neighboring countries. Second, we determine the extent to which own and neighbor's institutional quality affects the implementation of environmental regulations. By focusing on a region such as the OECD, the sampled countries will have some form of economic interaction and there is some variability in institutional quality. This is the first study that we are aware of that examines the role of potential spillover effects of institutional quality in one country on the choice of environmental regulations in other countries.

Strategic regulatory interactions may occur in the presence of tax/fiscal competition or with the generation of transboundary pollution (Ulph 2000). Evidence of fiscal competition exists across local governments within states when deciding property taxes (Brueckner and Saavedra, 2001) and measures that control growth of a city (Brueckner 1998). Case et al. (1993) show that a state's level of per capita expenditure positively correlates with its neighboring state's spending level per capita. Given the relative uniformity of institutional quality in adopting a fiscal policy within a state or across a federal system, such fiscal competition is not surprising. However, we seek to determine if such strategic interaction exists across countries with more variable institutional quality.

Strategic interaction with environmental regulations across U.S. states with transboundary pollution may occur as own regulations depend on the regulations of neighbors (Fredriksson and Millimet 2002, Fredriksson et al. 2004, Levinson 2003, Konisky 2007). Strategic interaction can lead to a reduction in welfare but some claim that such competition across jurisdictions may improve social welfare in different cases (Revesz 1997). Others suggest that strategic interaction where regulations become less stringent to attract investment, has not occurred across U.S. states with respect to some specific environmental standards (Millimet and List 2003). Evidence of strategic interaction of environmental regulations exists across European countries when controlling for sulfur and nitrogen oxide emissions (Murdoch et al. 1997). Others report mixed results at the country level (Barret 1994, Ederington et al. 2005). The above studies do not control for the role of institutions in determining strategic interaction of environmental regulatory decisions within the country and its neighbors.

A government's institutional characteristics may impact the stringency of enforcement of environmental regulations. Zugravu et al. (2008) suggest that more stringent environmental policies in Central and Eastern European countries resulted in reductions of CO_2 emissions during the last 1990s and early 2000s, in part due to institutional factors. Others find that corruption may result in less stringent environmental policies (Damania et al. 2003, Fredriksson et al. 2003, Pellegrini and Gerlaugh 2006, Woods 2008). Fredriksson and Svensson (2003) claim that corruption and political instability jointly affect environmental regulation stringency.

The technology level within a country may play a role in determining environmental regulations.[1] Technology development in production practices that result in new environmental consequences may lead to new regulations, such as with shale gas development (Olmstead and Richardson 2014). Nentjes, et al. (2007) hypothesize that policy makers consider the current level of technology as they develop regulations that reduce environmental damage with policies producers can accommodate. Tarui and Polasky (2005) describe policy updating due to technology changes. Managi et al. (2005) suggest that changes in technology may result in new policies in order to capitalize on production advances or because the demand for environmental quality increases. As governments consider the technology level when determining environmental regulations, the quality of institutions will matter.

Hosseini and Kaneko (2013) develop a model of spatial institutional spillover effects. They hypothesize that institutional quality of a country may impact the environmental quality of a neighbor. Using panel data of CO_2 emissions from 129 countries from 1980-2007, they conclude that institutional spillovers represent a major factor in determining neighboring environmental quality. However, they do not establish a causal relationship or a mechanism to

[1] The Porter hypothesis states that more stringent environmental regulations leads to technological advances (Porter 1991). However, a few researchers find support to question the causation of the Porter hypothesis (Managi et al. 2005, Managi 2004).

explain this spatial relationship. Also, they only consider the pollution spillover effects and not environmental policies related to the control of such pollutants.

One explanation of institutional spillovers may come from the link between government institutions such as the degree of international integration and technology adoption within a country. This may influence the regulations in that country and in neighboring countries (Cremer and Gahvari 2005, Lovely and Popp 2011). Maddison (2007) suggests the diffusion of technological production processes may directly impact the environmental policies of neighbors. We consider how characteristics of government institutions, such as government stability, the strength and impartiality of the legal system and bureaucratic quality, affect regulation stringency. We also investigate how technology impacts these institutions and may indirectly affect environmental regulation stringency.

This work contributes to the existing literature by estimating an empirical model that allows neighboring policies and government institutions to impact regulations. First, we examine if strategic interaction of environmental regulations exist across countries by using a measure of *implemented* environmental policies instead of the legislated policy. To do so, we use a measure of environmental regulation stringency developed by Van Soest et al (2006) which more accurately reflects the stringency or laxity of a regulation over time and across countries. Second, we examine the impacts of government institutions on implemented environmental regulations through two channels: technology and regulatory enforcement. Finally, we examine if any institutional factors have spillover effects on environmental regulations of neighboring countries through the same channels. We present a theoretical model that incorporates key stylized facts regarding the role of institutions in advancing technology (Acemoglu et al. 2002) and regulatory enforcement (Acemoglu et al. 2003).

We start by presenting a two-country model where each country has two sectors: a clean sector and a dirty sector that emits a transboundary pollutant. Each government maximizes utility from Gross Domestic Product (GDP) net of disutility from aggregate pollution from both countries by choosing an environmental tax stringency level. We theoretically determine that when governments do not coordinate with each other, each government sets a tax lower than the socially optimal level because they do not consider the pollution emitted by the other country. We find that strategic interaction may occur if output in the dirty sector of one country affects the marginal pollution from the dirty sector in a neighboring country. Furthermore, we show that one's own institutions positively affect the stringency of environmental regulations as well as the stringency of neighbors through two channels: the overall technology and the enforcement level of legislated environmental regulations.

We empirically test the determinants of environmental regulations stringency by estimating a panel Spatial Durbin model. There are several measures of environmental regulations in the literature. Some of the most common are abatement expenditure as a proxy for environmental regulation stringency while others use pollution emissions. It is difficult to compare abatement expenditures across countries given the variability of its definition while pollution emissions may not accurately reflect the level of environmental regulation stringency. Instead, we employ what Brunel and Levinson (2013) call a *regulation based measure* that more accurately reflects the stringency or laxity of a regulation over time and across countries.

Our estimates shows no significant effect of a neighboring country's environmental regulations on a government's environmental regulation stringency. Thus, we do not find evidence of strategic interaction after controlling for institutions. However, institutional quality does matter. Better institutional quality increases environmental regulation stringency because regulatory enforcement levels rise and dominate the negative effects through technology. Surprisingly, we find spillover effects of good institutional quality for other countries where they choose a more stringent environmental regulation because of the high institutional quality of their neighbor. This may occur as a response to regulatory enforcement levels rising for particular pollutants leading to the spillover of other pollutants from the neighboring country.

We provide a theoretical model in the next section that relates policies and government institutions to implemented regulations. We derive an empirical model in the third section followed by a section discussing our data. We summarize our results in the fifth section followed by our conclusions in the final section.

2. Theory

We develop a simple theoretical framework to determine the interactions between institutional quality to environmental stringency. Our model incorporates two stylized facts regarding the role of institutional quality: (1) better institutions lead to widespread adoption of new technology (Acemoglu et al. 2002)[2] and (2) better institutions make it easier to enforce regulations set by the government (Acemoglu et al. 2003).

