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Do Environmental Taxes Improve Environmental Quality? Evidence from OECD Countries*

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Abstract

This article investigates the relationship between environmentally related taxes introduced in OECD countries and air pollution, represented by carbon dioxide and greenhouse gas emission levels in the atmosphere. The article makes a statistical analysis of data on environmental taxes, specifically energy and transport taxes, and other variables that might affect air quality in the OECD member countries. The ARDL model used on the panel data of all OECD member countries shows statistical significance in only one out of five models. A subsequent comparative analysis of the reduced sample of OECD countries that are members of the EU exhibits a statistically significant effect of environmentally related tax revenues on the air emission levels, indicating that this relationship is present in the reduced sample.

Keywords: Environmentally related taxes, environmental taxation, air pollution, air emissions, ARDL model

JEL Classification: H20, Q53, C23

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Introduction

The environment is a vital factor in our lives, and the way we interact with it in the present defines our future. The industrial revolution has increased the number and effectiveness of life-changing innovations; however, the price paid for the development was environmental quality.

The Intergovernmental Panel for Climate Change (IPCC) reports human-induced warming of global temperatures of about 1°C above pre-industrial levels (Allen *et al*., 2019). Countries around the world have recently started to take measures to mitigate this climate change. The Kyoto Protocol and the Paris Agreement that followed are tools that help countries cooperate and agree on actions that must be taken to tackle environmental issues.

Environmentally related taxes are one of many ways of dealing with the so-called negative externalities of human activities (Coase, 1960), such as water and air pollution, resource depletion, biodiversity loss, *etc*. The concept was first introduced by Pigou (1920), and later the idea behind it found its way into policies of governments around the world. In the 1990s, the Scandinavian countries started to introduce environmental taxes into their tax mixes, soon followed by others.

The aim of this article is to examine the effectiveness of environmentally related taxes in their relation to environmental quality. This hypothesis will be tested using a dynamic panel data analysis.

1. Measures and Instruments to Reduce Emissions

One of the agreements addressing climate change was signed by the United Nations in Kyoto in 1997 (Kyoto Protocol). It was in force from 2005, and it aimed to reduce emissions of six greenhouse gases (GHG) by the year 2020. As of 2021, there are 192 countries that signed the Protocol (UN, 2021b). The effectiveness of the protocol has, however, been questioned. Firstly, because two major contributors to air pollution, China and the USA, chose not to commit to the protocol. In addition, one of the most recent studies by Almer and Winkler (2017) suggests that there is little evidence that emissions have decreased in the countries studied (only in Finland, Norway and Sweden), while other countries have even worsened their results. On the other hand, some studies, such as Grunewald and Martinez-Zarzoso (2016), find significant reduction of carbon dioxide emissions by 7%. What most studies agree on is the fact that more serious measures must be taken in order to achieve the targeted emission levels in all the countries. In 2015, the Paris Agreement was signed as a separate instrument to ensure that the second commitment period of the Kyoto protocol would be in effect. The aim of the agreement is to maintain the rise of global temperatures at a maximum of 2°C above the pre-industrial level by 2025 or 2030. Overall, 195 countries have signed, and 189 countries have ratified the agreement by February 2021 (UN, 2021a).

Germanwatch (2019) analysed 57 countries' and the European Union's compliance with their Paris Agreement goals and ranked them in accordance with their indices. The 4th place of the overall results is held by Sweden (the top three positions are vacant). The last, 61st position is held by the USA.

Regarding policies that consider only European countries, the European Environment Agency (EEA) has introduced the Environmental Tax Reform (ETR) to help them meet their carbon emission targets stated in the Protocol. It has resulted, among others, in Council Directive 2003/96/EC of 27 Oct 2003 Restructuring the Community Framework for the Taxation of Energy Products and Electricity (ETD). It was subsequently amended by Directive 2009/28/EC of the European Parliament and of the Council of 23 Apr 2009 on the Promotion of the Use of Energy from Renewable Sources, whose goals were aimed at 20% renewable energy usage in the EU by the year 2020. Afterwards, Directive 2018/2001 of the European Parliament and of the Council of 11 Dec 2018 on the Promotion of the Use of Energy from Renewable Sources joined it, setting the target of 32% of renewable energy out of all energy generation by the year 2030.

Rathi (2019) stated that the UK has consumed less energy than in 1970. Mathis (2021) says that renewable energy surpassed coal for the first time in European countries, generating 38% of energy in EU. It is possible to make a conclusion that results of the rules set in the directives are showing.

Furthermore, the ETD underwent a revision in July 2021 (Kostova Karaboytcheva, 2022). The revision proposal aimed at the production side, promoting cleaner modern technologies and making environmentally unfriendly ones less appealing. Moreover, the European Council has agreed upon a new tool called the Carbon Order Adjustment Mechanism (CBAM) that will allow to avoid carbon leakage (Council of the EU, 2022). The CBAM is supposed to function along with the existing EU emission trading mechanism (introduced in the Kyoto Protocol).

Impact of COVID-19 on emission reductions

In 2020, a pandemic was declared by the WHO due to an outbreak of COVID-19. Among other precautions taken by countries to prevent COVID-19 from spreading, travel bans and various other movement restrictions were imposed all over the world. This implied that people were leaving their homes less and therefore, there must have been a shift in emission levels (as well as environmental tax revenues).

According to the International Energy Agency (IEA, 2021), at the beginning of 2020 the energy consumption dropped by about 4%, and, as a result, global CO_2 emissions from the energy sector decreased by 5.8%. However, the effect did not last long, as once the economic activity started recovering, emission levels rebounded. The IEA reports that the levels of global emissions in December 2020 were 2% higher than in December 2019. At the time of writing, the pandemic is not yet over, and due to the time lag in data collection and publication, data reflecting the effects of the pandemic are not yet available.

