THE EFFECT OF TAXATION ON GREENHOUSE GAS EMISSIONS

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Abstract

This paper examines the effect of governmental environmental taxes on greenhouse gas (GHG) emissions using a panel data set of 19 EU countries for the time period 1995-2010. We estimate both direct and indirect effects of governmental environmental taxes on GHG emissions in industrial processes. The indirect effect in particular operates through the effect of environmental expenditure for reduction of GHG emissions in industry. To take into account the dynamic nature and to properly address the potential endogeneity, adequate econometric methods are applied. We have shown that the direct effect of environmental taxes on GHG emissions is negative, while the indirect effect through environmental expenditures is also negative and even more statistically significant. Consequently, some policy implications may be derived from the results.

Keywords: greenhouse gas emission, industrial process, environmental taxation, environmental impact, environmental economic, panel data.

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1. Introduction

The need for effective control of global warming has arisen from growing public concern about the negative effects that this phenomenon has for society as a whole. A number of efforts to promote the effective and efficient use and allocation of resources have also taken shape over the last years (e.g. Aristovnik, 2012; Grubb and Neuhoff, 2006). Policy makers have therefore developed an interest in different economic and financial instruments in order to tackle the issue of global warming. Environmental taxes have been frequently advocated as a cost-effective instrument for reducing greenhouse gas (GHG) emissions. The objective of this paper is to address this question, by defining whether taxes for environmental purposes have had an important impact on GHG emissions. We investigate the interaction between collected and spent public appropriations on one side, and their impact on GHG emissions, expressed in CO2 equivalents, from industrial processes, on the other. According to the Intergovernmental panel on climate change, emissions from industrial processes represent one of the main sources of greenhouse gasses (GHG). Taking into account all three categories, we evaluate the direct effect of environmental taxes, and the indirect effect of environmental taxes through environmental expenditures on GHG emissions in industrial processes. In this respect, the model discussed in this paper represents a simple methodological innovation. The article contributes to the debate whether environmental taxes and, consequently, environmental policy have been effective. We used a panel of 19 EU countries for the time period 1995-2010. Countries included in the analysis are: France, Italy, Latvia, Lithuania, Hungary, Czech Republic, Romania, Greece, Malta, Portugal, Netherlands, Bulgaria, Austria, Finland, Sweden, United Kingdom, Denmark, Germany and Spain. The criterion for selection of countries was the availability of data for direct and indirect effects of environmental taxes and GHG emissions in industrial processes. The major results of the analysis are that the direct effect of environmental taxes on the optimization of environment-related processes for minimizing GHG-related pollution in industrial processes is confirmed. We also confirmed the indirect effect of environmental taxes through environmental expenditures on the reduction of GHG emissions and found that the indirect effect is more statistically significant and more robust than the direct effect alone. The remainder of the paper is organized as follows: section two presents a literature review, section three describes the model and variables used in this analysis, section four presents empirical findings, while section five concludes.

2. Literature review

In the last twenty years EU countries have introduced Environmental Tax Reforms (ETR) in national legislations. This included a transfer of tax burden from factors of production to polluters themselves, summarized as a step from economic ‘goods’ to environmental ‘bads’ (Morley, 2010). EU countries have tried to achieve this, *inter alia*, through the introduction of energy taxes with the aim to stimulate CO_2 abatement[1].

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[1] There has been a broad discussion on the issue of double dividend and earmarking of environmental taxes (e.g. Goulder, 1995; Bosquet, 2000; Brett and Keen, 2000; Do Valle *et al.*,

Conversely, this may not always be the case. Ekins and Speck (1999) indicated that energy intensive industries are often exempted from paying environmental taxes due to the fear of possible loss of competitiveness. This may compromise the effectiveness of environmental taxes. Yet, these industries may adopt different measures to enhance the energy efficiency and restrain unwanted effects of environmental taxes and, consequently, improve their own competitive advantages in the long term.