We begin with a two-country model where production in each country i or j occurs in two sectors, a clean and a dirty sector denoted as c or d. We incorporate the first stylized fact of technology adoption by specifying a production function for each sector such that $Y_{si} = A_{si}(\boldsymbol{I_i})f(K_{si})$ where A_{si} represents technology in sector s in country i which depends on a vector of institutional quality variables, $\boldsymbol{I}_i$, and K_{si} is the capital allocated to each sector in each country. The production function is increasing and concave in capital.

Production in the dirty sectors of each country creates transboundary pollution, Z, which affects both countries. Here, Z is an aggregate measure of pollution and can come from a mix of

[2] Acemoglu et al. (2002) call these institutions as "institutions of private property."

different types of pollutants. Output in each dirty sector can create multiple pollutants and this contributes to aggregate pollution such that $Z = Z(Y_{di}, Y_{dj})$. We assume $\frac{\partial Z}{\partial Y_{di}} > 0$, and $\frac{\partial^2 Z}{\partial {Y_{di}}^2} > 0$ such that more production in either dirty sector generates more transboundary pollution at an increasing rate. We make no assumption about the sign of the cross partial. This relationship represents substitutability or complementarity between the pollutants from different countries. The pollutants act as substitutes when $\frac{\partial^2 Z}{\partial Y_{di} \partial Y_{dj}} < 0$ and complements when $\frac{\partial^2 Z}{\partial Y_{di} \partial Y_{dj}} > 0$. For example, Kumar and Managi (2011) explain that a reduction in organic water pollution as measured by biological oxygen demand is associated with a reduction in chemical oxygen demand. These pollutants serve as complements. Sulfur dioxide and carbon dioxide act as substitute pollutants as a significant amount of carbon generating energy is required to reduce sulfur emissions from power plants.

Each government chooses a *legislated* environmental tax, τ_i, on the output produced in the dirty sector. However, this legislated tax may not represent the tax producers face. We incorporate the second stylized fact that better institutions result in more enforcement of regulations to show that the amount of tax actually implemented, t_i, depends on a vector of government institutional quality variables, $\boldsymbol{I}$. Following Lopez et al. (2011), the *implemented* environmental tax equals,

(1) $t_i = \theta(\boldsymbol{I})\tau_i$,

where $0 \leq \theta(\boldsymbol{I}) \leq 1$ measures institutional effectiveness in implementing legislative environmental regulations characterized by $\frac{\partial \theta}{\partial I_i} > 0$ and $\frac{\partial^2 \theta}{\partial {I_i}^2} < 0$. The implemented tax represents some fraction of the legislated tax, which increases with institutional quality at a decreasing rate.

The representative firm optimally selects capital. Aggregate fixed capital in each country is allocated across the two sectors, $\bar{K_i} = K_{ci} + K_{di}$. Each country can sell their output in the international and domestic market at a price p_{di} and p_{ci}, with the price of the clean good normalized to 1. Given differences in trade barriers across countries, domestic prices are not necessarily equal to the world price such that $p_{di} = \gamma\, p_d^w$ where p_d^w is the world price of the dirty good and γ is a measure of trade friction such that $\gamma>1$ ($\gamma<1$) implies the country is a net importer (exporter) of the good. The rental rate of capital, r, is also exogenously determined in a competitive world market.

The revenue function for each country is defined as,

(2) $$R_i(A_{ci}(\boldsymbol{I_i}), A_{di}(\boldsymbol{I_i}), \gamma p_d^w, \theta(\boldsymbol{I})\tau_i, \bar{K_i}) \equiv \max_{K_{di},K_{ci}}\{A_{ci}(\boldsymbol{I_i})f(K_{ci}) - rK_{ci} + (p_{di} - t_i)A_{di}(\boldsymbol{I_i})f(K_{di}) - rK_{di}\ s.t. \bar{K_i} = K_{ci} + K_{di}\}.$$

The capital endowment and the equalization of value of marginal product across sectors determine the equilibrium level of capital.

We define gross domestic product, G_i, as the sum of the revenue function and any tax collected by the government in the dirty sector,

(3) $$G_i = R_i(A_{ci}(\boldsymbol{I_i}), A_{di}(\boldsymbol{I_i}), \gamma p_d^w, \theta(\boldsymbol{I})\tau_i, \bar{K_i}) + t_i Y_{di}{}^*(A_{ci}(\boldsymbol{I_i}), A_{di}(\boldsymbol{I_i}), \gamma p_d^w, \theta(\boldsymbol{I})\tau_i, \bar{K_i}),$$

where $Y_{di}{}^*$ is the indirect production function in the dirty sector. Production in each sector is non-decreasing in prices, capital endowment and technology.

The representative consumer in the country receive utility from gross domestic product, and disutility from pollution. The indirect utility, V, takes a quasilinear form,

(4) $V = U(G_i) - \delta Z$,

where δ is the marginal disutility from pollution and $U(G_i)$ represents the aggregate indirect utility from gross domestic product and it is increasing and concave in G.

2.1 Decentralized versus socially optimal environmental tax regulations

The government maximizes consumer welfare by optimally selecting the *legislated* environmental tax, τ_i, that maximizes equation (4). The first order condition from the government's problem is,

$$(5)\ \frac{\partial V}{\partial \tau_i} = U_{G_i}\left(\frac{dR_i}{d\tau_i} + \theta(\boldsymbol{I})Y_{di}{}^{*} + \theta(\boldsymbol{I})\tau_i \frac{dY_{di}{}^{*}}{d\tau_i}\right) - \delta \frac{\partial Z}{\partial Y_{di}{}^{*}} \frac{dY_{di}{}^{*}}{d\tau_i} = 0.$$

Using the envelope theorem, $\frac{dR_i}{d\tau_i} = -\theta(\boldsymbol{I})Y_{di}{}^{*}$, we can solve for the legislated environmental tax rate as,

$$(6)\ \tau_i = \frac{\delta \frac{\partial Z}{\partial Y_{di}{}^{*}}}{\theta(\boldsymbol{I})U_{G_i}}.$$

Equation (6) is a standard Pigouvian tax equal to marginal damages weighted by the institutional quality. The legislated environmental tax does *not* account for the pollution affecting neighboring country.

We solve for the socially optimal tax while taking into account the transboundary nature of the pollutant. Given identical and symmetrical countries, the social planner maximizes welfare of both countries, *W*, by choosing a legislated environmental tax rate,

$$\max_{\tau} W = 2(U(G) - \delta Z).$$

The first order condition for the social planner equals,

$$(7)\ \frac{\partial W}{\partial \tau} = 2\left(U_G\left(\frac{dR}{d\tau} + \theta(\boldsymbol{I})Y_d{}^{*} + \theta(\boldsymbol{I})\tau \frac{dY_d{}^{*}}{d\tau}\right) - 2\delta \frac{\partial Z}{\partial Y_d{}^{*}} \frac{dY_d{}^{*}}{d\tau}\right) = 0.$$

Employing the envelope theorem and simplifying, we find,

$$(8)\ \tau = \frac{2\delta \frac{\partial Z}{\partial Y_d{}^{*}}}{\theta(\boldsymbol{I})U_G}.$$

Comparing equations (6) and (8), the social planner will set a higher tax than the decentralized government because the marginal disutility from the transboundary pollution is internalized.

