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Are environmentally related taxes effective?

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Abstract

This paper focuses on the question of whether the magnitude of long-established environmentally related taxes (ERT) is related to countries environmental performance. While environmental taxes efficiencies have previously been discussed, those taxes contribution to reducing pollution and improving environmental quality has not been fully explored. This paper therefore analyzes the effectiveness of environmental taxes by examining the environmental performance of 50 countries from all regions in association with the amount of revenues from environmentally related taxes each country collects. Using a cross-section regression and a panel dynamic regression, the paper finds that countries with higher revenues from these types of taxes also exhibit higher reductions in CO2 emission, PM10 emissions, and energy consumption and production from fossil sources.

JEL classification: H23, Q58, Q530.
Keywords: Environmental Tax; Environmental Policy; Pollution.

1 Introduction

In the economic literature, environmental taxes have been proposed as one of the main instruments for the mitigation of environmental problems such as pollution and climate change (e.g., Pigou , 1920). Such instruments are classified as incentive-based mechanisms, as it is argued that taxes create the right incentives for agents to refrain from polluting above the socially "accepted level", internalizing the external costs. They can also be more efficient than so called command-and-control mechanisms, and their administration costs tend to be low (Baumol and Oates , 1988). Pollution is an example of a negative externality that needs to be corrected, and taxes, fees and charges can induce polluters to internalize the cost of pollution they are imposing on the rest of society.

However, in the real world the debate is much more complicated. It is not easy to achieve a socially optimal outcome, and there is not a clear formula to establish the most efficient tax rate (e.g., Parry and Small , 2004, Newberry , 2004). Besides, as different studies have shown, environmental taxes may have some negative consequences. Wier et al. (2005), for example, concludes that environmental taxes in Denmark have undesirable consequences in terms of distributional effects, as those taxes are shown to be regressive. Similar results are found by Brännlund and Nordström (2004), West and Williams III (2004) for Sweden and the United States. These implications enhance the importance of compensatory mechanisms that should come with the adaptation of such measures.

Environmental taxes clearly have political costs that complicate their implementation. Nonetheless, countries have employed taxes that, despite not being established for environmental reasons, perform similarly to an environmental tax. Some of the best-known and most frequently implemented environmentally related taxes (ERTs) are taxes on the use of fossil fuels such as petrol (gasoline) and diesel, the widespread adoption of which is explained by their ability to raise large fiscal revenues. The efficiency and distributional consequences of those taxes have been examined in many studies. Beyond these considerations, however, environmental taxes have been continually constraining agents in the economy, possibly affecting the consumption of fossil fuels and other pollution-intensive goods. Relatively few studies have considered the effectiveness of those taxes in this regard.

The rates and number of ERTs varies considerably from country to country. While some countries may impose higher taxes as part of their environmental policy, others may grant huge subsidies for fossil fuel consumption or the use of other pollution inputs. These differences may be easily perceived when comparing levels of ERT revenues. In this paper, revenue from ERTs will be used as a proxy of the level and magnitude of ERTs. The majority of these revenues come from fuel and transport activities, and these fuel taxes have had the aim of raising revenue rather than reducing fuel use. Although ERTs were not originally established as an environmental policy instrument, they could perform well in dealing with some environmental problems, and it is therefore essential to determine the extent of such side effects.

Studies analyzing the short and long-run demand elasticities of fossil fuels have shown that their demand is not very price sensitive. However, in the long run fuel taxes can lead to a negative time trend in price elasticity, mainly driven by responses in fuel efficiency and mileage per car for the case of gasoline (Brons et al. , 2008). In this study we will focus on long-run impacts, and our proxy for ERTs may have the advantage of considering the general impact of different tax rates rather than of only one particular tax rate. Therefore, the idea of this work is to shed light on the association between the revenues from environmentally related taxes and the performance of some environmental variables. This work uses data from the OECD for 50 countries, mainly OECD countries but also including some countries from Latin America and Eastern Europe, as well as China and South Africa. The evidence here does not show any causal relationship or prove the efficiency of each environmental tax, but it does suggest that the magnitude and quantity of these taxes may affect environmental quality. In other words, countries that differ in revenues from environmental taxes experience different results in pollution abatement and environmental conservation.

Given global concern about climate change and pollution costs, market-based instruments may have the potential to mitigate those problems. Market-based instruments have been less used than command-and-control standards, [1] but some experiences have shown that, with a correct design and in the correct circumstances, these instruments can be appropriate for dealing with environmental problems.

Section 2 describes some of the literature on environmentally related taxes and their incidence. It is followed by Section 3, in which ERTs are defined and explained. This section also describes other variables taken into account. Section 5 shows the benchmark estimations using a cross-section approach, while Section 6 estimates a dynamic panel model using GMM. Finally, conclusions are presented in Section 7.

2 Literature Review

One main branch of the literature on the effects of environmentally related taxes on environmental performance focuses on carbon taxes, which are levied on fossil fuels and other products according to their carbon content in order to reduce CO2 emissions. For example, Gerlagh and van der Zwaan (2006) use a top-down energy demand model to analyze various instruments including carbon taxes. The authors find that a portfolio standard for carbon dioxide emission intensity by recycling carbon taxes as subsidies to non-fossil energy is the cheapest option for mitigating climate change in comparison to subsidies for non-fossil energy production and to carbon and fossil fuel taxes.

Bruvoll and Larsen (2004), using an applied general equilibrium simulation, analyze the effect of carbon taxes on emissions change in Norway. They found that carbon taxes had a modest effect on the reduction of CO2, contributing to a 2% decrease. The reduction in emissions per unit of GDP is significant, however, and the main effect was the reduction on energy intensity and process emissions. The main argument shared by some studies is the null effects of environmental taxes on CO2 emissions if they are accompanied by tax exemptions on energy-intensive industries and if they are applied to sectors with high inelastic demands. Liang et al. (2007) arrive at the same conclusion after using a CGE model to evaluate the impact of different carbon tax scenarios for China. In a scenario where energy and trade-intensive sectors are fully exempted and where all un-exempted sectors are subsidized, mitigation effects are very weak and exempted sector CO2 emissions rise. On the other hand, in this scenario the negative impacts of carbon taxes on GDP, employment and consumption are reduced, and output and exports in the trade-intensive sector are not affected.

In a forecast study on the effect of energy and carbon taxes on the energy system in Japan, Nakata and Lamont (2001) support the idea that these taxes are a suitable instrument for reducing

[1] typically known as regulations or standards that impose strict restrictions on activity or use of inputs

CO2 emissions. Wissema and Dellink (2007) studies the Irish case and finds that a reduction of 25% relative to the 1998 level of CO2 can be achieved with a carbon tax of 10 to 15 euros per ton of CO2. Di Cosmo and Hyland (2011), also taking into account the Irish case, use different tax scenarios to look at impacts on energy demand and carbon dioxide emissions. With a scenario of carbon tax increase from 21.5 euros in 2012 to 41 euros in 2025, the authors find that CO2 emissions will be reduced by 861,000 tons relative to a zero carbon tax scenario.