Environmental taxes are an economic instrument of environmental protection whose primary purpose is to promote the reduction of environmental pollution through the polluter pays principle. The majority of researchers (see e.g. Clinch, Dunne and Dresner, 2006; Bosquet, 2000; Do Valle *et al.*, 2012) advocated that environment-related taxes and ETR may contribute to favorable environmental impacts. Environmental taxes, especially carbon taxes to address the problem of global warming, also have an enormous revenue potential. Oates (1995) argued that green taxes promise a double dividend, i.e. they may both decrease excessive levels of pollution and increase the efficiency of the overall tax system by reducing reliance on income, sales and other distorting taxes. In short, Oates (1995) claims that pollution taxes can offer us both enhanced environmental quality and a better tax system. Pearce (1991) also claimed that environmental taxes may produce a double dividend because of discouraging environmental damaging activities, and also by reducing the distortional costs of the tax system. Clinch, Dunne and Dresner (2006) argued that revenues from environmental taxes are partly used for environmental projects and partly to reduce labor taxes. However, other theoretical analyses (e.g. Goulder, 1995) raise doubts on the strong double dividend claims, and argue that environmental tax revenues are raised primarily for financing cuts in existing taxes[2]. However, several more recent authors (e.g. Brett and Keen, 2000; Haibara, 2009; Do Valle *et al.*, 2012) discuss that environmental taxes are in fact earmarked, in the sense of the revenues they raise being pre-committed to specific expenditure programs, e.g. revenues of these taxes are redistributed to polluters in the form of subsidies for abatement technologies (Millock and Nauges, 2006). Brett and Keen (2000) indicate good examples, e.g. in the US the incomes of a bewilderingly large number of environmental taxes are paid into a large number of trust funds that finance various clean-up activities, incomes of the Swedish charge on GHG and other emissions are returned to companies in proportion to the energy each generates. Road construction and maintenance is financed worldwide by use of road and fuel taxes; and water charges are not rarely used to improve in-

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2012) that will only be discussed briefly in the next paragraphs because it offers an important support to our theoretical basis, but it does not represent the main focus of the article.

[2] It is also true that in times of economic crisis environmental tax revenues collected are also intensely used for other purposes and that the amount of taxes is not equal to the amount of expenditures for environmental purposes. Although there is a lot of talk on greening fiscality (OECD, 2010; Speck, 2013), in reality the importance of revenues from environmental taxes is stagnating or even decreasing (Eurostat and European Commission, 2012, p. 40).

dustry's efficiency and infrastructure. Another instance of our general argument is provided by Teja and Bracewell-Milnes (1991) who, in the case of US states, argue that environmental funds have to be devoted to clean-up in advance, otherwise states not affected by pollution harm would have an *ex post* incentive not to pay up. Further, in proposing a European carbon tax at a time when it is also widely urged that the European Union finds a transparent source of finance for itself, the European Commission has made it clear that it would not wish to use this as a source of finance (Brett and Keen, 2000). A possible reason for this may be that the tax would not otherwise receive political support.

Despite the fact that the idea of double dividend is not universally accepted it is hard to argue that a certain level of earmarking of environmental taxes is not present. Earmarking is, of course, unlikely to be optimal, i.e. that raised revenues on some polluting activity will exactly equal the efficient level of expenditure to mitigate damage to the environment, but, given the above, the link between financing public abatement and pollution tax revenue or tariff revenue cannot simply be ignored. On this assumption, we follow the arguments of authors (e.g. Brett and Keen, 2000; Haibara, 2009; Do Valle *et al.*, 2012) that revenues from environmental taxes appear quite frequently to be earmarked to specific spending programs and, as such, an income source for environmental protection for municipal and state budgets. In this respect, environmental taxes are far from being just used to secure a 'double dividend' by reducing distorting taxes.

The link between environmental taxes and air pollution due to GHG and other emissions has also been recognized by several scholars. Studies (López, Vinod and Wang, 2008; Lopez, Galinato and Islam, 2011; López and Galinato, 2007) measured the impact of fiscal spending patterns on the environment by taking into account GHG and other emissions. They found out that a reallocation of government spending composition towards social and public goods, including mitigation of climate change, significantly reduces the burden on the environment. More expenditure for environmental purposes decreases the level of GHG and other emissions. Further, Pezzey and Park (1998) examined the correlation between different air emissions and energy taxation. They argued that countries introduce different public policy instruments, such as exemption from traffic charges or tax levy on raw materials, in order to reduce air emissions. Their findings showed that a tax on energy helps to reduce CO_2 and SO_2 emissions. In another study Clinch, Dunne and Dresner (2006) argued that the tax on energy is closely associated with air emissions generation through a decrease in fossil fuel consumption. The increase in energy tax is reflected in the improvement of climate and air quality, i.e. by reduction of CO_2, SO_2 and NO_x emissions. Albrecht (2002) studied the case of Belgium and showed that environmental subsidies in the field of transport, e.g. for heating equipment and consumer goods, reduce energy consumption and CO_2 emissions level. Khanna and Zilberman (1997) on the other hand claimed that environmental taxes reduce carbon emissions even in the absence of environmental policy. Speck and Ekins (2002) summarized several *ex-post* evaluations that studied different EU countries. They found out that countries which had already implemented environmental taxes in their legislation showed positive environmental impacts, which was reflected in the reduction of GHG emissions as a result of taxation. One of the shortcomings of these studies is that they address, e.g. only effect of taxes on GHG emissions without separation of environmental taxes to their direct effect and indirect effect through environmental expenditures on the reduction of GHG emissions. In this paper we want to go a step further because addressing both tax components at the same time provides us with more detailed insight when addressing the problem of GHGs emissions.