2.2 The role of institutions and neighboring country choices

By substituting the optimal environmental tax chosen by a decentralized government into (1), we find the effect of a neighboring country's implemented environmental regulation stringency on own environmental regulation stringency levels,

(9) $\frac{dt_i}{dt_j} = \theta(\boldsymbol{I_i})\frac{d\tau_i}{dt_j}$.

The relationship depends critically on the sign of $\frac{\partial^2 Z}{\partial Y_{di}\partial Y_{dj}}$ (see Appendix 1). If the pollutants for each country act as complements where $\frac{\partial^2 Z}{\partial Y_{di}\partial Y_{dj}} > 0$, then $\frac{dt_i}{dt_j} < 0$. The neighboring country "free rides" on the effectiveness of environmental regulations of its neighbors. The opposite occurs when the pollutants in each country are substitutes. If the effect of output in another country has no effect on marginal pollution, no strategic interaction exists across countries.

Institutions affect the implemented environmental regulations through two channels. This can be seen by substituting the optimal tax regulation from the decentralized planner's problem into equation (1) and taking the derivative with respect to an institutional characteristic,

(10) $\frac{dt_i}{dI_i} = \frac{\partial\theta(\boldsymbol{I})}{\partial I_i}\left(\tau_i + \theta(\boldsymbol{I})\frac{d\tau_i}{d\theta(\boldsymbol{I_i})}\right) + \theta(\boldsymbol{I})\left(\frac{d\tau_i}{dA_{di}}\frac{\partial A_{di}}{\partial I_i} + \frac{d\tau_i}{dA_{ci}}\frac{\partial A_{ci}}{\partial I_i}\right)$.

The first two terms represent the effect through regulatory enforcement. There is a positive effect of institutions on the effectiveness of environmental policies but there is also a negative effect because more regulatory enforcement reduces the need for more stringent legislated environmental regulations, i.e. $\frac{d\tau_i}{d\theta(\boldsymbol{I_i})} < 0$. If the former effect outweighs the latter effect, we expect the impact of institutions through the regulatory enforcement channel to increase implemented environmental regulations.

In the last two terms, we observe an effect through technology which is ambiguous. Ambiguity occurs because more stringent environmental regulations are enforced when the technological level increases in the dirty sector, $\frac{d\tau_i}{dA_{di}} > 0$, but it is ambiguous in the clean sector, $\frac{d\tau_i}{dA_{ci}} \gtreqless 0$ (see Appendix 1).

A neighbor's institutional quality also affects the environmental regulation set by the own country. By substituting the decentralized government's optimal environmental tax into equation (1) and taking the derivative with respect to a neighbor's institutional characteristic, we find,

(11) $\frac{dt_i}{dI_j} = \theta(\boldsymbol{I}) \frac{d\tau_i}{d\theta(\boldsymbol{I_j})} \frac{\partial\theta(\boldsymbol{I_j})}{\partial I_j} + \theta(\boldsymbol{I}) \left(\frac{d\tau_i}{dA_{dj}} \frac{\partial A_{dj}}{\partial I_j} + \frac{d\tau_i}{dA_{cj}} \frac{\partial A_{cj}}{\partial I_j} \right).$

The first term is the impact of neighbor's institutions through the regulatory enforcement channel. The effect depends on the impact of output in one country on the marginal pollution in another country, i.e. $\frac{\partial^2 Z}{\partial Y_{di} \partial Y_{dj}}$ (see Appendix 1). When pollutants are substitutes, i.e. $\frac{\partial^2 Z}{\partial Y_{di} \partial Y_{dj}} < 0$, the neighboring country sees a marginal decrease in pollution brought about by better enforced environmental regulations. Firms in the neighboring country produce less of one pollutant (for example less sulfur dioxide emissions) but increases another type of pollutant that spills over to own country (for example more CO_2 emissions) leading to higher environmental regulations in own country. The opposite occurs when the pollutants are complements.

The last two terms in the bracket is the effect through technology. When pollutants are substitutes, a positive effect of institutional spillover through technology occurs in the clean sector of the neighboring country but a negative effect exists through the technology spillover in the dirty sector leading to an ambiguous effect. The opposite occurs when pollutants are complements but the total effect through the technology channel remains ambiguous (see Appendix 1). Thus, the total spillover effect through technology and the regulatory enforcement channels is ambiguous. We rely on our empirical model to determine which channels dominate when relating the effect of institutions on environmental regulations.

3. Empirical Model

We empirically estimate a model to test if strategic interaction occurs in implementing environmental regulations across countries and to determine the effect of institutions. We derive a reduced form version of the implemented tax by substituting equation (6) in equation (1) along with the indirect production functions in the dirty sector of all countries. The reduced form specification shows that the determinants of environmental regulation stringency depend on environmental regulations of neighboring countries, own institutions, institutions of neighbors, trade openness, relative price in the dirty sector and capital endowment in the country as well as its neighbors. Drawing on the empirical literature of tax competition, we use a Spatial Durbin Model specification,

$$t_{iy} = \rho \sum_{j=1}^{n} w_{ij} t_{jy} + \alpha_0 + \alpha_1 p_{iy} + \alpha_2 K_{iy} + \alpha_3 \gamma_{iy} + \alpha_4 A_{iy} + \sum_{k=3}^{K} I_{iyk} \alpha_k + \beta_1 \sum_{j=1}^{n} w_{ij}\, p_{jy} + \beta_2 \sum_{j=1}^{n} w_{ij}\, K_{jy} + \beta_3 \sum_{j=1}^{n} w_{ij}\, \gamma_{jy} + \beta_4 \sum_{j=1}^{n} w_{ij}\, A_{jy} + \sum_{k=3}^{K} \sum_{j=1}^{n} w_{ij} I_{jyk} \beta_k + \mu_i + \epsilon_{iy}, \tag{12}$$

where t_{iy} is the measure of environmental regulation stringency in country *i* at year *y*; w_{ij} is the weight assigned to country j by country *i*; t_{jy} is the measure of environmental regulation stringency in country j at year *y*; p_{iy} is a measure of a consumer price index for energy in country i at year *y*; K_{iy} is a measure of capital in country i at year *y*; γ_{iy} is a measure of trade openness in country *i* at year *y*; A_{iy} is a measure of technology in country *i* at year *y*; I_{iyk} is the k[th] institutional variable of country i at year *y*; p_{jy} is a measure of a consumer price index for energy as a proxy for the dirty sector price in country *j* at year *y*; K_{jy} is a measure of capital in country j at year *y*; γ_{jy} is a measure of trade openness in country *j* at year *y*; A_{jy} is a measure of technology in country j at year *y*; I_{jyk} is the k[th] institutional variable of country j at year *y*; ρ measures the effect of neighboring environmental regulation decisions on the own country; α_k is the effect of the k^th^ own institutional variable on environmental regulation stringency; β_k is the effect of the k^th^ neighboring institutional variable on own environmental regulation stringency; μ_i are country fixed/random effects and ϵ_{iy} is a random error term. Unobserved differences across countries may be correlated with the decision of countries to establish environmental stringency regulations. We employ fixed and random country effects to control for these characteristics to reduce omitted variable bias.