Some experiences with ERTs have been adversely affected by incorrect tax exemptions and poorly planned refund systems. Vehmas (2005) analyzes the experience of Finland with environmentally-based energy taxation and concludes that fiscally motivated deviations from the ideal environmental tax have undermined the real purpose of the tax.

Certain authors highlight the importance of fossil fuel taxes. For example, Sterner (2007) show the positive long-run effect of fossil fuel taxes in Europe in terms of reducing fuel demand and reducing carbon emissions. The author explains that carbon emissions are cut more than half by introducing high fuel taxes and the carbon content of the atmosphere is reduced by more than 1 ppm. In the same line, Yan and Crookes (2009) explain the importance of a scenario with fossil fuel taxes in order to deal with the rapid growth of vehicles and energy demand in China. This scenario leads to a potential reduction of 16.3% in energy demand, 18.5% in petroleum demand and 16.2% in GHG emissions by 2030 compared to the business as usual scenario.

Concrete empirical evidence has shown the effectiveness of some environmentally related taxes. Convery et al. (2007) underscore the effectiveness of the plastic bag levy in Ireland which started in 2002. One main result is that consumption of plastic bags in retail outlets fall by more than 90% and the annual revenues from this tax are around 13 million euros. Deyle and Bretschneider (1995) analyze waste taxes in United States, in particular taxes on land disposal, and find that higher taxes reduce wastes sent to landfills in comparison to other form of management.

Other works look at the effect of carbon taxes on emissions. Lin and Li (2011) use a difference in differences approach to analyze the effect of carbon taxes on per capita CO2 emissions. The authors find some significant effect in reducing CO2 emissions in Finland and a negative but not significant coefficient for the Netherlands, Denmark and Sweden. For Norway the effect was the opposite, an increase in CO2 emissions per capita, explained by the growth of energy products.

2.1 Hypothesis

As seen above, the introduction of environmental taxes can be effective in controlling pollution. When taxing energy or any pollution-intensive good, firms producing that good will internalize the social cost of pollution, which in the before-tax situation did not appear in the final price of that good. The price of these goods will thus increase with the tax and, therefore, the production of that good will decrease. Additionally, the resources freed up will help increase the production of environmentally friendly goods. Nonetheless, the effect of introducing these types of taxes could only be seen in long-term periods. Firms need time to substitute their inputs and production, and high demand inelasticity of energy goods will make also the environmental tax less effective in the short run. For this reason, we will initially consider periods of 15 years in the cross-sectional results and periods of at least two years in the dynamic GMM results when analyzing the impact of ERTs on pollution and pollution-intensive goods.

The hypothesis tested here is that countries that establish higher ERTs will have lower levels of pollution and less future production and consumption of non-renewable energy. A set of outcome variables for environmental pollution and fossil-related energy production and consumption is used. Environmental taxes will trigger agents in an economy to follow a diminishing path of energy consumption and pollution emission. Therefore, we expect a greater reduction in these variables in countries with higher initial ERTs. Initially, we will use the longest available period of the dataset, 15 years, by using a cross-sectional regression. To take advantage of the panel structure of the data and have more power for our regressions results, however, we will also use a dynamic system GMM to analyze the two or four-year change in our variables of interest. Using a GMM system allows us to deal with small sample bias, given that the number of time periods is small, with high persistence of variables.

3 Data Description

4 Environmentally Related Taxes

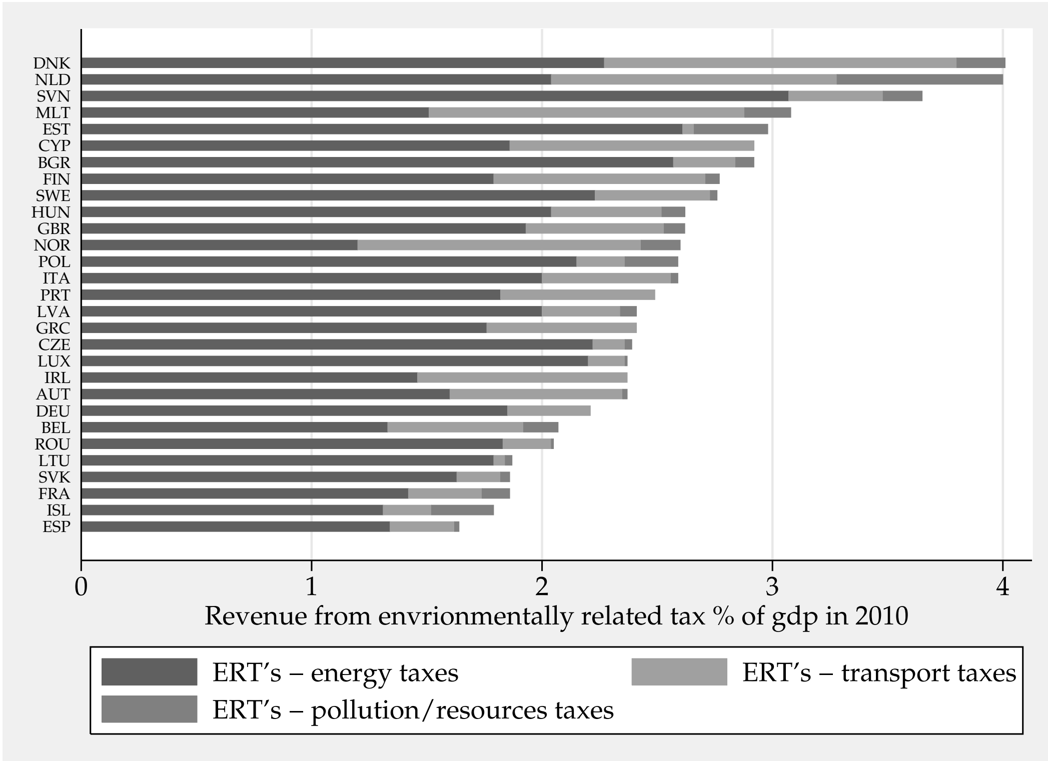
Environmentally related taxes are defined by the OECD as every payment to the general government levied on tax bases that have any environmental relevance[2]. Taxes are unrequited in the sense that benefits provided by government to taxpayers are not in proportion to their payments. Therefore, this definition takes into account the effect on relevant price elasticity and also implies that not every ERT was implemented with a specific environmental goal but does have, at least theoretically, a final positive impact on the environment. The main feature of ERTs is consequently that they incorporate the cost of pollution into final prices and thus create incentives for producers and consumers to change their behavior toward less environmental damage. The ERTs data analyzed in this paper were obtained from OECD, Eurostat and IEA[3].