3. The model

The original source for applying time series and cross-sectional data comes from Wooldridge (2003). In our model we linked together the direct effect of environmental taxes and the indirect effect of environmental taxes through environmental expenditures on GHG emissions in industrial processes. Collected environmental taxes and expenditures used for environmental purposes are expected to have a negative impact on GHG emissions but the question is to what extent? We use the following baseline specification to explain our model:

$$I_t = \alpha_0 + \sum_{j=1}^{L} \alpha_j T_{j(t-k)} + \sum_{k=L+1}^{L+M} \alpha_k z_{(t-m)1} + \sum_{j=1}^{N} \beta_j E_{j(t-l)} + u_1 \qquad (3.1)$$

We are primarily interested in the impact of changes in explanatory variables on the dependent variable, so we use differentiated values of these variables (3.2). Differentiation is used in order to eliminate fixed effects.

$$\Delta I_t = \alpha_0 + \sum_{j=1}^{L} \alpha_j \Delta T_{j(t-k)} + \sum_{k=L+1}^{L+M} \alpha_k z_{(t-m)1} + \sum_{j=1}^{N} \beta_j \Delta E_{j(t-l)} + u_1 \qquad (3.2)$$

I	CO_2 (equivalent) emissions in industrial processes;
$\Delta I_t = I_t - I_{t-1}$	differentiation between CO_2 (equivalent) emissions in industrial processes (I) of two successive years;
E	environmental expenditures (N categories);
$\Delta E_t = E_t - E_{t-1}$	differentiation between environmental expenditures (E) of two successive years;
T	direct effect of environmental taxes (L categories);
$\Delta T_t = T_t - T_{t-1}$	differentiation between direct effect of environmental taxes (T) of two successive years;
j	counter by category (direct effect of environmental taxes, environmental expenditures);
t	time period (1995-2010);
k, l, m	time lags;
α, β	coefficients (parameters to be estimated);
z_{t1}	control variables;
u_1	idiosyncratic structural errors.

A detailed description of the variables used is found in Appendix A. Equation (3.2) shows the direct effect of the change in environmental taxes and the indirect effect of environmental taxes through the change in environmental expenditures on the change in GHG emissions in industrial processes. There are several fixed effects (i.e. constant in time) that influence the effects of the given covariates. In literature most often used are e.g., GDP per square kilometer, government expenditure in public goods (Bernauer and Koubi, 2006; Lopez, Galinato and Islam, 2011), which are here added in the model as control variables. We have applied standard OLS regression analysis to our panel data (19 countries, 1995-2010), with the required correction (due to the cross sectional dimension of the data) for heteroskedasticity. Further, we have run robust regressions in order to be sure that our results are not unduly influenced by outliers. The estimates in equation (3.2) may be affected by biases because of reverse causality, omitted variables, or measurement errors in the explanatory variables. To mitigate possible biases caused by omitted variables we use differentiation of the explanatory variables, lags, and to test for possible biases caused by reverse causality we conduct Hausman to test for potential endogeneity.