Two important issues exist when estimating equation (12). We begin with the choice of weighting matrix. We rely on the empirical tax competition literature to guide us in selecting a reliable weighting scheme. Devereux et al. (2008) show that the degree of strategic interaction between countries may depend, not on geographic proximity but the relative size of countries and the degree to which they are open to trade. Thus, we adopt foreign direct investment inflow from one country to another as well as the gross domestic product of an economy in creating our weighting matrices. We contrast this with a baseline weight where neighboring countries are of equal weight.

Potential endogeneity of the spatially lagged environmental tax variable may lead to concerns in the direction of causation. A single country's environmental tax level could directly affect environmental taxes of its neighbors. We estimate equation (12) using maximum likelihood estimation which yields a consistent and efficient estimator for ρ which implies that there is no need to instrument for the lagged effect (Anselin 1988). Another concern is the potential endogeneity of the institutional variables because the environmental regulatory taxes themselves could influence the institution of the country. However, the size of government expenditures to control for environmental externalities are small relative to government fiscal expenditures and the whole economy making this causal effect unlikely.

To determine if strategic interaction of environmental regulations across countries exists, a significantly non-zero ρ suggests strategic interaction. A negative coefficient indicates that free-riding may occur and the current level of environmental regulation stringency is lower than the socially optimal level.

To measure the effects of own and neighboring institutions on own environmental regulations, we estimate marginal effects. However, the parameters α_k and β_k do not capture the marginal effect of the institution variables on environmental regulation stringency because in this spatial framework, the institutional change in one country not only changes its own environmental regulations (direct effect) but also that of its neighbor (indirect effect). The marginal effect of the institutional variable on environmental regulations in a Spatial Durbin Model is calculated as (LeSage and Pace 2009),

$$(13) \qquad \frac{\partial \tau_{iy}}{\partial I_{iyk}} = (I - \rho W)^{-1} \begin{bmatrix} \alpha_k & \cdots & w_{1k}\beta_k \\ \vdots & \ddots & \vdots \\ w_{1k}\beta_k & \cdots & \alpha_k \end{bmatrix},$$

where W is the weighting matrix. The marginal effect measured by equation (13) captures the regulatory enforcement channel as described in equation (10). The sign of this effect is likely positive as long as the impact of institutions on the legislated environmental tax is non-negative or small in magnitude compared to the effect of institutions on regulatory enforcement as described in our theoretical model.

To obtain the effect of institutions on implemented environmental regulations through the technology channel, we estimate the following determinants of technology,

$$(14) \qquad A_{iy} = \theta_1 \gamma_{iy} + \sum_{k=2}^{K} I_{iyk}\theta_k + \varphi_i + \sigma_{iy},$$

where φ_i is a fixed or random effect and σ_{iy} is a random disturbance term. Thus, the impact of institutions through environmental regulations is,

(15) $$\frac{\partial \tau_{iy}}{\partial I_{iyk}} = \theta_k (I - \rho W)^{-1} \begin{bmatrix} \alpha_4 & \cdots & w_{1k}\beta_4 \\ \vdots & \ddots & \vdots \\ w_{1k}\beta_4 & \cdots & \alpha_4 \end{bmatrix}.$$

Even though we expect technology to be increasing in institutions, i.e. $\theta_k > 0$, the effect of technology on implemented environmental taxes is ambiguous. By combining equations (13) and (15), we obtain the total effect of own institutions on implemented environmental taxes.

The marginal effect of a neighboring country's institutional characteristic on the own country's environmental regulation stringency through the regulatory enforcement channel is determined using,

(16) $$\frac{\partial \tau_{iy}}{\partial I_{jyk}} = (I - \rho W)^{-1} \begin{bmatrix} \beta_k & \cdots & w_{1k}\alpha_k \\ \vdots & \ddots & \vdots \\ w_{1k}\alpha_k & \cdots & \beta_k \end{bmatrix}.$$

The marginal effect of equation (16) is equivalent to the effect of regulatory enforcement channel in equation (11). The spillover effect of institutions through the regulatory enforcement channel is ambiguous and depends on the cross partial effect of output on pollution.

The effect of institutions on implemented environmental regulations through technology is also ambiguous. We calculate this by combining the marginal effect of institutions on technology in equation (14) with the spillover effect of institutions on implemented regulations in equation (12) to derive,

(17) $$\frac{\partial \tau_{iy}}{\partial I_{iyk}} = \theta_k (I - \rho W)^{-1} \begin{bmatrix} \beta_4 & \cdots & w_{1k}\alpha_4 \\ \vdots & \ddots & \vdots \\ w_{1k}\alpha_4 & \cdots & \beta_4 \end{bmatrix}.$$

The sum of equations (16) and (17) yield the total effect of neighbor's institutional quality on *implemented* environmental taxes.

4. Data

We compile a unique panel dataset containing OECD countries from 1984 to 1996. Appendix 2 provides a description of our data and their sources. Table 1 shows the summary statistics of the data. The most crucial variables are the environmental regulation variable and the measures for institutional quality.

Various measures of environmental regulations in the literature have different strengths and weaknesses.[3] The most promising type of indicator is the *regulation based measure* which measures the stringency or laxity of a given regulation over time and across countries (Brunel and Levinson 2013). Van Soest et al. (2006) created such a measure of environmental stringency based on a polluting input's shadow price. They define the polluting input's shadow price as the change in spending on the polluting input given a change in its use. The shadow price is compared to the undistorted market price. If the former is greater than the latter, the firm would reduce the use of the polluting input because it could reduce its spending. The reduced use of the input indicates stringency of the environmental regulation implemented by the government. If the shadow price is lower than the undistorted market price than this implies the firm faces a subsidy in consuming the dirty input due to lax regulations. With sufficient trade across countries of the polluting input, the undistorted market price would just equal the world price and shadow prices across countries can be directly used as a measure of environmental regulation stringency.

[3] Brunel and Levinson (2013) categorize five types of environmental regulation measures: (1) pollution abatement expenditures (2) pollution emissions or energy use (3) pollution control efforts by regulators (4) composite index and (5) regulation based measures. Abatement expenditure data is difficult to compile across countries since not all firms report such measures and the definition of the data may differ across countries. On the other hand, pollution emissions data is more readily available and comparable across countries but it is not clear if a high level of pollutions actually implies stringent or lax environmental regulations. Pollution adoption efforts such as passing legislation or joining international conventions vary widely in countries depending on how such laws are enacted in each country. Based on our theoretical framework, this would only capture, τ but not t. Finally, composite indices are difficult to create in a panel dataset since it may be hard to compare changes in some characteristics over time.