2. Literature Review

There is a large body of research on the effectiveness of environmental taxes on environmental indicators; all of them, however, differ either geographically or in variables and models used. Grossman and Krueger (1995) is not directly related to taxes, but the authors used the so-called Environmental Kuznets curve model. They analysed the relationship between countries per capita income and air and water quality. Other variables were GDP per capita and, for example, population density. The authors found that after a certain point of income in wealthier countries, the environmental conditions – that is, air and water quality – are significantly better than in less developed ones. They concluded that it is not an automatic relationship, but instead, wealthier countries have the financial capacity to improve their environment.

Morley (2012) analysed effectiveness of environmental taxes in the European countries between 1995 and 2006. The model he used is based on Grossman and Krueger's (1995) model, which used pollution as the dependent variable and per capita GDP as an explanatory one. Other variables include per capita capital formation, environmental taxes as percentage of both GDP and total taxes, and population. Morley opined: "*A number of studies have suggested that to maintain 'international competitiveness', the effectiveness of [environmental] taxes has been reduced through offering exemptions to these industries*" (p. 1818). As a result of competitiveness, environmental taxes may be ineffective. His results suggest a statistically significant negative effect (inverse relationship) of environmental taxes on air pollution, where approximately a 1% rise in taxes as percentage of GDP resulted in a 1% decrease in pollution. There is no significant effect of GDP on air pollution, which speaks against the Kuznets curve hypothesis contrary to Grossman and Krueger (1995). As for energy use, there was no significant effect found in said study, which lead the author to believe that the pollution reduction is a result of cleaner technology.

Grdinić *et al*. (2015) studied the effect of environmental taxation on GHG emissions in the energy sector. In addition, they also investigated the effect of environmental expenditures sourced from environmental taxes. They analysed data from 1995–2010 on a sample of 17 EU countries. The authors used panel regression for cross-sectional panel data and expected environmental taxes to have a significant negative effect. They found that both taxes and environmental spending were effective in EU countries and found a significant positive relationship between GDP and air emissions (countries with higher GDP had higher emissions), from which they concluded that government size and economic activity correlated with emissions levels. This contradicts the Kuznets curve theory and suggests a free-rider problem: "… *countries are not willing to reduce emissions themselves for fear of becoming less competitive*…" (p. 108), which is in line with Morley (2012).

Scrimgeour *et al*. (2005) studied three types of environmental taxes (energy tax, a carbon tax and a petroleum tax, which could be classified as transport taxes) that were at the time applied in European countries, and run a simulation for the case of New Zealand. One important outcome is that environmental taxes should not be treated as ones to fulfil the fiscal function – that is, they should not be constructed in a way to raise tax revenues, but rather to regulate activities that are harmful for the environment. The authors analysed the meaning of the taxes for three main sectors – government, households and industries. The results show that a carbon tax is the most effective tax type.

Miller and Vela (2013) analysed relationship between environmental taxes revenues and levels of air pollution and energy consumption in 50 countries for the period 1995–2010. They hypothesized that countries with higher environmentally related taxes would have lower levels of pollution and energy consumption. The authors used cross-sectional regression and ran it for 9 dependent variables, which were each of the greenhouse gas emissions. The results show a negative relation between environmentally related taxes and levels of CO_2 emissions, meaning that higher tax revenues are associated with lower emission levels. The authors concluded that countries with higher tax revenues "*perform better in the environmental domain*" (p. 16), which means that they have statistically significant lower emission levels, and reduced energy consumption.

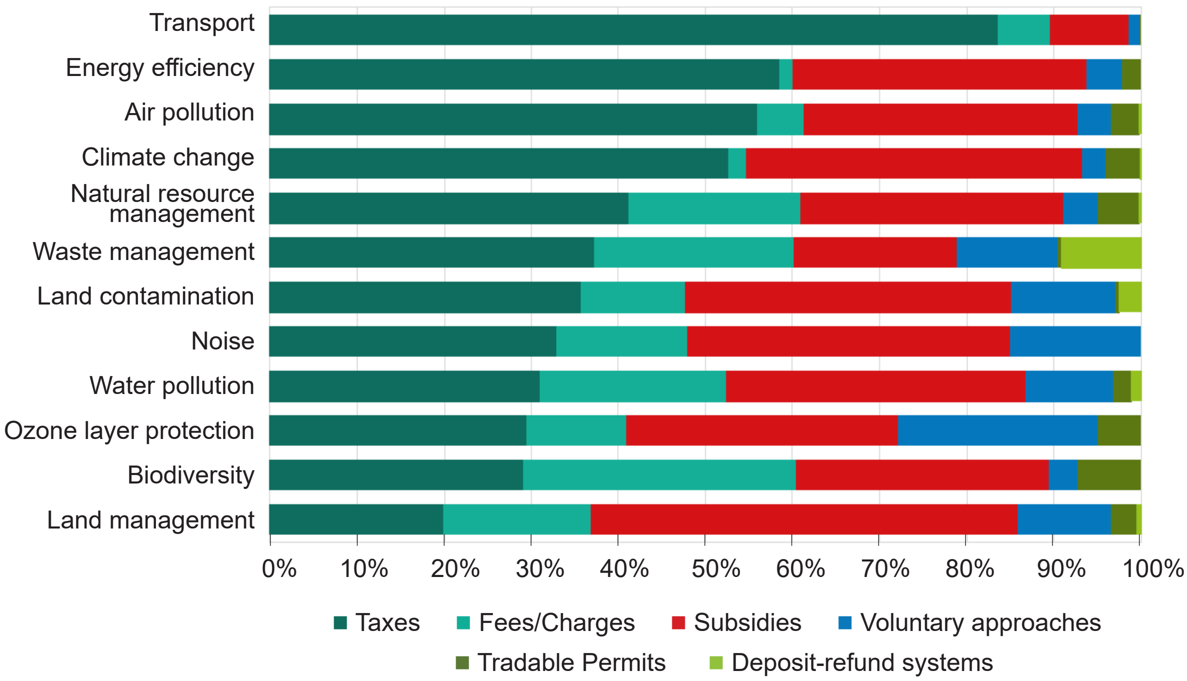
Cadoret *et al*. (2020) investigated whether the Pigouvian taxes in the EU countries are effective. The authors identified four main interpretations of the existing literature on environmental taxation and defined their models as a strict Pigouvian, broad Pigouvian, the double dividend interpretation[1], and the Leviathan government model. The authors further stated that for the revenue-based models it is sensible to expect lower revenues, given that governments use taxation to reduce externalities. Their results suggest that high Pigouvian tax rates indeed reduce negative environmental externalities. Moreover, the authors found evidence that supports the double dividend hypothesis.