4. Empirical results

Suppressing time subscripts on variables for simplicity of exposition, the empirical specification of our static-baseline equation is the following:

$$gind = \alpha + \beta_1 entax + \beta_2 enexp + \beta_3 gdpl + \beta_4 tge + \beta_5 gepg + \beta_6 ecol + \varepsilon \quad (4.1)$$

Where (*gind*) is a yearly change of CO_2 (equivalent) emissions from industrial processes (tonnes of CO_2 equivalent per 1.000.000 € GDP), (*entax*) is a yearly change of energy taxes, including fuel for transport (€ per 1.000 € GDP), (*enexp*) is a yearly change of environmental expenditure for reduction of GHG emissions in industry (€ per 1.000 € GDP), (*gdpl*) is GDP per square kilometer, (*tge*) is total general government expenditures (millions of € per 1.000.000 € GDP), (*gepg*) is government expenditure in public goods (in % of total government expenditure), and *ecol* serve as ecolabel licenses (number of ecolabel licenses per 1.000.000 € GDP). Finally, ε is the error term.

Table 1: Descriptive statistics

Variable	Median	Mean	Std. Dev.	Observations
gind	-1.581	-7.557	40.394	285
entax	-0.347	-.146	2.156	247
enexp	-0.005	-0.023	0.970	228
gdpl	1.469	3.232	4.110	266
tge	4.540	4.567	0.685	247
gepg	1.700	1.728	0.420	266
ecol	3.563	4.636	5.260	266

Notes: Observations=227.

Source: Eurostat (2014), own calculations.

Table 1 presents the variables used in the analysis.

The variables CO_2 (equivalent) emissions from industrial processes, environmental taxes on energy, and environmental expenditures in industry are differentiated in time. The averages of these mentioned variables are negative which signifies their values are on average decreasing. Table 2 shows the correlations between the variables used in the analysis. None of the correlations shows extreme correlations between pairs of variables, which suggests there is no apparent multi-collinearity.

Table 2: Correlations

	gind	entax	enexp	gdpl	tge	gepg	ecol
gind	1						
entax	-0.2489	1					
enexp	-0.2405	0.0179	1				
gdpl	0.2334	0.0221	0.0167	1			
tge	0.3135	-0.0853	-0.0149	0.052	1		
gepg	-0.2339	0.0225	-0.0622	-0.0557	-0.448	1	
ecol	0.0219	-0.091	0.0468	0.0985	0.1891	-0.3509	1

Notes: Observations=227.

Source: Eurostat (2014), own calculations

It shows that the correlation coefficients for all pairs of the independent variables are away from unity which suggests there is no apparent multi-collinearity. Other collinearity diagnostics show similar results (Appendix B). The model is estimated with the ordinary least square method (OLS), robust OLS and robust Huber regression (Table 3). We present empirical results from regression analyses to illustrate a possible use of our model. OLS estimates in Table 3 present empirical results of the estimated regression without correction for heteroskedasticity.

Table 3: Estimations of GHG emissions in industrial processes

Variable	Coefficients	OLS	robust OLS	Huber robust regression
entax	β_1	-1.464*** (0.356)	-1.464** (0.702)	-0.325*** (0.113)
enexp	β_2	-3.325*** (0.789)	-3.325*** (1.244)	-1.136*** (0.252)
gdpl	β_3	0.727*** (0.179)	0.727*** (0.150)	0.172*** (0.057)
tge	β_4	4.542*** (1.314)	4.542** (1.817)	1.257*** (0.420)
gepg	β_5	-5.331** (2.106)	-5.331* (3.063)	1.419** (0.673)
ecol	β_6	-0.289* (0.157)	-0.289** (0.135)	0.043 (0.050)
Constant	α	-18.677** (8.364)	-18.677 (12.826)	-10.918** (2.673)
Observations		227	227	227

Notes: OLS, robust OLS and robust Huber regression are used; dependent variable is yearly difference in CO_2 (equivalent) emissions from industrial processes (*gind*); standard errors are reported in parentheses; ***, ** and * denote statistically significant values at 1,5 and 10% on a two-tailed test, respectively.

Source: Eurostat (2014), own calculations.