Environmentally related taxes have been established in many countries and in different periods of time. The early 1990s witnessed increasing interest in environmental policy and the introduction of many "green" reforms; at that time Nordic countries were among the pioneers in implementing ERTs with a primarily environmental focus. Of these taxes, taxes on fuels are the most common type and generate the largest amount of revenues. Figure 1 shows that for most countries energy taxes are more important than pollution, resource and transport taxes.

[2] Value added taxes (VAT) are excluded.

[3] Information about environmentally related taxes and some data description can be found at http://www2.oecd.org/ecoinst/queries/

Figure 1. Revenue from Environmentally Related Taxes as Percentage of GDP in 2010



Source: OECD, Eurostats.

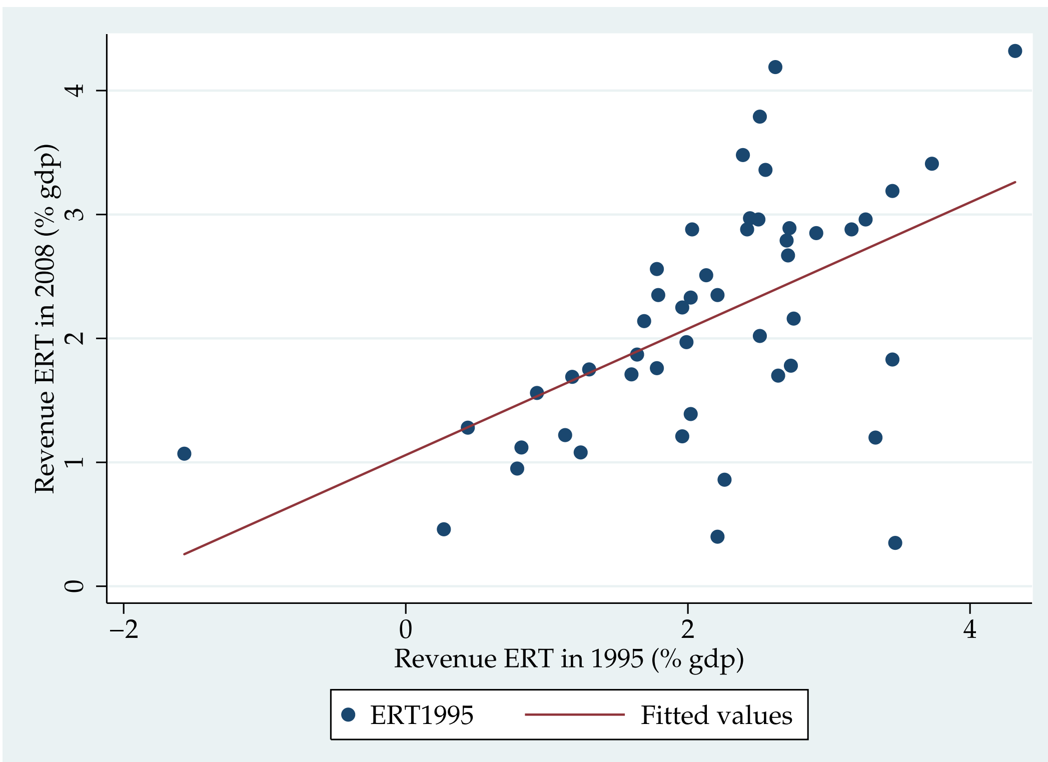
The variation in the level and timing of carbon taxes illustrates the overall divergence among countries' ERTs. Finland was the first to introduce a carbon tax in 1990 with a rate of $30 per metric ton of CO2, and Sweden adopted a carbon tax in 1991 with a rate of $105 per metric ton of CO2, while in the U.S. state of California a carbon tax was only introduced in 2008, with a rate of only $0.045 per metric ton CO2 (Summer et al. , 2009). It is important to note, however, that environmentally related taxes are not the only environmental instrument used and not always the most efficient one (O′Ryan et al. , 2003). In fact, this instrument has always been accompanied by command-and-control policies such as environmental standard regulations.

In this paper, revenues from ERTs as a percentage of GDP will be used as a proxy for ERTs. Information from OECD and the Eurostat database of 50 countries is available, mostly OECD countries but also including some countries of Latin America and Eastern Europe, as well as China and South Africa. Table A.5 in the Appendix shows all the countries and the average of some variables for the period of analysis between 1995 and 2010.

Higher revenues from ERTs will not necessarily be linked to higher tax rates, as a scenario with high consumption of lightly taxed goods is possible. Additionally, a more effective tax may diminish the base of the environmental tax, thereby reducing total revenue from ERTs. Nevertheless, this situation is not common, and countries with higher revenues from ERTs generally have higher tax rates (OECD , 2006). Most of the revenues from ERTs comes from taxes on motor fuels[4] and have existed for a long time. Furthermore, demand inelasticity from these goods is such that these taxes do not cause reductions in the base of the tax, and actually, these taxes are far from consistent with the environmental damage generated by motor fuel consumption (O′Brien and Vourc'h. , 2002, Albrecht , 2006). In contrast, taxes explicitly created to achieve environmental goals, better known as green taxes, have been in place for a relatively short time, and their revenues still represent only a small portion of total ERT revenues. The bulk of the growing tax base is still provided by energy use and transport activities, and most of these taxes are designed to raise revenue. Table A.3 in the Appendix extends this analysis and estimates several regressions to show the significant and positive correlation of revenues from ERTs with different fuel energy tax rates.

An interesting of ERT revenues is their very high persistence over time[5]. Figure 2 shows the correlation of ERTs in 1995 and those in 2008. For most countries the revenues from ERTs have not greatly changed over time.

Figure 2. Correlation of ERTs between 1995 and 2008



Source: OECD, Eurostats.

[4] More than 70% of the revenues from ERTs for the majority of countries comes from motor fuel taxes

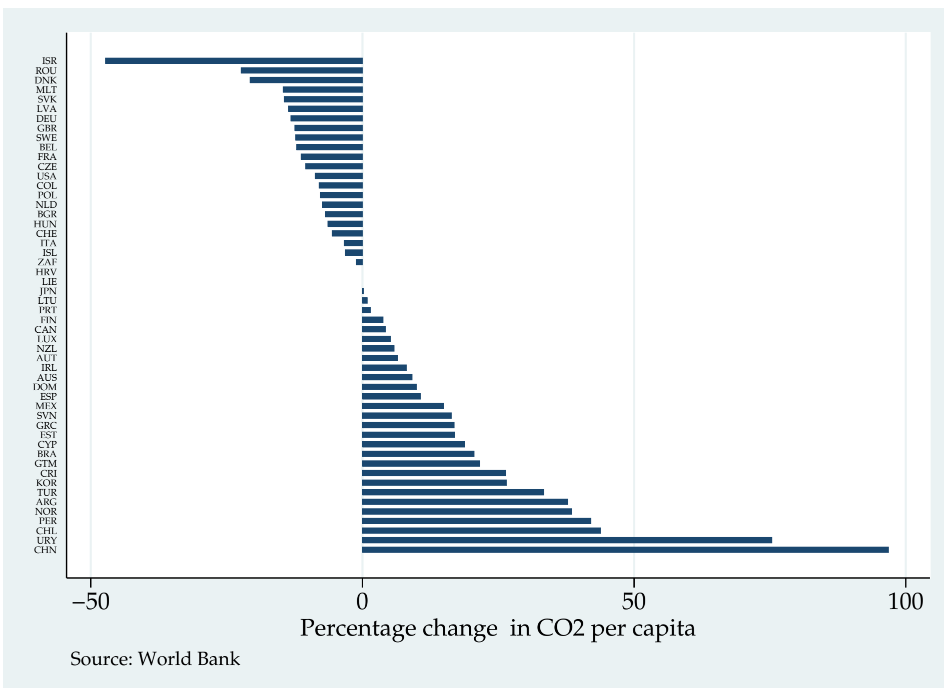
[5] The correlation of ERTs between 1995 and 2009 is 0.59