3. Types of Environmental Policy Instruments

Taxes are one of the ways to deal with externalities. However, the construction of taxation that is optimal for a given country is dependent on its specifics. The Policy Instrument for the Environment (PINE) database (OECD, 2017) contains all the important data regarding environmental taxes and other instruments in each OECD member country. Figure 1 shows the instruments and types of pollution they are mostly used for.

1 The double dividend hypothesis suggests that introducing environmental tax brings two dividends: improvement of the environment and improvement of efficiency of direct taxes, such as income taxes (Fullerton and Metcalf, 1997).

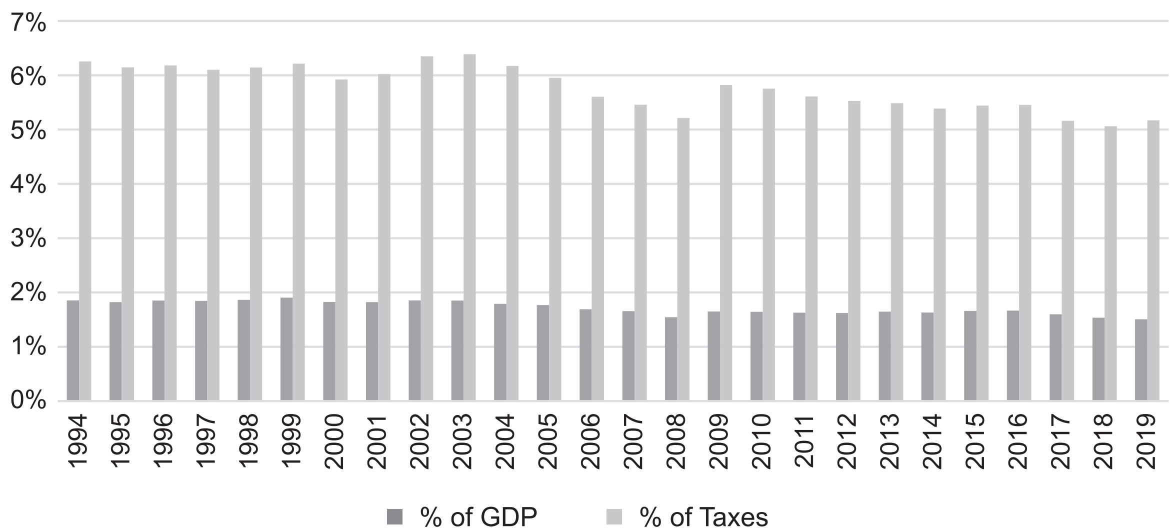
Figure 1: Environmental policy instruments by type (2017)



Source: OECD (2017)

Environmental tax revenues have been relatively stagnating over the time of their existence, with recorded data starting in the 1980s. As OECD average (OECD, 2021), environmental taxes represent about 5–7% of total tax revenues, and somewhat below 2% of GDP (Figure 2). Obviously, this share heavily depends on the countries' GDP and total tax revenues, as each OECD country has a different economic background.

Figure 2: Environmental taxes in OECD countries



Source: OECD (2021)

Environmental taxes are usually divided with respect to industry in which they are applied into taxes on energy, transport, pollution, and taxes on resources. Energy taxes hold the biggest share (about 72%) of total environmental taxes. Another important segment is transport tax revenues (about 26%) and pollution taxes and taxing the use of environmentally exhaustible resources (only about 3.5%; therefore, we abstract from them in the further analysis).

OECD (2019, p. 15) divides energy taxes into three categories: explicit carbon tax (all taxes for which the rate is explicitly linked to the carbon content of the fuel), fuel excise tax (levied on fuels and not carbon taxes), and electricity excise tax.

Indicators employed as variables

According to the PINE database (OECD, 2017), air pollution falls into an environmental domain that is covered by energy and transport taxes. The greenhouse gases are namely the following, along with activities that generate them most: CO_2 (occurs naturally but is also a result of human activities, *e.g.*, fossil fuel combustion), N_2O (agricultural and industrial activities), NO_2 (road traffic and other fossil fuel combustion processes), SO_x (increased levels are a result of fuel combustions and industrial activities), CH_4 (fossil fuel use, industrial and agricultural activities).

In addition to the air emission variables, there are two more indicators that could prove to be important for environmental quality: agricultural land area and forest land area. Forests increase oxygen levels by reducing the carbon dioxide in the air, and so they are a natural mechanism that tackles air emissions. On the other hand, the agricultural sector is known to be one of the main pollutants (apart from the energy and transport sectors), so the more land is given to agricultural activities, the more emissions one might expect to see in the data.

OECD countries vary greatly in terms of their income distribution and general welfare. Environmental conditions might depend on the general wealth of the country, and for the purposes of this thesis the GDP per capita will be analysed, along with the tax revenues. Another measurement of development that is taken from the so-called OECD Better Life Index (BLI) is the life expectancy of the population.

4. Data and Methods

4.1 Data

In addition to the variables listed in the previous section, we will also use the indicators listed below (Sokolova, 2021). The panel data analysis on a sample of 37 OECD member[2] countries captures a period of fifteen years from 2004 to 2018. Table 1 contains a list of all the considered variables.