Consistent with evidence that part of revenues accruing from environmental taxes is issued to make environmental improvements (e.g. Brett and Keen 2000; Haibara, 2009; Do Valle *et al.*, 2012) our results for GHG emissions are unambiguous. All coefficients (except for ecolabel licenses) are statistically significant at the 1% level and have the expected sign (a negative sign indicates a favorable effect on the change of CO_2 (equivalent) emissions from industrial processes). The main results showed that increasing energy taxes directly have a statistically significant and negative impact (-1.464***) on the change of CO_2 (equivalent) emissions from industrial processes. This finding is in line with the studies (e.g. Clinch, 2002; Pezzey and Park, 1998; Corbacho, Cibils, and Lora, 2013) that environmental taxes directly contribute to the improvement of GHG and other emissions. The analysis showed that environmental taxes have an impact on the level of GHG emissions in industrial processes also indirectly, through environmental expenditures in industry (-3.325***). This indirect impact of environmental taxes signifies that direct spending on activities for prevention, reduction and elimination of GHG emissions is extremely important for environmental improvement. However, the role of direct impact of environmental taxes should not be overlooked because economic entities seek to reduce their tax burdens. In this context, the EU countries use different economic and financial instruments for the protection of the environment, e.g. financial guarantees, environmental deposits, taxes and other forms of security, direct and indirect subsidies, and tax allowances. Especially the last two represent financial incentives and opportunities for polluters to take advantage of using advanced green technologies in order to reduce costs and improve competitiveness by reducing energy and resource consumption, and thus contribute to lowering the total amount of GHG emissions. Such measures are usually more stimulating for polluters than taxation or sanctions. In this context, polluters partly avoid paying environmental taxes and are entitled to subsidies.

Different control variables are included in the model that measures economic activity and environmental responsibility. The estimated effects of total general government expenditure and GDP per square kilometer are positive and statistically significant, at the 1% level, suggesting negative impact on GHG emissions. Higher scale of economic activity translates into higher GHG emissions, while higher environmental responsibility tends to reduce GHG emissions. Similarly, the central finding of Bernauer and Koubi (2006) suggested that economic activity and government size have a negative effect on air emissions due to GHG and other emissions. Evidence is found by Lopez, Galinato and Islam (2011), who suggested that increased public spending contributed to higher environmental degradation in case of GHG and other emissions. Our results in Table 3 do not indicate that increasing total governmental spending has been determined by factors other than concern for public good, but it reflects a higher level of economic activity. We included in our analysis – without relying on – the environmental Kuznets curve (EKC) that may question our findings. EKC is a U-shape relationship between certain types of pollution and per capita income. If growth is driven primarily by capital accumulation in the early stages of development, and primarily by technological progress in later years, as countries become rich enough to pay to clean up their environments, the EKC indicates that air pollution may fall with increases in income per capita (e.g. Grossman and Krueger 1993; Antweiler, Copeland and Taylor, 2001). However, Frankel and Rose (2005) claimed the EKC is valid for certain pollutants, e.g. NO_2, SO_2 and particulate matter (PM) but not for CO_2[3]. Their results confirmed that higher economic activity has adverse effects on the environment in terms of CO_2 emissions. In this respect, the results of our analysis do not support the EKC theory, but support the idea of a free-rider problem because the loss of competitiveness obstructs countries from reducing GHG emissions on their own. Since CO_2 is a global externality individual countries are not motivated to tackle the issue by themselves in the absence of international cooperation and regulation of environmental protection.

The quality of the environment may, to a great extent, be understood as a pure public good. Government expenditure on public goods may induce an effect that could be pro-environment (e.g. Lopez, Galinato and Islam, 2011). Higher level of government expenditure on public goods in comparison to expenditure on private goods may lessen the negative effects of market failure, while the latter may not. More funding for R&D and dissemination of technology through expenditures on public goods may result in the expansion and use of low-emission technologies under certain circumstances. Expenditures on public goods may cause increases in peoples' income. This may increase the population's demand for cleaner environment and higher level of environmental regulation, which may consequently reduce air pollution due to GHG and other emissions. The results empirically showed that increasing the government share in public goods decreases GHG emissions from industrial processes.

Emission from GHGs may also be mitigated in other ways. The European Ecolabel is a voluntary market tool that promotes the environmental excellence for products and services at European level by means of the 1980/2000 Regulation of the European Parliament and of the Council. Organizations that promote energy efficiency through the reduction of GHG emissions are awarded ecolabel licenses (Vinagre Díaz, Wilby and Rodríguez González, 2013). We used it also because Sankar (2005) indicated that use of ecolabelling as one of the signals for environmental compliance may be a good indicator that organizations carried out their businesses with a level of responsibility for environment. The results showed that the estimated effect of ecolabel licenses on pollution is negative, suggesting that a number increase has a beneficial effect.