Such a theoretically consistent measure allows comparability over time as well as across countries that adopt different types of regulations such as a pollution tax or a quota. Van Soest et al. (2006) use energy as a measure of polluting input and calculate the corresponding shadow price of energy use for several developed countries in Europe. We use their measure of environmental regulation stringency since we believe it the most reflective measure of *implemented* environmental regulation stringency comparable across countries over time. However, using this measure limits our sample to the countries used in the Van Soest et al. study. Based on our sample of countries, all environmental regulation indicators are positive which indicate relatively stringent environmental regulations. The average shadow price shows that an increase by 1 kilo-ton of oil increases the industry's spending by 0.195 million dollars.

Our measures of institutional quality come from the International Country Risk Guide published by the Political Risk Services Group. Knack and Keefer (1995) first introduced the dataset, which has been widely used. We use three institutional measures that capture the efficacy of adopting environmental regulations and incentives to allow technological growth as reflected in our model. The first measure called Bureaucratic Quality measures the institutional quality of the bureaucracy in its role to minimize the effect of revisions of policy when governments change. The index ranges from 0 to 4 with 4 as a measure of high bureaucratic quality. The second measure, Law and Order, assesses the strength and impartiality of the legal system and the observance of the law. The index ranges from 0 to 6 with 6 as a measure of high observance of law and order. Finally, we include Government Stability which measures the government's ability to implement its programs and to stay in office. This index is composed of three subcategories: government unity, legislative strength and popular support. Each subcategory receives a score between 0 (high risk) and 4 (low risk). These scores are added which gives a measure of the stability index ranging from 0 (high risk of instability) to 12 (low risk of instability). Most of our countries have a high bureaucratic quality level (mean of 3.9) and law and order (mean of 5.7). We observe more variability with Government Stability across our group of countries with a mean of 7.4.

We compile proxies for technology, the output price of the dirty sector, aggregate capital in the economy and a measure of trade openness. Technology is measured by total factor productivity (TFP) derived from the United Nations database. It accounts for other determinants of economic output aside from labor, physical capital and human capital. Unfortunately, we do not have disaggregated TFP for clean and dirty sectors. Our TFP measure is an overall measure of technical efficiency so our estimates can be interpreted as the effect of institutions on implemented environmental taxes via *aggregate* technological level. Since we base our measure of environmental regulation stringency on the shadow price for energy use, our proxy for price in the dirty sector is the consumer price index for energy which includes household purchases of electricity, gas and other fuels. We proxy for aggregate capital in the economy with gross capital formation which consists of capital outlays and fixed assets along with changes in inventory levels within the economy. Finally, our measure of trade openness is the sum of inward and outward foreign direct investment (FDI), divided by Gross Domestic Product (GDP).

We use three weighting matrices: a uniform weight, a weight based on size of GDP and a weight based on inward FDI between trading partners. Data for GDP is obtained from the World Bank while the FDI data is taken from the OECD.

One limitation in the estimation of the panel Spatial Durbin model is that an unbalanced panel cannot be estimated. Thus, we utilized multiple imputation to fill in the missing data for our environmental regulation indicator to create a balanced panel data set. There are 87 original observations across 8 OECD countries that are usable from Van Soest et al. (2006).[4] To complete the dataset, 17 additional observations are added using 10 multiple imputations to complete a balanced panel dataset with each country having 13 observations over time. Without the multiple imputation method, the number of observations in our sample would decrease by half.

5. Results

We present fixed and random effects estimates for equation (14) and spatial Durbin estimates for equation (12). All estimates are presented using standard errors robust to heteroskedasticity. Using these parameters, we derive the elasticity of various institutional measures on environmental regulation stringency.

Table 2 shows the factors influencing the level of TFP. Aside from the institutional variables, we incorporate a measure of trade openness since it is an important determinant of the level of TFP (Chanda and Dalgaard, 2008). As with the current literature, we find that trade openness positively significantly influences the level of TFP. A 1% increase in the proportion of foreign direct investment to total GDP leads to a 0.02% increase in TFP. Institutions are also a positive determinant of TFP. In particular, bureaucratic quality, and to a lesser extent law and order, significantly improves TFP.

Table 3 presents the coefficient estimates of the determinants of *implemented* environmental regulation stringency. Columns 1 to 3 contain random effects while columns 4 to 6 show fixed effects. We present the estimated coefficients from the variables in own country in the top half of the table, and the effects from neighboring countries in the bottom.

Consumer price index of energy negatively affects environmental regulation stringency but such an effect is not consistently significant. Gross capital formation, which proxies for

[4] The eight OECD countries are Belgium, Denmark, Finland, France, United Kingdom, Italy, Netherlands and Sweden.

aggregate capital, does not consistently generate a significant negative effect on own regulations. Trade openness, though positive, is not significant.

TFP negatively affects environmental regulations though the result is not significant in all specifications. Our theory provides one plausible explanation for the negative effect of TFP. If technological productivity leads to more output in the clean sector while the dirty sector shrinks, there is less need for strong enforcement of environmental regulations.

Based on the coefficient for the spatial lag of the dependent variable, which reveal the impacts from neighboring country variables, we observe no strategic interaction across countries when setting environmental regulations. Our result contrasts with Fredriksson and Millimet (2002) where they show that environmental regulations are strategically chosen across US states such that states with strict stringent environmental regulations improve the environmental regulations of their neighbors. At the country level, we do not find regulators enforcing environmental regulations while considering environmental regulations of their neighbors. Two potential reasons for this difference in results exist. First, we focus on the level of *implemented* environmental regulations instead of abatement expenditures. Our measure captures the shadow price of energy which is a more comparable measure across countries. Second, more variation occurs in institutions across countries versus across states. Less variation may exist in institutions across states in the United States that have an overarching federal law which could make it easier to select environmental regulations strategically in response to the behavior of a neighboring state. However, with more variation of institutional quality across countries, it may make it futile to attempt legislating environmental regulations that depend on choices of neighboring countries because there will be more variability on the *implemented* environmental regulations.

Some support for this argument exists given the significance of institutions affecting a government's own choice of environmental regulations through the technology channel and directly which implies through the regulatory enforcement channel. Among our three measures of institutional quality, we find a consistent, significant and positive effect of bureaucratic quality and government stability influencing environmental regulation stringency. Hence, more politically stable countries better equipped to deal with changes in administration are more likely to enforce strict environmental regulations.

We estimate the elasticity of institutional quality on own environmental regulations using equations (13) and (15) and present them in Table 4. The own elasticity of government stability through the regulatory enforcement channel remains fairly stable ranging from 1.45 to 1.63 when significant. Given the ordinal nature of our institutional variables, there is little meaning in interpreting the magnitudes on their own. However, we can illustrate the effect of government stability on environmental regulations by comparing its affect across countries in our sample. The least stable government in our sample was Italy with an average measure of 6.2 while the most stable was Finland at 8.4. If Italy's government stability was raised to the same level as Finland over that same period, the shadow value of energy would increase by 51% to 58%.