4.1 Environmental and Energy Variables

The change in nine environmental or energy variables will be analyzed. Non-renewable energy sources are an important pollution input that needs to be considered, including fossil fuels that remain the primary source for energy. All variables are obtained from the World Bank or the International Energy Agency and include the following: CO2 emissions per capita, forest area as percentage of land area, energy use per capita in kilograms of oil equivalent per US$1,000 GDP, fossil fuel energy consumption as a percentage of total energy consumption, electric power production from fossil fuel sources in kWh per capita, electric power production from renewable sources in kWh per capita, PM10 in micrograms per cubic meter, organic water pollutant emissions in kg per day and electric power consumption in kWh per capita[6]

Figure 3 shows the wide range of CO2 per capita percentage change among countries. Some countries such as China have increased their level of per capita CO2 emissions by almost 100%, while many othersespecially in Europehave achieved reductions[7].

Figure 3. Per Capita CO2 Emissions Change



Source: World Bank

Figures 4 and 5 show the scatter plot of the percentage change between 1995 and 2010 of eight of the environmental or energy variables and the revenue from ERTs as percentage of GDP

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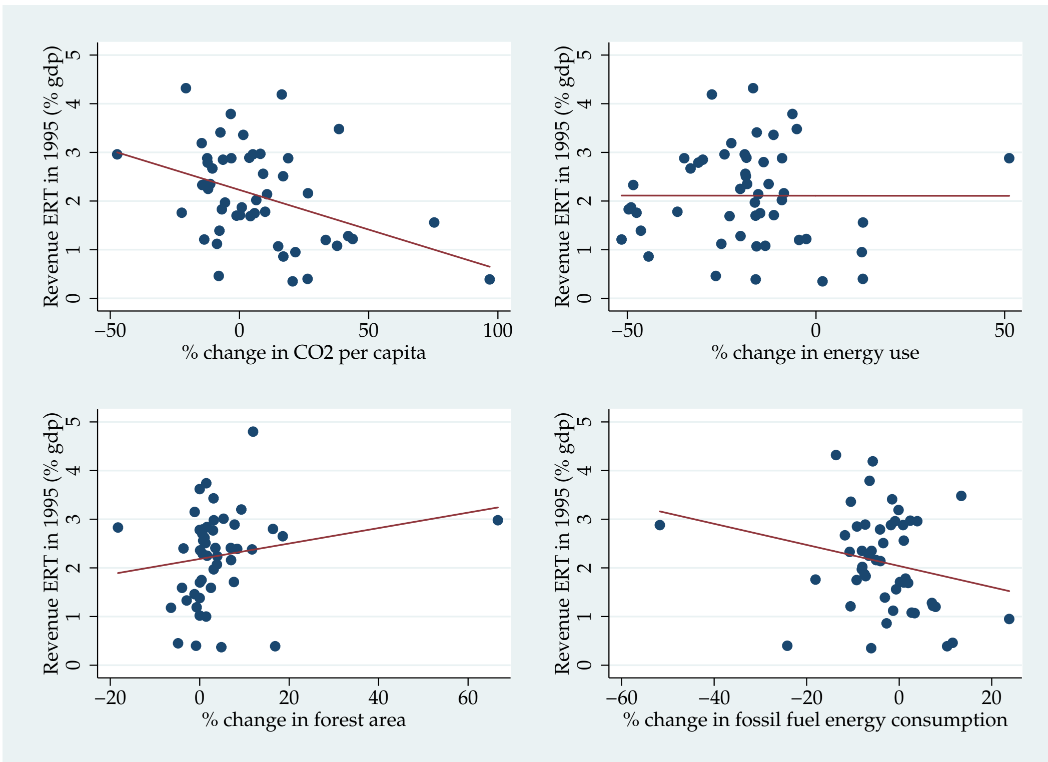
[6] A list of all the variables, the summary statistics and the sources can be seen in Section A of the Appendix.

[7] See Table A.2 in the Appendix for the summary statistics of the growth of all variables during the period 1995 to 2010.

in 1995 [8]. Some of these variables seem to have a clear correlation with the initial level of ERTs in 1995. CO2 emissions per capita during the period seem to have declined more in countries that had higher ERT revenues in 1995. For other variables such as PM10, energy use and electricity production from fossil fuels the relation is not clear. Furthermore, the percentage change during the period of analysis of variables as forest area and electricity production from fossil fuels resources is almost cero for many of the countries. Energy consumption increase is another variable that seem to be negatively correlated with higher ERTs in 1995.

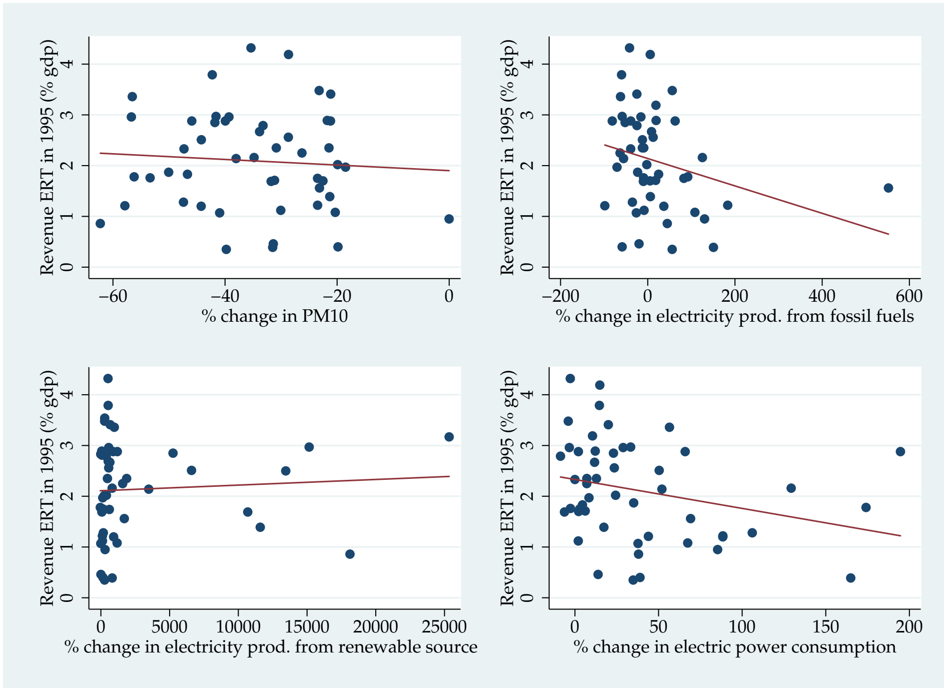
Figure 4. Correlations



Source: World Bank, IEA, OECD

8 Because of missing data, for the variable of forest area the period of analysis is 2000 to 2008 and the ERTs from 2000. For the variable of CO2 per capita the data go up to 2009.