Is it possible that the results are due to existence of cross-sectional dependence? The robust OLS estimates with the correction for heteroskedasticity in Table 3 are practically the same to those presented in the OLS model. Although OLS and robust OLS estimates showed statistical significance at 5% level of the majority of control variables, Huber robust regression in Table 3 indicated that one of the control vari-

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[3] Several studies testing the EKC are available (e.g. Frankel, 2003); some authors (e.g. Bradford, Schlieckert and Shore, 2000) get mixed answers.

ables, e.g. ecolabel licenses, is not robust. However, the sign and significance of the main coefficients of interest (direct and indirect effects of environmental taxes) are not substantially affected. The estimated coefficient for energy taxes descents (from -1.46 to -0.33) and for expenditures from sector industry (from -3.33 to -1.14), but they both stay fairly large, both qualitatively and statistically. The statistical significance of both direct and particularly indirect effect of environmental taxes through environmental expenditures in Huber regression is very robust since they have become even stronger than the one corrected for heteroskedasticity.

The direct and indirect impact of environmental taxes may not happen instantaneously. Therefore, we used the lagged environmental taxes variables that may alleviate the bias from reverse causality[4]. In the case where the lagged taxes variables are correlated with omitted variables that have an impact on GHG emissions but which may not be causally linked to environmental taxes variables, other biases could still be present. For this reason, we used fixed-effects model to control for time-invariant omitted variables, and random-effects model to control for time-varying effects (Table 4). The latter prevents these biases as long as the omitted variables are economy wide, i.e. they have an effect in each country and year. We also followed the argumentation of Antweiler, Copeland and Taylor (2001) who argue that it is possible to assume that unobserved country effects (i.e. regulations, tariffs) that may impact the determinants of GHG emissions are fixed over time due to the short number of observations for each country.

Table 4: Estimations of CO_2 (equivalent) emissions in industrial processes: fixed effects, random effects, and Hausman test

Variable	Fixed Effects	Random Effects
entax	-1.375*** (0.317)	-1.408*** (0.310)
enexp	-3.408*** (0.678)	-3.408*** (0.670)
gdpl	1.340* (0.778)	0.865** (0.378)
tge	2.356 (2.872)	3.308 (2.044)
gepg	-6.028* (3.279)	-6.034** (2.707)
ecol	-0.353* (0.204)	-0.321* (0.185)
Constant	-9.305 (13.635)	-12.113 (11.087)
Observations	227	227
Hausman	0.9877	

Notes: Fixed effects model, random effects model and Hausman test is used; dependent variable is yearly difference in CO_2 (equivalent) emissions from industrial processes (gind); standard errors are reported in parentheses; ***, ** and * denote statistically significant values at 1,5 and 10% on a two-tailed test, respectively.

Source: Eurostat (2014), own calculations

Comparison between fixed and random effects showed important properties, namely: there is a comforting consistency across the coefficients in both the size and sign of the estimated coefficients. Random effects showed even better results than

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[4] Following the same consideration we also used lagged values for selected control variables.

fixed effects. All explanatory coefficients of interest (direct and indirect effects of environmental taxes) are statistically significant and empirical results are practically completely in line with theoretical assumptions.

Smaller differences in coefficients between fixed and random effects in the estimation may be ascribed to the country and time omitted variables. We also checked the endogeneity of the explanatory variables using the Hausman test: the hypothesis was rejected. This means, we may strongly believe that the unobserved variability is not correlated with the coefficients of interest and therefore, the model does not contain endogeneity. These statistical tests, particularly robust Huber regression reported earlier, allow us to conclude that the results are sufficiently robust, thus not driven by dominant observations.

5. Conclusion

The most important conclusion of this paper is that both direct effect of environmental taxes and indirect effect of environmental taxes through environmental expenditures have statistically significant effect on GHG emissions in industrial processes. This is, in essence, confirmed by OLS, robust OLS and Huber regression. So it is highly likely that this is the case. We estimated fixed and random effects models. No substantial difference was found when comparing both models. The results pass rigorous sensitivity tests and do not seem to be driven by confounding fixed or time-varying omitted variables. Further, the indirect effect of environmental taxes is much more significant and robust than the direct effect. The evidence for direct effect of environmental taxes is less robust but it hints at a possible pollution-decreasing effect as well.

The results showed that considering both direct and indirect effects of taxation could present an interesting policy option. They contribute to a more comprehensive understanding of assessment of environmental policy measures and could be useful for designing economic instruments in environmental policy. For public policy-makers this article may help to find the best balance between direct environmental taxation and the level of expenditures on environmental protection as a means to palliate the effects of GHG emissions. This will enable to achieve best value for money in terms of desired level of GHG emissions. It would be recommended to test other policy areas using the same methodology to get a broader picture before making a judgment about direct and indirect effects of environmental taxes.