2 Australia, Austria, Belgium, Canada, Chile, Colombia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, UK, USA.

Based on the available data and a review of the literature, it is best to use a panel data model that includes both cross-section and time series data. For the panel data analysis, it is important to determine what order of integration each panel of the time series is (Pesaran, 2015), because the relationship between panels is meaningful only if the panels are of the same order of integration. Therefore, we use a panel unit root test, namely the Levin, Lin and Chu test (Levin *et al*., 2002). The results are in Table 2, where I(0) and I(1) stand for stationary and nonstationary data, respectively.

Table 1: Description of variables

Indicator	Description
Explained variables	
GHG	greenhouse gas emissions, tonnes of CO_2 equivalent
CO2	CO_2 emissions in the air, tonnes
Explanatory variables	
AGR	agricultural land area, thousands of ha
ELEC	electricity generated (GWh), this indicator is therefore a mixture of green energy sources with those that produce negative externalities
ENER	one of the three environmentally related tax indicators, that are the main focus of the analysis, millions of USD
ENVIT	total environmental taxes (millions of USD); this variable includes both *ENER* and *TRANS*
FOR	forest land area, km^2
GDP	gross domestic product, millions of USD
Gdppc	GDP per capita
GINI	Gini coefficient
LIFE	life expectancy at birth of the population, both male and female
MEDI	median income, domestic currency
MTR	marginal tax rate – tax rate on the last unit of income
PAT	patents on environmental technologies, % of total patents
PIT	personal income tax rate, this variable might capture the double dividend hypothesis, as might *MTR*
POP	total population
POV50	% of people who fall under the 50% poverty line
PROD	level of production gross output measured in current prices, national currency
RENEW	contribution of renewable energy to total primary energy supply, thousands of tonnes of oil equivalent
TAXR	total tax revenues, millions of USD
TRANS	transport tax revenues, the third environmental tax revenue variable
TRIN	transport infrastructure investments and maintenance spending, EUR

Source: Authors' own elaboration

Table 2: Levin, Lin and Chu test

	OECD countries			EU sample		
Variable	**Stat.**	**Prob.**	**Type**	**Stat.**	**Prob.**	**Type**
CO2	−5.276	0.0000	I(0)	−3.517	0.0002	I(0)
GHG	−4.919	0.0000	I(0)	−3.818	0.0001	I(0)
AGR	−3.019	0.0013	I(0)	−6.052	0.0000	I(0)
ELEC	−2.728	0.0032	I(0)	−2.304	0.0106	I(0)
ENER	−3.787	0.0001	I(0)	−3.131	0.0009	I(0)
ENVIT	−4.014	0.0000	I(0)	−3.979	0.0000	I(0)
FOR	−4.271	0.0000	I(0)	−4.625	0.0000	I(0)
GDP	3.993	0.9999	I(1)	3.192	0.9993	I(1)
GDPPC	−1.112	0.1330	I(1)	−0.018	0.4927	I(1)
GINI	−2.446	0.0072	I(0)	−2.106	0.0176	I(0)
LIFE	−8.554	0.0000	I(0)	−9.540	0.0000	I(0)
MEDI	0.799	0.7879	I(1)	2.000	0.9773	I(1)
MTR	−7.677	0.0000	I(0)	−4.164	0.0000	I(0)
PAT	−6.817	0.0000	I(0)	−5.893	0.0000	I(0)
PIT	−1.731	0.0417	I(0)	−3.037	0.0012	I(0)
POP	−10.050	0.0000	I(0)	−7.459	0.0000	I(0)
POV50	−2.835	0.0023	I(0)	−1.997	0.0229	I(0)
PROD	0.528	0.7014	I(1)	0.242	0.5958	I(1)
RENEW	−0.732	0.2321	I(1)	−1.004	0.1577	I(1)
TAXR	−5.272	0.0000	I(0)	−6.747	0.0000	I(0)
TRANS	−5.338	0.0000	I(0)	−6.563	0.0000	I(0)
TRIN	−2.335	0.0098	I(0)	−1.578	0.0573	I(1)

Source: Author's own calculations

From the results of the unit root test, it could be concluded that the dependent variables *CO2* and *GHG* are stationary (I(0)). In accordance with the econometric theory, it is possible to model a relationship using only stationary variables. For the nonstationary variables *GDP*, *GDPPC*, *MEDI*, *PROD* and *RENEW* it was proven that they do not affect pollution, and thereby provide no evidence for the EKC hypothesis.

The second important step is the verification of multicollinearity. In accordance with the correlation analysis, *e.g.*, the indicators *ENER* and *TRANS*, *GINI* and *POV50*, *AGR* and *ELEC* cannot be used in the same equation, which required splitting the analysis of the effect of these indicators on the explained variable into multiple models. *ENVIT* and *TAXR* are omitted from the model due to their strong correlation with other explanatory variables.

4.2 Methods

A basic way to write a linear panel data model is the following equation:

$$y_{it} = c_i + \boldsymbol{\beta} \boldsymbol{X}_{it} + \varepsilon_{it} \tag{1}$$

