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Environmental Taxes and Economic Growth: Evidence from Panel Causality Tests.

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ABSTRACT:

The aim of this study is to determine the causal relationship between environmental taxes and economic growth, using different measures of environmental taxes with GDP as well as adjusted net savings. A panel of European countries and a separate panel of OECD countries are used from 1995 to 2006 and the standard Granger non-causality approach is applied. The results suggest some evidence of long-run causality running from economic growth to increased revenue from the environmental taxes, with also some evidence of short-run causality in the reverse direction. The inclusion of population and a proxy for economic subsidies had little effect on the long-run relationship, although the proxy for subsidies did have some short-run effect on growth.

Key Words: economic growth; environmental taxes; Granger causality.
J.E.L.: H23, Q5, E60.

I. Introduction

Over the recent past, the European Union (EU) member states in particular and other countries in general have been set voluntary targets for the reduction in pollution and emission of greenhouse gases, which have facilitated the sometimes controversial use of environmental taxes across the world, especially in the EU. As a result of recent concerns relating to the harmful effects of global warming, policy makers have become increasingly interested in the use of environmental taxation as a means of combating the problem, in order to meet targets set at the 1997 Kyoto protocol to reduce greenhouse gases.

Also, during the 1990s, beginning with the Scandinavian countries, there has been a number of attempts to introduce Environmental Tax Reform (ETR) in EU member states. This has involved shifting the burden of taxation away from factors of production to pollution and the users of natural resources, summarised as a move from economic 'goods' to environmental 'bads'. Again, one of the main ways in which EU governments have attempted to do this is through the use of energy taxes, in order to encourage a reduction in carbon emissions.

The aim of this paper is to determine the direction of causality in the long and short run between economic growth and environmentally orientated taxes using two separate datasets for the EU and the Organization for Economic Co-operation and Development (OECD) countries. The novel element to this paper is the use of Granger causality tests to test for the causal relationship between environmental taxes and various measures of economic growth, within the context of a panel dataset, which the authors believe to be the first time this has been attempted. This could potentially be important as it has been hoped that increases in environmental taxes would not only improve the environment but also increase economic growth, at a time when economies are struggling to grow. For the OECD dataset, this allows us to not only include the US in the study, but also use the adjusted net saving (ANS) measure of economic performance, which includes a measure of the environment, instead of gross domestic product (GDP). Other factors are also considered as determinants of both growth and taxes, such as population and environmental subsidies. This paper attempts to contribute to the debate on the effects of environmental taxes on the economy, by using the EU and OECD panel data sets to determine, using standard panel Granger non-causality tests, if there is any causal link between environmental taxes and economic growth[1].

Following the introduction, the methodology used in this study is outlined and the form that ETR has taken in the EU member states discussed. The data and results are then examined and finally we suggest some conclusions and policy implications of the study.

1.1 Previous literature of taxation and economic growth

Granger causality tests have been extensively used to determine the direction in which causal relations lie between a set of variables. However as far as we know, they have not been used on economic growth and environmental taxes. As Granger (1988) suggests that if there is cointegration between a set of I(1) variables, then there must be causation in one direction at least. This is because the presence of cointegration implies an error correction model can be formed, in which the error correction term has a significant effect on the dependent variable. However the causality approach has been used to determine causal relations between energy consumption, energy prices and economic growth (Constantini and Martini, 2010).[2]

To date most of the taxes particularly environmental ones and the growth literature has been theory based, either using environmental taxes in an endogenous growth framework as in Bovenberg and De Mooij (1997) or as a general measure of environmental policy as in Ricci (2007). The empirical literature on this issue has mainly concentrated on the use of simulation exercises rather than the use of econometric modelling, due to the lack of suitable macro-data so far. There have also been parallel studies which have empirically assessed the effects of personal and

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[1] This study uses GDP and adjusted net saving to represent economic growth. An alternative approach used in many simulation studies is to use unemployment, which is usually highly correlated with GDP. This study has not used unemployment data as in some countries such as the UK there is a strong argument that it underestimates the true value, as many who are long-term unemployed are on alternative benefits instead, so do not appear on unemployment lists.

[2] The definition of Granger causality is that if variable X Granger causes variable Y, then past values of X contain information that can be helpful in predicting Y above the information contained in past values of Y alone.

corporate taxes on economic growth, such as Lee and Gordon (2005). However these studies have not used causality tests to determine the relationship between taxes and economic growth. They have tended to be panel regressions and in general they find that increasing taxes reduces economic growth. A further study by Kneller *et al.*(1999) also shows that in general taxes reduce economic growth although they suggest only distortionary taxes reduce growth, these would include corporate and income taxes.