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Appendix A: Variable description

Greenhouse gas emissions: **CO_2 (equivalent) emissions from industrial processes (code: gind)**

The indicator shows the greenhouse gas emissions of key source categories. A key source category is defined as an emission source category that has a significant influence on a country's greenhouse gas inventory in terms of the absolute level of emissions, the trend in emissions, or both. The different greenhouse gases are weighted by their global warming potential, and the results are expressed in CO_2 equivalents. The inventory contains data on carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6). The EU inventory is fully consistent with national greenhouse gas inventories compiled by the EU Member States. Unit: in tones of CO_2 equivalent per 1.000.000 € GDP. Data were obtained from Eurostat (2014).

According to the Intergovernmental Panel on Climate Change (IPCC) industrial processes are one of the main sources of greenhouse gasses. Emissions of CO_2 equivalents in industrial processes include by-product or fugitive emissions of greenhouse gases (Eurostat, 2014). We have chosen CO_2 equivalents because GHG emissions are widely regarded as one of the most important environmental indicators. Further, CO_2 equivalents are a meaningful measure of emissions into the air in general because, according to studies such as Bernauer and Koubi (2006), various important forms of emissions such as SO_2, CO_2 equivalents, N_2O and NO_x behave similarly across countries and time.

Direct effect of environmental taxes: **energy taxes, including fuel for transport (code: entax)**

An environmental tax is a tax whose tax base is a physical unit (or a proxy of a physical unit) of something that has a proven, specific negative impact on the environment, and which is identified in ESA95 as a tax. Only payments that are identified as taxes in the national accounts can be environmental taxes whereas other types of compulsory payments to government are not considered environmental taxes. Environmental tax statistics uses the tax definition of the national accounts as a reference because this improves international comparability of the statistics, and allows integration of the tax data with the national accounts and with systems of integrated environmental and economic accounting. Unit: € per 1.000 € GDP. Data were obtained from Eurostat (2014).

Energy taxes (including fuel for transport) include taxes on energy products used for both transport and stationary purposes. The most important energy products for transport purposes are petrol and diesel. Energy products for stationary use include fuel oils, natural gas, coal and electricity. Carbon dioxide (CO_2) taxes are included under energy taxes rather than under pollution taxes. The reason for this is that CO_2 taxes are in many cases levied on the same tax bases as energy taxes and are substitutes for energy taxes. Including CO_2 taxes with pollution taxes rather than energy taxes would distort international comparisons (Eurostat, 2014).

Indirect effect of environmental taxes: **environmental expenditure for reduction of GHG emissions in industry (code: enexp)**

The scope of environmental protection is defined according to the Classification of Environmental Protection Activities (EC, 2000). Environmental protection expenditure in industry is defined as the money spent on all activities directly aimed at the prevention, reduction and elimination of GHG emissions and other nuisances resulting from the production processes. Activities that, while beneficial to the environment, primarily satisfy technical needs or health and safety requirements are excluded. Unit: € per 1.000 € GDP. Data were obtained from Eurostat (Eurostat, 2014).

Economic activity

Although we are interested primarily in the impact of environmental taxation on GHG emissions in industrial processes, we need to control for a number of other factors that have been identified in the relevant literature as important determinants of air emissions due to GHG and other emissions. These additional explanatory variables are justified in theory and may be assembled into two categories that cover economic development and environmental responsibility of a country. Many papers examined the relationship between economic activity and GHG and other emissions. Economic activity of a country may be measured by intensity of economic activity, government spending composition and government size (e.g. Lopez, Galinato and Islam, 2011; López, Vinod and Wang, 2008; Bernauer and Koubi, 2006), and may present a great pressure on the environment (Baiardi and Menegatti, 2011).

Intensity of economic activity: **GDP per square kilometer (code: gdpl)**

We measure the scale of economic activity by GDP per square kilometer. This measure reflects the concentration of economic activity within a given geographical area. It is constructed by multiplying per capita GDP by population density (population / square kilometers) – this, in effect, results in a coefficient measuring GDP per square kilometer. This measure reflects the concentration of economic activity within a given geographical area. We expect a positive relationship between economic activity and GHG emissions (Eurostat, 2014; Bernauer and Koubi, 2006). Unit: GDP/km^2. Data were obtained from Eurostat (Eurostat, 2014). We have chosen GDP per square kilometer because, according to authors (e.g. Bernauer and Koubi, 2006), the larger the scale of economic activity per unit, the higher the level of environmental air emissions due to GHG and other emissions is likely to be. A similar explanation offers López, Vinod and Wang (2008) who suggest that the scale of economic activity ought to be measured by country GDP per square kilometer to give an idea of the output scale pressure on the natural environment.