This simple model is usually not enough (Pesaran, 2015), and therefore it must be extended with the time lags to become the so-called autoregressive distributed lag (ARDL) model (Pesaran *et al.*, 1999):

$$y_{it} = \mu_i + \sum_{j=1}^{p} \alpha_{ij} y_{i,t-j} + \sum_{j=0}^{q} \boldsymbol{\beta}'_{ij} \boldsymbol{X}_{i,t-j} + \varepsilon_{it} \tag{2}$$

where i and t represent country and time respectively, y_{it} is the explained variable, $\boldsymbol{X}_{it}$ a k-dimensional vector of explanatory variables, μ_i represents the fixed effects, α_{ij} is the short-run parameter of the lagged explained variable, β_{ij} is the short-run parameter of the explanatory variables and ε_{it} is the iid$(0, \sigma^2_{\varepsilon_i})$ across i and t, and is distributed independently of the regressor $\boldsymbol{X}_{it}$. In our case, we will construct a model for stationary variables, so that the condition for using the ARDL model is satisfied, namely that the variables must not be integrated of the order I(d) for $d \geq 2$. The estimated ARDL model will thus reflect only short-term relationships (hence, there is no need to use the bounds test for cointegration). The choice of the optimal number of lags, eliminating serial correlation, will be performed on the basis of the AIC and SBC information criteria. The model parameters are estimated using the OLS method. The estimated coefficient β_0 is called the impact multiplier, and the total multiplier is $\beta = \sum_{j=0}^{q} \beta_{ij}$ (this conversion is used in the equations of estimated models (4)–(8)), *i.e.*, the ARDL model from Equation (2) is thus another form of the ECM model for stationary variables. The error component of the resulting model must be tested for white noise. The explanatory variables were tested by the exogeneity test before inclusion in the model.

5. Results

Taking into account the two explained variables and the identified multicollinearity between some of the explanatory variables, it was necessary to separate the analysis into multiple submodels. Tables 3 and 4 show the results of the estimated models for *CO2* and *GHG* as an explanatory variable, respectively. In the tables, the individual models are identified by letters to which we will refer further on. At the bottom of the tables are the results of important tests – the LLC test for unit roots of residuals in the static model (1), the Hausman test for testing of fixed/random effects (see Equation (2)) and diagnostic tests (DW test and Jarque-Bera test).

In the case of 37 OECD countries, the analysis in Tables 3 and 4 shows that only in one out of five models (model A) did environmentally related tax revenues have a significant effect on air emissions. Variables such as *GINI* are eliminated by the regression with fixed effects, as the model by definition incorporates such fixed within-country effects. Therefore, it is not possible to make any conclusions on either the double dividend or the EKC hypothesis.

Model A in Table 3 shows that, at a 10% significance level, the transport taxes indeed have a significant effect on the level of air emissions. After recalculating the lagged parameters, the equation for this relationship can be expressed as follows:

$$\widehat{CO2_{it}} = 1{,}016{,}072 + 0.657\,AGR_{it} - 3.172\,FOR_{it} + 2.065\,TRANS_{it} \tag{3}$$

Assuming *ceteris paribus*, agricultural land area has a positive coefficient, meaning that with each additional hectare of land used for agricultural purposes, emissions grow on average by 0.66 units. On the contrary, each km^2 of forest reduces the level of CO_2 emissions by 3.17 units, which is shown by the negative coefficient of the variable *FOR*. In the case of tax revenues, based on the declining *CO2* emission trend (Sokolova, 2021), it can be concluded that environmental taxes, specifically transport taxes, reduce their tax base (as the relationship is direct), thus fulfilling the allocation function of taxes – they internalize externalities in the form of CO_2 emissions.

However, this model only represents 20% of the analysed relationship of the data for OECD countries. The relationship between greenhouse gases as a total variable and both energy and transport taxes, and carbon dioxide with energy taxes is not proven to be significant. Thus, based on these results it is not possible to conclude that environmentally related taxes play a significant role for the OECD countries in internalizing externalities in the form of air emissions.

To test whether it is truly the lack of statistically significant relationship between the variables that is the problem, we performed an analysis on the same data, but on a sample of OECD member countries that are simultaneously members of the EU. The sample was thereby narrowed down to 23 countries[3]. Still, 23 countries out of 28 is a sample representative enough for the results to be applicable to all EU countries.

3 Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, UK

The unit root tests are in Table 2. The results indicate that the variables *GDP*, *GDPPC*, *PROD*, *RENEW* and *TRINV* are nonstationary (I(1)); therefore, they cannot be used in the analysis where the dependent variables are stationary, and so have no effect on the dependent variables *CO2* and *GHG*. The correlation for the EU sample shows that *ENVIT* was, same as before, dropped from the model due to its strong correlation with other explanatory variables. Moreover, *AGR* and *ELEC* could not be used in the same model, and *ELEC* is also strongly correlated to energy tax revenues, and thus could not be used in equations where *ENER* is tested.

CO_2 emissions and transport taxes

For the OECD countries, only one relationship was found (model A in Table 3) where transport taxes had a statistically significant coefficient. Model B shows the same model for the EU sample. Interestingly, while the coefficient for transport taxes in Equation (3) is 2.065, for the EU sample it is negative (−1.76). However, the variable *AGR* is statistically insignificant in this model.

Models C and D show model estimates where, compared to models A and B, due to the multicollinearity identified in both models, the variable *ELEC* is included instead of *AGR*. Model C does not show a statistically significant effect of transport taxes in the OECD country model, while in the EU sample the relationship (model D) can be described by the equation:

$$\widehat{CO2}_{it} = 114,713.5 - 2.793TRANS_{it} - 1.144FOR_{it} - 0.019ELEC_{it} - 766.5LIFE_{it} \quad (4)$$

Even in this model, the variable *TRANS* is negative; thus, the effect of the transport taxes on air emissions for the EU countries is negative, meaning that an increase in environmentally related taxes decreases the air emissions. A decrease in the tax base does not result in a decrease in tax revenues, and thus it could be said these taxes in the EU are not only effective in internalizing the externalities but also fulfil the fiscal function.

CO_2 emissions and energy taxes

A further analysis was performed for the effect of energy taxes on CO_2 emissions. In EU countries (model F), energy taxes also have a statistically significant effect on CO_2 emissions:

$$\widehat{CO2}_{it} = 94,694.19 - 0.446ENER_{it} - 0.493FOR_{it} - 612.16LIFE_{it} \quad (5)$$

Same as before, only life expectancy and forest land area have a statistically significant effect on the emissions, and the coefficient signs remain the same as in Equation (4). Once the analysis is performed on the OECD countries sample, all significance is gone (model E).