We find a more elastic measure of the elasticity of bureaucratic quality through the regulatory enforcement channel ranging from 9.4 to 12.8 when significant. The country with the highest average bureaucratic quality in our sample is Sweden with a maximum score of 4 while the lowest is Italy with an average score of 3.2. If Italy's bureaucratic quality improved to the level of Sweden over the same period, the shadow price of energy would increase by approximately 235% to 320%.

The effect of the institutional variables on implemented environmental regulations through the technology channel is not as robust and the effects are relatively smaller in magnitude compared to the regulatory enforcement channel. As shown in the middle rows of Table 4, government stability has no significant effect while bureaucratic quality and law and order weakly negatively affect environmental regulations. The magnitudes through the technology channel are about 10% of the effect through the regulatory enforcement channel.

The total effects of institutions on implemented environmental regulations are positive and significant for bureaucratic quality and government stability. In this case, the regulatory enforcement channel clearly dominates the technology channel. It must be noted that since technology has potentially very long run effects on policies (Acemoglu et al. 2002), we are only capturing a relatively short run effect through technology. In this case, it is interesting to find that such an effect in the short run is still significant.

Interestingly, we also find a positive spillover effect of bureaucratic quality and government stability on the environmental regulations of neighboring countries in the bottom half of Table 3. This implies that given a more politically stable neighboring country better equipped to deal with changes in administration, your own government would choose a more stringent environmental regulation. Our theoretical model provides one plausible explanation for this relationship. The pollutants across countries may act as substitutes to one another instead of complements, where the reduced production in one country leads to less of one type of pollutant but more of another type that spills over to another country. The country experiencing more spilled over pollution will respond by implementing more stringent environmental regulations.

Using equations (16) and (17), we calculate the elasticity of this spillover effect through the regulatory enforcement and technology channels and present them in Table 5. The elasticity of environmental regulations through the regulatory enforcement channel from a neighbor's government stability and bureaucratic quality is mostly significant across the various specifications where the magnitude in the latter is larger than the former. None of the institutional variables significantly affect environmental regulations through the technology channel. Thus, the total effect is dominated by the regulatory enforcement channel where bureaucratic quality and government stability in a neighboring country positively influences implemented environmental regulations.

6. Conclusions

We model the determinants of environmental regulations when transboundary pollution occurs across several OECD countries. We examine how the policies of neighboring countries influence implemented regulations to determine if strategic interaction exists when setting environmental policies. Additionally, we consider how government institutions affect own regulations and their neighbor's regulatory choice through two channels: a regulatory enforcement channel and a technology channel.

We find that neighboring regulations do not play a significant role when these countries implement these regulations. However, various government institutional quality measures do affect the implemented environmental regulations. Higher levels of bureaucratic quality that measure the ability to prevent policy revisions with leadership change and government stability that captures the ability of leadership to implement policy, yield more stringent environmental regulations for that country. There is a robust positive effect through the regulatory enforcement channel and a weak negative effect through the technology channel. Since the former effect outweighs the latter effect, total effect of institutions on own environmental regulations is positive.

Bureaucratic quality and government stability appear to have spillover effects that influence the policy of neighboring countries. We observe more stringent environmental regulations of neighboring countries when the quality of these institutional characteristics are higher. In this case, these spillovers are more significant through the regulatory enforcement channel but not the technology channel.

Given the potential long run effects of technology, a future study may consider comparing the short run, medium run and long run effects of institutions on environmental regulations via the channels that we outlined.

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Table 1. Summary Statistics of the Data

Variable	Mean	Standard Deviation	Minimum	Maximum
Environmental regulation stringency indicator (millions of US dollars per ton)	0.195	0.118	0.007	0.564
Consumer price index for energy	50.063	10.071	24.600	68.300
Gross capital formation (millions of US dollars)	126,000	107,000	21,000	312,000
Bureaucratic quality	3.898	0.273	3.000	4.000
Law and order	5.699	0.527	4.000	6.000
Government stability	7.383	1.481	3.167	10.083
Total Factor Productivity	0.773	1.009	0.917	1.052
Trade openness	0.034	0.026	0.001	0.107

Table 2. The Impact of Institutions on Log of Total Factor Productivity

Model	Fixed Effects	Random Effects
Log of Bureaucratic quality	0.152***	0.287***
	(0.032)	(0.035)
Log of Law and order	0.021	0.034***
	(0.015)	(0.011)
Log of Government stability	0.013	0.023
	(0.025)	(0.024)
Log of Trade openness lagged	0.017***	0.017***
	(0.005)	(0.005)
Constant	-0.466***	-0.688***
	(0.120)	(0.108)
Observations	128	128
Overall R-squared	0.050	0.017
Hausman Test (Prob Chi-squared)		0.000***

Notes: This an unbalanced panel with 8 countries and a total number of observations equal to 128. All standard errors are in parentheses and are robust to heteroskedasticity. Here, * = significance at the 15% level; * * = significance at the 10% level; *** = significance at the 5% level

Table 3. Determinants of Log Environmental Regulation Stringency using a Spatial Durbin Model

	Random Effects			Fixed Effects		
Weighting Matrix	Uniform Weight	GDP weight	FDI weight	Uniform Weight	GDP weight	FDI weight
Own Country						
TFP	-5.290*	-6.295***	-0.768	-3.177	-2.842	1.871
	(3.435)	(2.697)	(2.707)	(5.472)	(5.282)	(5.108)
Lagged CPI for energy	-0.524	-0.395	-0.855	-0.634	-0.468	-1.361**
	(0.757)	(0.663)	(0.672)	(0.846)	(0.820)	(0.785)
Gross capital formation	0.529	0.453	-0.482	-0.327	-0.709	-2.570**
	(0.439)	(0.357)	(0.341)	(1.366)	(1.479)	(1.354)
Bureaucratic quality	16.774***	9.904***	-0.117	17.255***	9.880**	0.686
	(7.108)	(4.955)	(1.633)	(7.664)	(5.842)	(4.490)
Law and order	1.346	0.692	0.344	1.686	1.244	1.550
	(1.772)	(1.507)	(1.350)	(1.678)	(1.508)	(1.470)
Government stability	1.526*	1.390*	1.382***	1.636*	1.563**	1.363**
	(0.918)	(0.887)	(0.584)	(0.963)	(0.913)	(0.739)
Trade openness lagged	0.044	0.076	-0.076	0.104	0.131	0.076
	(0.138)	(0.140)	(0.112)	(0.142)	(0.139)	(0.139)
Constant	278.354**	-87.899	8.913			
	(162.888)	(88.207)	(11.476)			
Neighboring Country						
TFP	-7.716	-6.338	5.751	-10.076	-7.674	7.343
	(20.169)	(13.846)	(6.225)	(19.271)	(17.449)	(11.797)
Lagged CPI for energy	-1.338	-1.235	-0.382	-1.141	-1.645	-0.419
	(2.763)	(1.936)	(1.069)	(2.803)	(2.241)	(1.329)
Gross capital formation	2.814	0.666	0.918	3.341	1.572	1.322
	(3.043)	(2.180)	(0.700)	(3.064)	(2.826)	(1.393)
Bureaucratic quality	114.187***	29.532***	-14.019	106.679***	28.911**	-10.546
	(48.816)	(13.590)	(14.256)	(45.566)	(16.728)	(22.859)
Law and order	-1.714	-0.933	0.518	-2.167	-0.794	1.256
	(7.688)	(2.832)	(2.219)	(7.412)	(3.021)	(2.808)
Government stability	7.726***	2.918***	-0.360	7.114***	2.632**	-0.221
	(3.138)	(1.368)	(1.098)	(2.916)	(1.500)	(1.149)
Spatial coefficient(ρ)	-0.494	-0.116	-0.017	-0.405	-0.102	0.021
	(0.381)	(0.258)	(0.227)	(0.363)	(0.267)	(0.246)