Figure 5. Correlations (cont)



Source: World Bank, IEA, OECD

4.2 Other Variables

Several authors have analyzed different variables that may affect the change in pollution. The first variable that may impact the change in environmental variables is the level of GDP per capita in PPP constant prices. This variable measures the level of wealth and has been used in various empirical studies (Jobert et al. , 2002, Martin , 2008, e.g.,). Industrial intensity is also used as a proxy of the weight of polluting sectors in the economy. Economic growth, measured by GDP growth, has also been found to affect the level of pollution. As analyzed by Lin and Li (2011), the level of urbanization (percentage of population in urban areas) will be used. Finally, to include a level of environmental stringency, a dummy for countries with high regulatory stringency for the pollutants from automobiles[9].

5 Cross-Sectional Regressions

5.1 Methodology

The aim of the following empirical section is analyze the correlation of the change in different environmental or energy variables with the initial level of ERT. The achievement in environmental protection coming from environmental policies is determined mainly by its effects on the development and spread of new technologies (Kneese and Schultze , 1975). In this way, it is necessary

[9] The index was constructed by Perkins and Neumayer (2012) is used, and it is coded on a scale from 0 to 5. In this case it was transformed into a dummy for countries with regulation above 3.

to consider longer periods when looking for the effects of ERT. In particular, this first regression considers a period of 15 years for most of the variables. Different models of regressions will be used to analyze these relationships. At first, the following model is estimated:

$$\ln\left(\frac{EV_{2010}}{EV_{1995}}\right) = \alpha + \beta EV_{1995} + \gamma ERT_{1995} + \delta X + \varepsilon \quad (1)$$

where EV is one of the nine environmental variables mentioned above. Therefore, nine regressions are estimated to determine the change during the period between 1995 and 2010 [10]. The initial level of the environmental variable will be included in the regressors; the reason will be explained in further detail in the next section. The main variable of interest will be ERTs in the initial year. Finally, X includes all the control variables. In this first part, only GDP per capita in 1995, GDP growth, and the percentage of urban population will be used [11] and ε the error term.

5.2 Results

Table 1 shows the nine estimations for each variable measuring environmental performance. Most of the signs of the coefficients of the ERTs variable show that revenue from ERTs is correlated with better environmental performance. Higher levels of revenue from environmentally related taxes are associated with a decrease in the level of CO2 emissions per capita, energy consumption, fossil fuel energy consumption, water pollutants and PM10. At the same time, greater revenues from ERTs in the initial year are positively correlated with increase in forest area and electricity production from renewable sources. The coefficients of revenue from ERTs in 1995 are statistically different from zero when using the percentage change of CO2 emissions per capita and PM10 as dependent variables[12].

[10] Because of missing data, the period of analysis for the estimation using the variable of forest area is from 2000 to 2010; when using water pollutants the period goes from 1995 to 2002; data on CO2 emissions per capita go from 1995 to 2009.

[11] Robustness checks including as variables environmental stringency, environmental concern, energy use, industrial intensity and a dummy for Western European countries were also estimated.

[12] Regressions are robust when changing some of the controls.

Table 1. Regressions Using Percentage Change of the Variables

VARIABLES	(1) $CO2pc$	(2) $PM10$	(3) $Water\ pol$	(4) $Energy$	(5) $Electricity$	(6) $F\ Fuel$	(7) $Fossil\ El$	(8) $Renew.\ El$	(9) $Forest$
ERT_{95}	-0.0730**	-0.0414*	-0.0462	-0.0194	0.0440	-0.0231	0.00710	13.88	0.000862
	(0.0334)	(0.0235)	(0.0523)	(0.0261)	(0.0702)	(0.0196)	(0.131)	(13.18)	(0.0122)
$Dependent\ variable_{95}$	-0.0164	0.000709	-4.78e-09	-0.000299	4.88e-06	0.00144	-2.05e-05	-0.0283***	-0.00172
	(0.0102)	(0.000515)	(3.23e-08)	(0.000617)	(2.66e-05)	(0.00174)	(5.54e-05)	(0.0103)	(0.00108)
$lnGDPpercap_{95}$	0.00730	0.0516	-0.0553	-0.0373	-0.387*	-0.0326	-0.730*	-10.03	0.0360
	(0.0957)	(0.0481)	(0.0868)	(0.0444)	(0.221)	(0.0306)	(0.412)	(22.18)	(0.0233)
$GDP\ growth$	0.0249	-0.191**	-0.0301	-0.317**	0.369	-0.0783	0.0325	76.49*	0.110***
	(0.124)	(0.0939)	(0.131)	(0.147)	(0.252)	(0.0601)	(0.509)	(41.03)	(0.0379)
$Urban\ population$	-0.105	-0.119	0.201	0.115	0.619	-0.0675	2.428	22.03	0.0401
	(0.355)	(0.191)	(0.309)	(0.259)	(0.560)	(0.141)	(1.878)	(36.21)	(0.127)
$Constant$	0.337	-0.631	0.498	0.327	3.434*	0.303	5.540*	50.69	-0.315
	(0.855)	(0.489)	(0.979)	(0.390)	(1.791)	(0.367)	(3.105)	(192.0)	(0.254)
Observations	50	49	40	50	50	50	49	49	50
R-squared	0.255	0.207	0.070	0.311	0.266	0.149	0.204	0.189	0.164

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The coefficients suggest that revenue from ERTs is a good proxy of the level of taxes, discouraging the consumption of pollution inputs and reducing emissions of CO2 and PM10. Moving a country from the first to the fifth quintile of the distribution of revenues from ERTs in 1995 implies on average a decrease in the growth rate of CO2 emissions per capita and PM10 by 12.2% and 6.9% points, respectively, over the 15-year sample period. With respect to the variables of energy and fossil fuel consumption, the lower growth rate is 3.2% points and 3.8% points, respectively. On the other hand, the results would imply an increase in the growth rate of forest area, electricity production from renewable sources, electricity power consumption, and electricity production from fossil sources of 0.1, 23.3, 7.3 and 0.1 percentage points, respectively [13].