Table 3: Comparative results of analysis of effects of transport and energy taxes on CO_2 emissions

	A		B		C		D		E		F	
	OECD		EU sample		OECD		EU sample		OECD		EU sample	
Variable	Coeff.	Prob	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
C	1,016,072	0.0000	89,502.7	0.1456	407,785.9	0.0017	144,713.5	0.0046	593,571.1	0.0013	94,694.2	0.1348
***CO2*(–1)**	0.596	0.0000	0.595	0.0000	0.868	0.0000	0.629	0.0000	0.638	0.0000	0.557	0.0000
***CO2*(–2)**	0.083	0.0940	0.317	0.0000	–0.064	0.0377	0.263	0.0000	0.107	0.0252	0.383	0.0000
TRANS	2.065	0.0738	–1.761	0.0525	1.014	0.3974	1.945	0.0335				
***TRANS*(–1)**					–0.644	0.5778	–4.738	0.0000				
***ENER*(–1)**									–0.217	0.7413	–1.638	0.0000
***ENER*(–2)**									0.295	0.6596	1.192	0.0012
AGR	–2.497	0.0020	–0.365	0.7778								
***AGR*(–1)**	3.155	0.0004	1.503	0.2229								
FOR	2.620	0.0506	–5.474	0.0091	2.455	0.0259	–6.767	0.0270	3.282	0.0459	–8.976	0.0178
***FOR*(–1)**					–3.749	0.0041	5.622	0.0534	–4.868	0.0064	8.483	0.0166
***FOR*(–2)**	–5.792	0.0002	4.236	0.0265								
ELEC					1.519	0.0000	0.666	0.0000				
***ELEC*(–1)**					–1.370	0.0000	–0.685	0.0000				
LIFE					–2,682.7	0.3645	–5,203.0	0.0012	–6,333.5	0.1975	–6,249.0	0.0019
***LIFE*(–1)**					2,511.2	0.3709	4,666.1	0.0020	5,957.1	0.1994	5,636.8	0.0030
R^2	0.999		0.998		0.999		0.999		0.999		0.998	
LLC test	–6.102	0.0000	–5.79	0.0000	–5.692	0.0000	–5.206	0.0000	–4.500	0.0000	–2.826	0.0024
Hausman test	85.26	0.0000	31.65	0.0000	48.16	0.0000	40.05	0.0000	70.12	0.0000	30.23	0.0002
DW test	2.256		2.181		1.916		2.139		2.318		2.064	
Jarque-Bera test	92,303.3	0.0000	951.8	0.0000	19,358.8	0.0000	91.29	0.0000	91,141.8	0.0000	853.56	0.0000

Source: Authors' our calculations

Greenhouse gas emissions and transport taxes

In this section, we will test the impact of transport taxes on greenhouse gas emissions. The results are shown in Table 4.

Table 4: Comparative results of analysis of effects of transport and energy taxes on GHG emissions

	G		H		I		J	
	OECD		EU sample		OECD		EU sample	
Variable	**Coeff.**	**Prob.**	**Coeff.**	**Prob.**	**Coeff.**	**Prob.**	**Coeff.**	**Prob.**
C	262,896.8	0.0350	143,831.9	0.0055	262,896.8	0.0350	100,136.3	0.1153
***GHG*(–1)**	0.867	0.0000	0.628	0.0000	0.867	0.0000	0.565	0.0000
***GHG*(–2)**	–0.020	0.5156	0.254	0.0000	–0.020	0.5156	0.368	0.0000
TRANS	0.765	0.5757	2.012	0.0305				
***TRANS*(–1)**	–0.350	0.7921	–5.002	0.0000				
***ENER*(–1)**					–0.287	0.6916	–1.547	0.0000
***ENER*(–2)**					0.277	0.7063	1.142	0.0019
FOR	–0.785	0.0314	–1.080	0.0627	4.235	0.0187	–7.618	0.0457
***FOR*(–1)**					–6.113	0.0017	6.987	0.0486
ELEC	1.639	0.0000	0.648	0.0000				
***ELEC*(–1)**	–1.504	0.0000	–0.669	0.0000				
LIFE	–2,505.4	0.4616	–5,717.3	0.0005	–6,158.4	0.2547	–6,485.6	0.0015
***LIFE*(–1)**	2,312.9	0.4742	5,209.8	0.0007	5,992.3	0.2405	5,943.7	0.0020
R^2	0.999		0.999		0.999		0.999	
LLC test	–5.591	0.0000	–5.081	0.0000	–4.576	0.0000	–2.751	0.0030
Hausman test	39.59	0.0000	51.99	0.0000	72.13	0.0000	36.42	0.0000
DW test	1.934		2.122		2.315		2.074	
Jarque-Bera test	31,350.8	0.0000	137.0	0.0000	71,047.6	0.0000	964.8	0.0000

Source: Authors' our calculations

Model H for the EU sample shows that transport tax revenues have a statistically significant negative effect on the level of GHG emissions, and the other variables work in the same direction. The equation of this model can be written:

$$\widehat{GHG}_{it} = 143,831.9 - 2.989 TRANS_{it} - 1.080 FOR_{it} - 0.022 ELEC_{it} - 507.5 LIFE_{it} \quad (7)$$

One would assume that electricity generation would contribute to the air emissions, but the results of the model H suggest that the relationship is inverse: the more electricity is generated, the fewer greenhouse gas emissions there are. The reason could be that renewable energy sources outperform fossil fuel energy production. However, a more detailed breakdown of this indicator would be needed to confirm this hypothesis. Model G contains a comparative model for the OECD countries; the coefficient of the transport-related taxes is not statistically significant.