Notes: All the independent variables are in log form. There are 8 countries each with 13 time periods leading to 104 observations. All standard errors are in parentheses and are robust to heteroskedasticity. Here, * = significance at the 15% level; * * = significance at the 10% level; *** = significance at the 5% level

Table 4. The Own Elasticity of Institutional Variables on Environmental Regulations

	Random Effects			Fixed Effects		
Weighting Matrix	Uniform Weight	GDP weight	FDI weight	Uniform Weight	GDP weight	FDI weight
Regulatory Enforcement Effect						
Bureaucratic quality	11.516*** (4.623)	9.565*** (4.532)	-0.025 (1.681)	12.803** (6.311)	9.356* (5.607)	0.890 (4.951)
Law and order	1.650 (1.555)	0.872 (1.485)	0.538 (1.331)	1.997 (1.518)	1.438 (1.481)	1.760 (1.429)
Government stability	1.292 (0.890)	1.451* (0.892)	1.455*** (0.580)	1.471* (0.932)	1.626** (0.904)	1.454** (0.749)
Technology Effect						
Bureaucratic quality	-1.456** (0.760)	-1.800*** (0.708)	-0.236 (0.693)	-0.819 (1.382)	-0.792 (1.391)	0.529 (1.330)
Law and order	-0.171** (0.104)	-0.212*** (0.106)	-0.028 (0.082)	-0.096 (0.165)	-0.093 (0.166)	0.062 (0.157)
Government stability	-0.114 (0.133)	-0.141 (0.157)	-0.018 (0.058)	-0.064 (0.127)	-0.062 (0.127)	0.041 (0.113)
Total Effect						
Bureaucratic quality	10.060*** (4.685)	7.765** (4.587)	-0.261 (1.819)	11.984** (6.460)	8.564* (5.777)	1.419 (5.127)
Law and order	1.478 (1.559)	0.661 (1.489)	0.511 (1.333)	1.901 (1.527)	1.345 (1.490)	1.823 (1.437)
Government stability	1.178* (0.900)	1.310* (0.906)	1.436*** (0.582)	1.407* (0.941)	1.563** (0.913)	1.496*** (0.757)

Note: All standard errors are in parentheses and are robust to heteroskedasticity. Here, * = significance at the 15% level; * * = significance at the 10% level; *** = significance at the 5% level

Table 5. The Spillover Elasticity of Institutional Variables on Environmental Regulations

	Random Effects			Fixed Effects		
Weighting Matrix	Uniform Weight	GDP weight	FDI weight	Uniform Weight	GDP weight	FDI weight
Regulatory Enforcement Effect						
Bureaucratic quality	76.875*** (29.961)	25.855*** (11.844)	-12.915 (12.173)	75.747*** (31.926)	26.002** (15.602)	-8.508 (20.362)
Law and order	-1.432 (5.252)	-0.874 (2.674)	0.428 (1.869)	-1.881 (5.014)	-0.741 (2.564)	1.088 (2.646)
Government stability	5.040*** (2.063)	2.467** (1.300)	-0.381 (0.794)	4.816*** (2.167)	2.217* (1.486)	-0.335 (0.866)
Technology Effect						
Bureaucratic quality	-1.269 (3.928)	-1.707 (3.567)	1.287 (1.596)	-2.018 (4.070)	-2.002 (4.638)	1.650 (3.112)
Law and order	-0.149 (0.464)	-0.201 (0.424)	0.151 (0.193)	-0.237 (0.484)	-0.235 (0.550)	0.194 (0.371)
Government stability	-0.099 (0.325)	-0.134 (0.312)	0.101 (0.163)	-0.158 (0.359)	-0.157 (0.398)	0.129 (0.279)
Total Effect						
Bureaucratic quality	75.606*** (30.218)	24.148** (12.369)	-11.627 (12.277)	73.729*** (32.184)	24.000* (16.277)	-6.859 (20.599)
Law and order	-1.581 (5.273)	-1.074 (2.707)	0.579 (1.879)	-2.118 (5.037)	-0.977 (2.622)	1.282 (2.672)
Government stability	4.941*** (2.088)	2.333** (1.337)	-0.280 (0.811)	4.658*** (2.197)	2.060* (1.538)	-0.206 (0.909)

Note: All standard errors are in parentheses and are robust to heteroskedasticity. Here, * = significance at the 15% level; * * = significance at the 10% level; *** = significance at the 5% level

Appendix 1. *The role of institutions and neighboring country choices*

To ensure an interior solution for the choice of the legislated environmental tax rate,τ, we assume that V is concave in τ which implies that $V_{\tau\tau} < 0$. From (5), $V_{\tau t_j} = -\delta \frac{\partial^2 Z}{\partial Y_{di} \partial Y_{dj}} \frac{dY_{di}^*}{d\tau_i} \frac{dY_{dj}^*}{dt_j}$ so that,

(A1) $\frac{d\tau_i}{dt_j} = -\frac{V_{\tau t_j}}{V_{\tau\tau}} = \frac{\delta \frac{\partial^2 Z}{\partial Y_{di} \partial Y_{dj}} \frac{dY_{di}^*}{d\tau_i} \frac{dY_{dj}^*}{dt_j}}{V_{\tau\tau}}$.

Recall that $\frac{dt_i}{dt_j} = \theta(\boldsymbol{I_i}) \frac{d\tau_i}{dt_j}$. Since $\frac{dY_{di}^*}{d\tau_i} < 0$ and $\frac{dY_{dj}^*}{dt_j} < 0$, then $\frac{dt_i}{dt_j} < 0$ if $\frac{\partial^2 Z}{\partial Y_{di} \partial Y_{dj}} > 0$. However, when $\frac{\partial^2 Z}{\partial Y_{di} \partial Y_{dj}} < 0$, then $\frac{dt_i}{dt_j} > 0$.

To derive the effect of technology in the dirty sector on tax rates, we find,

(A2) $\frac{d\tau_i}{dA_{di}} = -\frac{V_{\tau A_{di}}}{V_{\tau\tau}}$.

From (5), $V_{\tau A_{di}} = \left(U_{G_i G_i} \frac{\partial G}{\partial A_{di}} \theta(\boldsymbol{I}) \tau_i - \delta \frac{\partial^2 Z}{\partial Y_{di}^2} \frac{dY_{di}^*}{dA_{di}}\right) \frac{dY_{di}^*}{d\tau_i}$. From envelope theorem, $\frac{\partial G}{\partial A_{di}} = (p_{di} - t_i) f(K_{di}) + t_i \frac{dY_{di}^*}{dA_{di}} > 0$. Since $U_{G_i G_i} < 0$, $\frac{\partial^2 Z}{\partial Y_{di}^2} > 0$ and $\frac{dY_{di}^*}{dA_{di}} > 0$, then $V_{\tau A_{di}} > 0$. Therefore, $\frac{d\tau_i}{dA_{di}} > 0$.