5.3 Disaggregation of ERT

Taking into account the variety of taxes, Table 2 disaggregates revenue from ERTs into three main taxes: energy taxes, transport taxes and pollution taxes. The information is available for the period of analysis for only one set of countries, all European[14]. Energy taxes include taxes on energy products for transport purposes such as petrol, diesel, natural gas and others, and taxes on energy products for stationary purposes (coal, biofuels, heavy fuel oil, electricity consumption and production, and district heat consumption and production, among others). Transport taxes include taxes on motor vehicles, road use, congestion taxes, flights, use of motor vehicles and other means of transport. Finally, pollution taxes include taxes for emissions in the air (NO_x, SO2 contents, etc.), for ozone-depleting substances, for effluents to water, water pollution, water pollution and noise. The other classification of taxes includes resource taxes, in particular taxes on water abstraction, timber, fishing, extraction of raw materials and other resource extraction. This final classification was computed together with pollution taxes.

[13] In A of the Appendix the same regression is estimated as in Table A.4 but using a Seemly Unrelated Regression (SUR) model. The reason for estimating a SUR is the possible existence of correlated errors across the equations and therefore the efficiency of the estimator could be increased. The sample period for this regression is 1995 to 2008 because of missing years in the variables for forest area and water pollutants.

[14] Data from Eurostat

The results using the change in CO2 emissions per capita are presented in Table 2. The same variable controls were included as in Table 1 but, given that this disaggregation of revenue is not available for all countries, there are fewer observations than in the previous estimates. Higher revenue from energy taxes is negatively correlated with the increase of CO2 emissions per capita and significant, and the same occurs with revenues from pollution taxes. On the other hand, the coefficient is positive for transport taxes, but the null hypothesis of being zero is not rejected.

Table 2. Regression with Disaggregated Taxes Using CO2 Emissions Per Capita as Dependent Variable

VARIABLES	(1)	(2)	(3)	(4)
energy_tax95	-0.0643*			-0.0502
	(0.0357)			(0.0456)
transport_tax95		0.0477		0.0192
		(0.0403)		(0.0434)
pollution_tax95			-0.157	-0.202
			(0.108)	(0.122)
Observations	28	28	25	25
R-squared	0.449	0.456	0.429	0.466

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Including all Controls

6 GMM System Regressions

6.1 Methodology

The aim of this section is to estimate a dynamic panel model and to avoid inconsistent estimators once the lagged regressor is introduced. For this purpose Generalized Methods of Moments (GMM), proposed by Blundell and Bond (1998) and based on the Arellano-Bond method, are used. A two-step estimator is applied, using the level equation and the first difference regression equation, where the first order difference variables and the lagged variables are employed as instrument variables for the level and first difference equation, respectively [15]. As explained above, the effects of environmental policy should be long term and it is therefore preferable to consider periods longer than a year. For this panel, periods of two and four years will be used [16].

The following model will be estimated to capture the effect of the growth of each environmental or energy variable during the last two or four years:

[15] The assumption of $E(y_{i,s}\Delta\varepsilon_{i,t}) = 0$ and of $E(\Delta y_{i,t}\varepsilon_{i,s}) = 0$ for $s \geq t - d$ are necessary, where d is the interval lagged periods used in the regression.

[16] Regressions for a three-period interval was also estimated and showed similar results.

$$\ln\left(\frac{EV_t}{EV_{t-d}}\right) = \alpha - blnEV_{t-d} + \gamma ERT_{t-d} + \eta lnGDP_{t-d} + \delta X_t + \theta_t + \varepsilon_{it} \; where \; d = 2,4 \quad (2)$$

$b = 1 - e^{-\beta}$ where β captures the speed of convergence. X represents the control variables including GDP growth during the last 2 or 4 years, industrial intensity, urban population and a dummy for high regulation in pollutants from automobiles as a proxy of environmental regulatory stringency. θ captures time fixed effects.

6.2 Results

Tables 3 and 4 show the GMM estimations using a period lag of two and four years[17]. The p values from the AR test show that the second order residuals are not correlated and therefore the estimators are consistent. Likewise, the p value from the Hansen test implies validity of the instruments as the instruments appear to be exogenous for all regressions.

The main findings for the first table can be summarized as follows. The growth rates of CO2 emissions per capita, energy consumption, fossil fuel consumption, PM10, electricity production from fossil sources and water pollution are negatively correlated with the lagged level of revenue from ERT. On the other hand, the growth rates of electricity consumption and electricity production from renewable sources are positively correlated. Coefficients are significant with a 95% level of confidence when using CO2 emissions per capita, PM10, electricity production from fossil sources and electricity production renewable sources as dependent variables [18]. For an average country, an increase of revenue from ERTs as percentage of GDP by 1% point implies a reduction in 5.4% points in the growth rate of CO2 emissions during the two next years.

In Table 4, the growth of CO2 emissions per capita, energy use and electricity production from fossil sources continue to present negative correlation with the variable of ERT[19]. Contrary to previous estimations, the coefficient of the lagged revenue from ERTs and the growth rate of fossil fuel consumption and PM10 are now positive. For the former, the coefficient is significantly different from zero, but in the latter the coefficient is not statistically different from zero. On average, an increase of one percentage point of revenue from ERTs as a percentage of GDP is associated with an increase in electricity production from renewable sources in 33% points. In contrast, the same increase implies a reduction in 16% and 14% points in the growth rate of CO2 emissions per capita and energy consumption, respectively.

[17] For the variable of forest area the GMM estimation was not made because there are only two or three observations per country (for the years 2000, 2005 and 2010).

[18] Estimations are robust when modifying controls and excluding time fixed effects.

[19] Because of many missing years for the variable for water pollutant, the regression using an interval period of four years was not estimated.