Greenhouse gas emissions and energy taxes

When analysing the impact of energy taxes on greenhouse gas emissions, we find that from model J for the EU, the energy tax revenue variable has a significant negative effect on the dependent variable GHG. Based on the decreasing trend of the greenhouse gases, it could be said that energy taxes in the EU increase, thereby not only fulfilling the allocation function, but also a fiscal one, as the tax revenues do not decrease with a decrease in the tax base. After adjusting parameters for the lagged variables, the equation can be written in the following way:

$$\widehat{GHG}_{it} = 100{,}136.3 - 0.404ENER_{it} - 0.632FOR_{it} - 507.5LIFE_{it} \quad (8)$$

Forest land area has a negative sign, indicating that the more land area is forested, the less GHG emissions are present in the atmosphere. As for life expectancy, it seems that countries with higher average life expectancy have fewer greenhouse gas emissions. This result goes in line with the assumption made above, that countries with a higher BLI have more capacity for tackling the environmental issues. For comparison, the variables from model J are analysed on the broadened sample of the OECD countries. It can be concluded from model I that the results of the same equation do not hold for the OECD countries.

6. Discussion

Overall, most of the literature concentrates on analysing the EU countries, and various authors have found a statistically significant relationship between taxes and the environment. The present article tries to examine the relationship from the OECD countries' perspective. Moreover, it examines a more recent set of data.

One of the reasons why the relationship does not prove statistically significant for the OECD countries could be that this model abstracts from the emission trading mechanism. The mechanism might have a greater weight than environmental taxes for countries such as the USA.

The paper also works with the total greenhouse gas emissions as a dependent variable, while, for example, Miller and Vella (2013) (who performed their analysis on a set of 50 countries) worked with each greenhouse gas as separate variable. For future analysis, the greenhouse gas emissions could be examined separately (given their different main sources), as it is possible that the effects of environmental taxes on them cancel each other out when taken as a total.

Moreover, it would be interesting to examine the effect of new policies introduced, as well as the effect of the brief reduction in the emissions due to COVID-19, and, as of 2022, the effect of Russia's war in Ukraine.

Impact of Russia's invasion in Ukraine

The large-scale invasion of Russia in Ukraine on 24 February 2022 has already impacted on millions of lives. Many countries around the world have imposed sanctions on imports of various products from the aggressor's country, including bans on oil and gas. However, for some countries, *e.g.*, India and China, the import of the commodities has increased (Cahill, 2022). Moreover, constant bombing and shelling have caused multiple explosions and fires (apart from residential areas, also fires of oil depots, industrial compounds, *etc*.), which has an undeniably devastating effect on the environment. Thus, it is hard to say at the moment whether the potential benefits of reduced oil and gas consumption could outweigh the pollution caused by this unforgivable war.

Conclusions

To summarize the above, the main point is that the statistical significance of the effect of environmentally related tax revenues on the air emissions that holds for the panel data of the EU sample is not applicable to the selection of OECD countries. And, on the contrary, the statistical significance discovered in a single analysis on the OECD dataset holds for the EU countries.

Based on the declining curve of the air emissions, one could conclude that in the EU the tax revenues might also fulfil the fiscal function, as they do not decrease with the decreasing tax base, contrary to the idea behind the term "effectiveness" expressed in Cadoret *et al*. (2020).

One of the reasons why the analysis of the EU countries could not be generalized for the OECD countries might be the reason geographical location relationship of the two samples. In the case of EU countries, they mostly share borders and are located close to each other. These factors and the fact that emissions do not recognize borders might be one of the causes of the lack of statistical significance for the OECD countries. The standalone location of such great polluters as the USA and Japan could complicate the process of mitigating environmental problems. The EU member countries have similar policies (and more intense, as compared to, *e.g.,* USA, according to Sterner and Köhlin, 2004) and are generally more homogenous. Moreover, by essentially sharing the air, the positive results of successful countries might spill over to countries that are less successful in tackling air emissions.

Other variables that proved to be statistically significant in almost every case were life expectancy and forest land area. To some extent, forest land area is an indicator that cannot be changed completely by governments, as the predisposition of countries' climate areas of plays an important role. However, it is undeniable that human activities heavily influence this indicator. In all the equations, the forest land area had a significant positive impact on the level of air emissions, and thus, it is important for governments to maximize preservation of forests and possibly increase forest land areas. The life expectancy was added in the analysis on behalf of the BLI, which had to capture the difference in the development of the countries. Taking this interpretation into account, the life expectancy also had a positive effect on the dependent variable, indicating that countries with a higher life expectancy (meaning countries with a higher BLI) have better air quality. The BLI is, however, a complex indicator, and life expectancy is only one of many indicators that fall into the index. It is also true that the reverse relationship is possible, that is, that life expectancy depends on the level of air emissions, as air emissions have a negative impact on human health (WHO, 2021).

The electricity generation variable also turned out to be statistically significant in the analysis. As was mentioned before, it is plausible that electricity generation would contribute to the air emissions, but the results of the estimations suggest that higher electricity generation actually leads to fewer greenhouse gas emissions. This reverse relationship could be explained by the recent trend of green electricity generation, for example solar or wind, to surpass that from fossil fuels.

As for the evidence regarding the double dividend or the EKC hypothesis, none of the variables that could have provided any proof in favour of either of the hypotheses were statistically significant.

References

Allen, M. R., Dube, O. P., Solecki, W., et al. (2019). *Global Warming of 1.5°C: An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change Sustainable Development, and Efforts to Eradicate Poverty*. Geneva: Intergovernmental Panel on Climate Change. Available at: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_Low_Res.pdf

Almer, C., Winkler, R. (2017). Analyzing the effectiveness of international environmental policies: The case of the Kyoto Protocol. *Journal of Environmental Economics and Management*, 82(3), 125–151, https://doi.org/10.1016/j.jeem.2016.11.003

Cadoret, I., Galli, E., Padovano, F. (2020). How do governments actually use environmental taxes? *Applied Economics*, 52(48), 5263–5281. https://doi.org/10.1080/00036846.2020.1761536

Cahill, B. (2022, June 14). EU's latest sanctions on Russian Oil: what are they and will it work? In: *Energy Post* [online]. Available at: https://energypost.eu/eus-latest-sanctions-on-russian-oil-what-are-they-and-will-it-work/

Coase, R. H. (1960). The problem of social cost. *Journal of Law and Economics*, 3, 1–44.