A similar method is used to derive the effect of technology in the clean sector on environmental taxes. We find,

(A3) $\frac{d\tau_i}{dA_{ci}} = -\frac{V_{\tau A_{ci}}}{V_{\tau\tau}}$.

From (5), $V_{\tau A_{ci}} = \left(U_{G_i G_i} \frac{\partial G}{\partial A_{ci}} \theta(\boldsymbol{I}) \tau_i - \delta \frac{\partial^2 Z}{\partial Y_{di}^2} \frac{dY_{di}^*}{dA_{ci}}\right) \frac{dY_{di}^*}{d\tau_i}$. From envelope theorem, $\frac{\partial G}{\partial A_{ci}} = f(K_{ci}) > 0$. Since, $\frac{dY_{di}^*}{dA_{ci}} < 0$ and $U_{G_i G_i} < 0$, then the sign of $V_{\tau A_{ci}}$ is ambiguous. Therefore, $\frac{d\tau_i}{dA_{ci}}$ is also ambiguous.

The effect of the institutional effectiveness on the environmental tax is, (A4) $\frac{d\tau_i}{d\theta(\boldsymbol{I_i})} = -\frac{V_{\tau\theta}}{V_{\tau\tau}}$.

From (5), $V_{\tau\theta} = \left(U_{G_iG_i}\frac{\partial G}{\partial \theta}\theta\tau_i + U_{G_i}\tau_i - \delta\frac{\partial^2 Z}{\partial {Y_{di}}^2}\frac{d{Y_{di}}^*}{dt}\tau_i\right)\frac{d{Y_{di}}^*}{d\tau_i}$. From envelope theorem, $\frac{\partial G}{\partial \theta} = t_i\frac{d{Y_{di}}^*}{d\theta} < 0$. Since $U_{G_iG_i} < 0$, then $V_{\tau\theta} < 0$. Therefore, $\frac{d\tau_i}{d\theta(\boldsymbol{I_i})} < 0$.

The effect of technology in the dirty sector from a neighboring country on own environmental tax is,

(A5) $\frac{d\tau_i}{dA_{dj}} = -\frac{V_{\tau A_{dj}}}{V_{\tau\tau}}$.

From (5), $V_{\tau A_{dj}} = -\delta\frac{\partial^2 Z}{\partial Y_{di}\partial Y_{dj}}\frac{d{Y_{dj}}^*}{dA_{dj}}\frac{d{Y_{di}}^*}{d\tau_i}$. Since $\frac{d{Y_{dj}}^*}{dA_{dj}} > 0$, then $\frac{d\tau_i}{dA_{dj}} > 0$ if $\frac{\partial^2 Z}{\partial Y_{di}\partial Y_{dj}} > 0$. However, $\frac{d\tau_i}{dA_{dj}} < 0$ if $\frac{\partial^2 Z}{\partial Y_{di}\partial Y_{dj}} < 0$.

The effect of technology in the clean sector from the neighboring country on environmental taxes is,

(A6) $\frac{d\tau_i}{dA_{cj}} = -\frac{V_{\tau A_{cj}}}{V_{\tau\tau}}$.

From (5), $V_{\tau A_{cj}} = -\delta\frac{\partial^2 Z}{\partial Y_{di}\partial Y_{dj}}\frac{d{Y_{dj}}^*}{dA_{cj}}\frac{d{Y_{di}}^*}{d\tau_i}$. Recall, $\frac{d{Y_{dj}}^*}{dA_{cj}} < 0$ and $\frac{d{Y_{di}}^*}{d\tau_i} < 0$. If $\frac{\partial^2 Z}{\partial Y_{di}\partial Y_{dj}} > 0$, then $\frac{d\tau_i}{dA_{ci}} < 0$ but the opposite holds when $\frac{\partial^2 Z}{\partial Y_{di}\partial Y_{dj}} < 0$.

The effect of the institutional effectiveness from a neighboring country on the environmental tax is,

(A7) $\frac{d\tau_i}{d\theta(\boldsymbol{I_j})} = -\frac{V_{\tau\theta(\boldsymbol{I_j})}}{V_{\tau\tau}}$.

From (5), $V_{\tau\theta(\boldsymbol{I_j})} = -\delta\frac{\partial^2 Z}{\partial Y_{di}\partial Y_{dj}}\frac{d{Y_{dj}}^*}{d\theta(\boldsymbol{I_j})}\tau_i\frac{d{Y_{di}}^*}{d\tau_i}$. Since $\frac{d{Y_{dj}}^*}{d\theta(\boldsymbol{I_j})} < 0$ and if $\frac{\partial^2 Z}{\partial Y_{di}\partial Y_{dj}} > 0$, then $V_{\tau\theta(\boldsymbol{I_j})} < 0$. Therefore, $\frac{d\tau_i}{d\theta(\boldsymbol{I_j})} < 0$. However, if $\frac{\partial^2 Z}{\partial Y_{di}\partial Y_{dj}} < 0$, then $\frac{d\tau_i}{d\theta(\boldsymbol{I_j})} > 0$.

Appendix 2. Data Sources

Variable	Description of Variables	Source
Environmental regulation stringency indicator	Difference between a polluting input's shadow price and its purchase price	Van Soest et al. (2006)
Bureaucratic quality	A measure of institutional quality of the bureaucracy in its role to minimize the effect of revisions of policy when governments change. The index ranges from 0 to 4 with 4 as a measure of high bureaucratic quality.	International Country Risk Guide published by The PRS Group, Inc
Law and order	This measure of institutional quality assesses the strength and impartiality of the legal system and the observance of the law. The index ranges from 0 to 6 with 6 as a measure of high observance of law and order.	International Country Risk Guide published by The PRS Group, Inc
Government stability	Assesses the government's ability to implement its programs and to stay in office. This index is composed of three subcategories: government unity, legislative strength and popular support. Each subcategory is given a score between 0 (high risk) and 4 (low risk). All scores are added which gives a measure of the stability index ranging from 0 (high risk of instability) to 12 (low risk of instability)	International Country Risk Guide published by The PRS Group, Inc
Trade openness	Sum of inward and outward foreign direct investment as a proportion of Gross Domestic Product lagged one year.	Devereux et al. (2008)
Consumer price index for energy	Measure the average changes in the prices of electricity, gas and other fuels purchased by households. Base year 2010.	OECD statistics
Gross capital formation	Consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories. Units are in constant 2005 dollars.	World Bank
Gross Domestic Product	Sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. Units are in constant 2005 dollars.	World Bank
Total Factor Productivity	Portion of output not explained by the amount of inputs used in production.	UNIDO
Foreign Direct Investment	Foreign direct investment inflow from trading partners in dollars.	OECD statistics