Table 3. Panel GMM Estimation Using Interval Periods of Two Years

VARIABLES	(1) $CO2pc$	(2) $PM10$	(3) $Water\ pol$	(4) $Energy$	(5) $Electricity$	(6) $F\ Fuel$	(7) $Fossil\ El$	(8) $Renew.\ El$
ERT_{-2}	-0.0542**	-0.0804***	-0.0614	-0.0206	0.00823	-0.00605	-0.214*	0.296**
	(0.0261)	(0.0271)	(0.0449)	(0.0197)	(0.0228)	(0.00747)	(0.125)	(0.137)
$Dependent\ variable_{-2}$	-0.289***	-0.0399	0.0159	-0.128**	-0.183***	0.0711	0.0610	-0.511***
	(0.104)	(0.0679)	(0.0312)	(0.0480)	(0.0483)	(0.0578)	(0.0461)	(0.114)
$lnGDPpercap_{-2}$	0.280***	0.0480	0.0286	0.0121	0.200***	0.00741	0.205	0.287
	(0.0976)	(0.0438)	(0.0485)	(0.0182)	(0.0687)	(0.00734)	(0.126)	(0.419)
$GDP\ growth$	1.087***	0.0975	0.543	-0.210	0.778***	0.178***	1.908*	-4.159
	(0.186)	(0.171)	(0.371)	(0.144)	(0.117)	(0.0474)	(1.081)	(2.486)
Observations	-2.147***	-0.165	-0.359	0.519	-0.631**	-0.379	-3.248*	6.586*
	(0.787)	(0.606)	(0.710)	(0.358)	(0.280)	(0.263)	(1.718)	(3.571)
Observations	275	269	172	303	275	303	296	276
Number of country_id	48	47	37	48	48	48	48	47
AR(2)	0.00124	0.00655	0.0373	0.000487	0.0374	0.00140	0.00358	0.0590
AR(4)	0.341	0.670	0.329	0.816	0.486	0.190	0.0245	0.289
Hansen Test	0.914	0.671	0.678	0.862	0.763	0.991	0.897	0.990

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Controls: Industrial intensity, urban population, high regulation dummy. Including constant and time fixed effects

Table 4. Panel GMM Estimation Using Interval Periods of Four Years

VARIABLES	(1) $CO2pc$	(2) $PM10$	(3) $Energy$	(4) $Electricity$	(5) $F\ Fuel$	(6) $Fossil\ El$	(7) $Renew.\ El$
ERT_{-4}	-0.162***	0.0114	-0.143**	0.0661	0.0314*	-0.111	0.336
	(0.0587)	(0.0231)	(0.0538)	(0.0572)	(0.0174)	(0.257)	(0.307)
$Dependent\ variable_{-4}$	-0.0921	0.215**	-0.0326	-0.0770	0.417***	0.224**	-0.462**
	(0.138)	(0.0808)	(0.137)	(0.198)	(0.133)	(0.104)	(0.190)
$lnGDPpercap_{-4}$	0.200	0.118**	0.109**	0.0127	-0.00836	0.0159	0.115
	(0.139)	(0.0555)	(0.0456)	(0.256)	(0.0278)	(0.275)	(0.516)
$GDP\ growth$	0.746**	0.237	-0.306	0.296	0.131	0.330	-2.449
	(0.310)	(0.234)	(0.269)	(0.364)	(0.130)	(1.167)	(2.749)
Observations	123	120	123	123	123	120	108
Number of country_id	48	47	48	48	48	47	46
AR(4)	0.221	0.00372	0.102	0.185	0.00753	0.109	0.0760
AR(8)	0.646	0.879	0.653	0.482	0.800	0.930	0.347
Hansen Test	0.517	0.526	0.295	0.701	0.380	0.734	0.682

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Controls: Industrial intensity, urban population, high regulation dummy. Including constant and time fixed effects

7 Conclusion

Table 5 summarizes all the previous estimations according to each environmental or energy variable and includes the coefficient signs of the estimators. The most notable result from all estimations is the effect of ERTs on the growth of CO2 emissions per capita: all estimations show a clear negative relation between revenue from ERTs and the growth of this variable. As CO2 emissions are driven by a variety of economic activities, it is therefore not surprising to find that this variable is the one most affected by the level of total ERTs. It could be useful for future analysis to study the effect of ERTs on each economic activity on the CO2 emissions generated by that specific activity.

The results from energy use as a dependent variable are also very robust and significant for some estimations. PM10, with the exception of the last estimation, also shows also a negative and significant correlation. Higher revenue from ERTs is also associated with lower electricity production from fossil sources but higher production from renewable sources. On the other hand, electricity consumption seems to have grown more in countries with higher revenues from ERT.

Table 5. Effects of ERTs Using Different Estimations

Dependent Variable (% change)	Cross Section Regression	SUR estimation	GMM 2 lags estimation	GMM 4 lags estimation
CO2 emissions per capita	$-**$	$-*$	$-**$	$-***$
Energy use	$-$	$-$	$-$	$-**$
PM10	$-*$	$-$	$-***$	$+$
Electricity production fossil sources	$+$	$-$	$-*$	$-$
Water pollutant	$-$		$-$	
Fossil fuel energy consumption	$-$	$-$	$-$	$+*$
Electric power consumption	$+$	$+$	$+$	$+$
Electricity prod. from renewable sources	$+$	$+$	$+**$	$+$
Forest area	$+$			

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Countries with higher revenues from ERTs seem to perform better in the environmental domain. This means lower emissions, including CO2 and PM10 levels, decreasing water pollutants, and reducing energy consumption and production, especially from fossil fuel sources. Revenues from ERTs come mainly from fuel taxes, and most of these taxes were introduced to increase revenues rather than reduce fuel consumption or improve environmental quality. These results suggest that, while fuel taxes may not be as effective or efficient as the literature had argued, they did have some impact on environmental quality. For example, higher fuel taxes can lead to higher fuel efficiency, and it seems to do so when long-run impacts are analyzed, as this study does. Additionally, the effects on pollution can be at a local level, as shown with PM10, or at a more national level as occurs with CO2 emissions. Although previous studies have questioned the effectiveness of ERTs and highlighted their inefficiencies, the results from this work show that, despite all, ERTs are effective. Therefore, this market-based instrument has considerable potential for dealing with environmental problems.

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A Appendix Tables

Appendix Table A.1. List of variables

Variable	Meaning	Mean	SD	Source
ert_pgdp	Revenues from ERT's as perc. of GDP	2.4	0.8	OECD, Eurostat
CO2 pc	CO2 emissions (metric tons per capita)	7.6	4.4	World Bank
Forest	Forest area (perc. of land area)	32.6	18.2	World Bank
Energy	Energy use (kg of oil eq.) per 1000 GDP (const. 2005 PPP)	170	73.8	IEA
combustible_renewable	Combustible renewables and waste (perc. of total energy)	8.6	9.6	IEA
F Fuel	Fossil fuel energy consumption (perc. of total)	76.4	16.8	IEA
Electricity	Electric power consumption (kWh per capita)	6,387.2	5,764.6	IEA
Water pol	Organic water pollutant (BOD) emissions (kg per day)	334,294.8	942,027.2	World Bank
PM10	PM10, country level (micrograms per cubic meter)	34.6	25.6	IEA
Fossil El	Electricity production from oil and coal sources (kWh per capita)	2179.9	2159.8	IEA
Renew. El	Electricity prod. from renewable sources(kWh per capita)	364.2	1171.4	IEA
gdp_growth	GDP growth (annual perc.)	3.8	3	World Bank
ln gdp_per_cap	ln GDP per capita, PPP (const 2005 int.)	9.77	0.66	World Bank
Urban population	Percentage of urban population	0.71	0.15	World Bank
industrial_intensity	Industrial value / gdp	2.7%	6.3%	World Bank
RD	Research and development expenditure (per. of gdp)	1.4	1	World Bank
environmenta_concern	Per. of population that strongly agree to give part their income and accept an increase in taxes for the environment	9.5%	5.2%	World Value Survey
ESI2002	Environmental sustainability index in 2002	62.4	15.2	World Economic Forum, Yale Center for Environmental Law and Policy, and CIESIN
High regulation	Dummy for countries about 3 in the scale from 0 to 5 of regulation stringency for automobile pollutants	0.49	0.50	Perkins and Neumayer (2012)