Government spending composition: **government expenditure in public goods (code: gepg)**

Government expenditure in public goods include the expenditure in education, health and other social transfers (direct subsidies to households), environmental protection, research and development (R&D), knowledge creation and diffusion as well as conventional public goods such as institutions, and law and order. Unlike government expenditures in private goods, these expenditures may mitigate the effects of market failure and complement rather than substitute for private sector spending. Household subsidies, both direct and indirect via education and health care provision, reduce the effects of liquidity constraints and enable households to increase investment in human capital (Grant *et al.*, 2007). Unit: in % of total government expenditure. Data were obtained from Eurostat (Eurostat, 2014). We have chosen government expenditure in public goods because according to the studies (e.g. López, Vinod and Wang, 2008; Lopez, Galinato and Islam, 2011) more spending on public goods may be associated with reduction of GHG and other emissions. To do so it is required to reallocate government spending away from subsidizing private goods that provide incentives leading to resource depletion, and towards providing more public goods. On the other hand, the reallocation of government spending may favor human capital-intensive activities to the detriment of physical capital-intensive industries, which tend to be among the most polluting industries.

Government size: **Total general government expenditures (code: tge)**

Total general government expenditure is defined in ESA-95 §8.99 by reference to a list of categories: intermediate consumption, gross capital formation, compensation of employees, other taxes on production, subsidies, payable property income, current taxes on income, wealth, etc., social benefits, some social transfers, other current transfers, some adjustments, capital transfers and transactions on non-produced assets. Unit: millions of € per 1.000.000 € GDP. Data were obtained from Eurostat (Eurostat, 2014). We have chosen total government expenditure because according to some authors (e.g. Bernauer and Koubi, 2006) government size and GHG and other emissions are closely connected. An expansion in government size is unambiguously associated with welfare improving for society as a whole; namely, i.e. when this expansion is demand-driven (citizen-over-state) and when it aims at the provision of a pure public good or the correction of an externality. The study of Bernauer and Koubi (2006) examined the relationship between government spending and air emissions due to GHG and other emissions in 42 countries over the 1971-1996 period. Their key finding was that countries with a larger government spending tend to suffer from more emissions into the air. However, a large body of literature (e.g. Grossman and Krueger, 1993) demonstrates the opposite results that follow the Kuznets curve theory.

Environmental responsibility: Ecolabel licenses (code: ecol)

This indicator is defined as the number of Ecolabels or 'EU Flower' licenses in European countries. The Community Ecolabel is awarded to products and services with reduced environmental impacts. This means that climate requirements are taken into account, and that CO_2 emissions (and other harmful gasses) are limited – where it is most relevant. It is administered by the European Commission and receives the support of all EU Member States and the European Free Trade Association (EFTA). The Ecolabel criteria are discussed in the European Union Ecolabelling Board (EUEB) whose membership includes representatives from industry, environmental protection groups, consumer organizations and representatives for small and medium-sized enterprises (SMEs) (Eurostat, 2014). Unit: number of eco licenses per 1.000.000 € GDP. Data were obtained from Eurostat (Eurostat, 2014). We have chosen ecolabel licenses because, according to Eurostat (2014), ecolabel licenses for products and services are related to reduction of air pollution. This suggests organizations take climate requirements (reduction of CO_2 equivalents) into account in their activities. Tietenberg and Lewis (2012) suggested that governments use ecolabeling as a means of putting at least some market pressure on the disputed GHG-related practices.

Appendix B: Collinearity diagnostics

Variable	VIF	Tolerance
gind	1.39	0.7212
entax	1.09	0.9136
enexp	1.09	0.9184
gdpl	1.09	0.9196
tge	1.33	0.7497
gepg	1.43	0.701
ecol	1.18	0.849
Mean VIF	1.23	

Appendix B shows that VIF and Tolerance values of the Model are within acceptable limits, which suggests there is no apparent multi-collinearity.