EP (2009). Directive 2009/28/EC of the European Parliament and of the Council of 23 Apr 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. In: *Official Journal of the European Union*, L 140/16, 05.06.2009, pp. 16–62. Available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009L0028

EU (2003). Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity (Text with EEA relevance). In: *Official Journal of the European Union*, L 283/51, 31.10.2003. Available at: http://data.europa.eu/eli/dir/2003/96/oj/eng

European Council (2022). Council agrees on the Carbon Border Adjustment Mechanism (CBAM). In: *European Council (Consilium.europa.eu)* [online]. Available at: https://www.consilium.europa.eu/en/press/press-releases/2022/03/15/carbon-border-adjustment-mechanism-cbam-council-agrees-its-negotiating-mandate/

Fullerton, D., Metcalf, G. E. (1997). Environmental taxes and the double-dividend hypothesis: Did you really expect something for nothing. *Chicago-Kent Law Review,* 73(1), 221–256.

Germanwatch (2019). *Climate Change Performance Index (CCPI)*. Bonn: Germanwatch e.V. Available at: https://www.climate-change-performance-index.org/

Grdinić, M., Klun, M., Kotnik, Ž. (2015). Environmental Taxation: New Evidence for Energy Taxes. *International Public Administration Review*, 13(3–4), 101–115, https://doi.org/10.17573/ipar.2015.3-4.05

Grossman, G. M., Krueger, A. B. (1995). Economic Growth and the Environment. *The Quarterly Journal of Economics,* 110(2), 353–377, https://doi.org/10.2307/2118443

Grunewald, N., Martinez-Zarzoso, I. (2016). Did the Kyoto Protocol fail? An evaluation of the effect of the Kyoto Protocol on CO_2 emissions. *Environment and Development Economics*, 21(1), 1–22, https://doi.org/10.1017/S1355770X15000091

IEA (2021). Global Energy Review: CO2 Emissions in 2020 – Analysis. *IEA.org* [online]. Available at: https://www.iea.org/articles/global-energy-review-co2-emissions-in-2020

Kostova Karaboytcheva, M. (2022). *Revision of the Energy Taxation Directive: Fit for 55 package*. EPRS Members' Research Service PE 698.883. Available at: https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2022)698883

Levin, A., Lin, C.-F., Chu, C.-S. J. (2002). Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics*, 108(1), 1–24, https://doi.org/10.1016/S0304-4076(01)00098-7

Mathis, W. (2021). Renewables Beat Fossil Fuels in EU for First Time Last Year. In: *Bloomberg.com* [online]. Available at: https://www.bloomberg.com/news/articles/2021-01-24/renewable-power-beat-fossil-fuels-in-eu-for-first-time-last-year

Miller, S. J., Vela, M. A. (2013). *Are Environmentally Related Taxes Effective?* IDB Working Paper Series No. IDB-WP-467. Available at: https://www.cbd.int/financial/mainstream/idb-tax.pdf

Morley, B. (2012). Empirical evidence on the effectiveness of environmental taxes. *Applied Economics Letters*, 19(18), 1817–1820, https://doi.org/10.1080/13504851.2011.650324

OECD (2017). *Policy Instruments for the Environment Database*. Paris: OECD. Available at: https://www.oecd.org/environment/tools-evaluation/PINE_database_brochure.pdf

OECD (2019). *Taxing Energy Use 2019: Using Taxes for Climate Action*. Paris: OECD. ISBN 9789264627444, https://doi.org/10.1787/058ca239-en

OECD (2021). *OECD.Stat*. Paris: OECD. Available at: https://stats.oecd.org/

Pesaran, M. H. (2015). *Time Series and Panel Data Econometrics*. Oxford: Oxford University Press. ISBN 9780191800504

Pesaran, H. M., Shin, Y., Smith, R. P. (1999). Pooled Mean Group Estimation of Dynamic Heterogeneous Panels. *Journal of the American Statistical Association*, 94(446), 621–634, https://doi.org/10.1080/01621459.1999.10474156

Pigou, A. C. (1920). *The economics of welfare*. 4th ed. London: Macmillan.

Rathi, A. (2019). *UK's energy consumption is lower than it was in 1970*. In: World Economic Forum: Energy Transition [online]. Available at: https://www.weforum.org/agenda/2019/08/uk-energy-same-as-50-years-ago

Scrimgeour, F., Oxley, L., Fatai, K. (2005). Reducing carbon emissions? The relative effectiveness of different types of environmental tax: the case of New Zealand. *Environmental Modelling & Software*, 20(11), 1439–1448, https://doi.org/10.1016/j.envsoft.2004.09.024

Sokolova, J. (2021). *Do Environmental Taxes Improve Environmental Quality? Evidence from OECD Countries*. Diploma Thesis. Prague University of Economics and Business. Available at: https://katalog.vse.cz/Record/000120012

Sterner, T., Köhlin, G. (2004). Environmental Taxes in Europe. In: Muller, A., Sterner, T. *Environmental Taxation in Practice*. London: Routledge. ISBN 9781315256252.

UN (2021a). The Paris Agreement. *UN.org* [online]. Available at: https://www.un.org/en/climatechange/paris-agreement

UN (2021b). What is the Kyoto Protocol? *UNFCCC.int* [online]. Available at: https://unfccc.int/kyoto_protocol

WHO (2021). Air Pollution. *WHO.int* [online]. Available at: https://www.who.int/health-topics/air-pollution#tab=tab_1