Source: OECD, Eurostat, World Bank, IEA

Appendix Table A.2. Environmental Variables: Percentage Change between 1995 and 2010

Variable	Mean	SD	Min	Max
Growth of CO2 emissions per capita	7.1	24.7	-47.3	96.8
Growth of energy use	-19.3	15.5	-57.7	32.5
Growth of fossil fuel consumption	-2.2	9.4	-44.1	17.6
Growth of PM10	-31.2	12.3	-56.3	-9.1
Growth of electricity production from fossil sources	30.5	71.9	-98.9	120.6
Growth of electricity production from renewable sources	919.6	154.3	-42.1	6530.1
Growth of electricity consumption	41.6	45.0	-3.9	187.8

Source: World Bank, IEA

Appendix Table A.3. Regressions Using Revenue from ERTs (as percentage of GDP) against Energy Taxes (constant US dollars, using PPP, per unit)

	Revenue from ERTs	
ERT varible	Coefficient	Std. Error
Light Fuel Oil	0.0015	0.0001***
Diesel	1.83	0.114***
Premium Leaded	2.07	0.151***
Unleaded Gasoline	1.83	0.098***
High Sulfur Oil	0.01	0.001***
Natural Gas	0.19	0.018***
Steam Coal	0.003	0.003
Coking Coal	0.03	0.006***
Electricity	0.01	0.004***

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: All estimations include time and country fixed effects. Units: sulfur fuel oil, steam coal and coking coal in tons; light fuel oil in thousand liters; diesel, unleaded and leaded gasoline in liters; natural gas and electricity in MWh.

Appendix Table A.4. SUR using percentage change of the variables

VARIABLES	(1) $CO2pc$	(2) $PM10$	(3) $Energy$	(4) $Electricity$	(5) $F\ Fuel$	(6) $Fossil\ El$	(7) $Renew.\ El$
ERT_{95}	-0.0673*	-0.0363	-0.0169	0.0492	-0.0145	-0.0132	9.685
	(0.0400)	(0.0247)	(0.0271)	(0.0756)	(0.0186)	(0.199)	(6.166)
$Dependent\ variable_{95}$	-0.0106	0.000281	-0.000201	-5.51e-06	.000425	-2.38e-05	-0.0131
	(0.00863)	(0.00102)	(0.000380)	(2.32e-05)	(0.000981)	(8.36e-05)	(0.0180)
$lnGDPpercap_{95}$	-0.0490	0.0395	-0.0348	-0.324	-0.0471**	-0.940*	-5.181
	(0.101)	(0.0480)	(0.0421)	(0.200)	(0.0233)	(0.537)	(10.54)
$GDP\ growth$	0.0292	-0.157**	-0.301***	0.266	-0.0727	-0.619	52.40***
	(0.140)	(0.0707)	(0.0753)	(0.231)	(0.0455)	(0.500)	(18.06)
$Urban\ population$	-0.0430	-0.0583	0.174	0.644	-0.0468	3.515	15.28
	(0.364)	(0.167)	(0.226)	(0.565)	(0.126)	(2.420)	(23.81)
$Constant$	0.781	-0.516	0.237	2.920*	0.499**	7.294*	13.57
	(0.877)	(0.471)	(0.373)	(1.721)	(0.233)	(3.987)	(93.91)
Observations	48	48	48	48	48	48	48
R-squared	0.260	0.227	0.423	0.215	0.197	0.220	0.288

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Robust Standard errors

Appendix Table A.5. Countries

country	Mean			
	ERTs % Revenue	ERTs % GDP	CO2 emissions (metric tons per cap)	GDP per capita
Argentina	5.2%	1.3%	4.0	10564
Australia	8.0%	2.3%	17.7	30201
Austria	5.9%	2.5%	8.2	31890
Belgium	5.1%	2.3%	10.8	30448
Brazil	5.7%	1.9%	1.9	8218
Bulgaria		2.5%	6.2	8322
Canada	4.0%	1.4%	16.6	32474
Chile	7.0%	1.4%	3.8	11684
China	4.5%	0.7%	3.5	3306
Colombia	2.2%	0.3%	1.5	7070
Costa Rica	7.8%	1.6%	1.5	8460
Cyprus		3.1%	7.3	23041
Czech Republic	7.6%	2.7%	12.0	19027
Denmark	9.6%	4.7%	9.9	31613
Dominican Republic	15.0%	2.1%	2.2	5937
Estonia	5.7%	1.7%	12.6	13333
Finland	6.9%	3.1%	11.4	27964
France	4.9%	2.1%	6.2	28123
Germany	6.6%	2.4%	10.3	30444
Greece	7.0%	2.3%	8.4	21768
Guatemala	6.9%	0.9%	0.9	3983
Hungary	7.7%	3.0%	5.7	14722
Iceland	7.6%	2.8%	7.5	30970
Ireland	8.6%	2.6%	10.3	37514
Israel	8.2%	3.0%	9.1	22655
Italy	7.5%	3.1%	7.8	27489
Japan	6.4%	1.7%	9.6	29502
Korea, Rep.	11.8%	2.7%	9.3	20130
Latvia		2.3%	3.2	10364
Lithuania		2.3%	4.1	11581
Luxembourg	7.5%	2.8%	20.9	61486
Malta		3.5%	6.6	20230
Mexico	5.6%	0.9%	3.9	11601
Netherlands	9.4%	3.7%	10.8	33515
New Zealand	4.6%	1.6%	8.1	23169
Norway	7.2%	3.0%	8.8	44526
Peru	5.9%	0.9%	1.2	6025
Poland	5.6%	1.9%	8.3	12358
Portugal	9.8%	3.0%	5.8	20586
Romania		2.4%	4.6	8320
Slovak Republic	6.5%	2.2%	7.4	14447
Slovenia	7.2%	3.2%	7.8	21019
South Africa	10.1%	2.7%	8.6	8132
Spain	6.0%	2.1%	7.3	25338
Sweden	5.8%	2.8%	5.9	29772
Switzerland	7.1%	2.0%	5.6	34747
Turkey	12.2%	2.9%	3.4	10318
United Kingdom	7.8%	2.7%	9.2	29790
United States	3.5%	1.0%	19.2	39547
Uruguay	6.4%	1.4%	1.7	9564
Total	7.1%	2.4%	7.6	21028

Source: OECD, Eurostat, World Bank, IEA