The approach to environmental taxation in the EU has concentrated on the use of taxes to improve the environment, whilst using the revenue raised to reduce the distortionary taxation on labour and production. This policy is often regarded as producing a double effect whereby the environment is improved and at the same time the economy benefits through the reduction in these distortionary taxes (Bosquet (2000)). However other studies (Myles, 2000) argue that for it to occur, the tax system must be inefficient, in which case a better policy would be to improve the system, rather than tax the pollutants. Nevertheless, Fisher and Van Marrewijk (1998) illustrated a theoretical model which suggests that pollution taxes can result in economic improvement.

Other studies have suggested further justifications for a positive causal effect from environmental policies to economic growth. Ricci (2007) suggests a number of ways in which measures to improve the environment can enhance economic growth, such as the prospect of a better environment may encourage saving. Pautrel (2009) suggests when the reduced effects of pollution on health are taken into account, the effects of the environmental policy can be positive on the economy. Causality could also run in the opposite direction from GDP to taxes, as a rise in the income and wealth of a country increases the ability and inclination of a country to pay for higher environmental taxes.

The main empirical work on environmental taxation and economic growth has centred around the use of simulations on the impact of ETR on the environment, use of natural resources and the wider economy, although Leiter *et* al. (2009) have also used the same EU environmental tax data as a determinant of investment. In their study they find that environmental tax revenue, as an example of an environmental regulation, has a positive but diminishing effect on investment. Also, studies like Patuelli *et al.* (2005) and Anger *et al.* (2010) focussed on a meta-analytical approach in analyzing the effects of environmental taxes on the economy, which involves the use of regression techniques to determine the effects from simulation studies. As far as we know there have been no econometric studies in general or Granger non-causality studies in particular on the relationship between environmental taxes and economic growth

2. Material and Methods

2.1. Environmental Tax Data

The measure of environmental tax revenue is based on the internationally recognised definition used by the Statistical Office of the European Union (Eurostat) and accepted by the main international bodies, such as the OECD. An environmental tax is defined as any tax, which has a physical unit as a base and for which there is evidence that it has a specific effect on the environment[3]. In this study the EU data is environmental tax revenue as a proportion of GDP and of total tax revenue, which is used as a proxy for the tax rate.

The data used in this study is annual, with 12 years and runs from 1995 to 2006, starting in 1995 as this is the earliest data available for the environmental tax measures. Specifically, the environmental tax revenue data is predominantly comprised of taxes on transport and energy products, such as the duty charged on hydrocarbons in the transport sector, as well as the industrial sector. It also includes the fossil fuel levy, which is a tax on electricity generated using fossil fuels. A recently introduced tax is the climate change levy, including petroleum, gasoline, coal and electricity. Further related tax sources include vehicle excise duty, the value added tax (VAT) applied to petroleum and the air passenger duty, which applies to air travel within the European Economic Area (EEA), but at a lower rate with countries

[3] As recognised in other studies, there is some debate over what counts as a tax, in particular the use of earmarked sources of revenue. For the benefit of this study we rely on the definitions used by Eurostat, which is common across all the countries in the study. As noted earlier this is a macro based study using aggregated data for both taxes, pollution and energy consumption, data on a more disaggregated level is not currently available.

outside the EEA. The transport taxes relate to the ownership and use of motor vehicles, which makes it comparable to the OECD data. However taxes on aeroplane flights are also included. The taxes refer to both recurrent and one-off taxes, such as road tax and sales of equipment respectively.

In European areas, the transport and energy taxes initially served as an energy security measure however in recent years the trend has shifted towards an environmental one (Davoust, 2008). There are about 375 environmentally related taxes in the OECD and about 90% of the revenues received from these taxes relate to motor vehicle fuels and motor vehicles (OECD, 2006). Among the EU 27 member states, the energy tax represents 75% of the environmental taxes of which 80% of this tax are from fuel taxes found in the transport sector (Eurostat, 2009). There is large variation in the fuel tax burden among the EU member states, in particular with regard to the proportion of transport taxes. In the transportation sector, two commonly used fuels are diesel and gasoline. The former is predominantly used in commercial vehicles such as freight transport whereas the latter which is unleaded and consumed in private vehicles. The estimated CO_2 emission in gasoline is at 22.2 pounds/gallon compared to diesel at 19.4 pounds/gallon (US Environmental Protection Agency (EPA), 2005).

On the one hand, an increase in transportation taxes impacts on households and firms which in effect changes the mode of transport i.e. from private to public transport. On the other hand, this type of tax is primarily for revenue generation where the revenue obtained from this transport related tax is said to be recycled back to the transportation sector for the construction and maintenance of roads. Indeed, about 2-2.5% of GDP is revenue raised from environmentally related fees and charges. For this study the transport taxes i.e. the fuel taxes from diesel and unleaded gasoline for commercial use were obtained from the International Energy Agency (IEA) in percentages for the years 1995-2006 (IEA, 2008) and were converted into US$ per litre.

2.2. Adjusted Savings Data

This study also incorporates adjusted net savings (ANS) also referred to as genuine savings which measures the economic growth in a sustainable manner. The difference between GDP and ANS is that the former measures the physical capital whereas the latter incorporates the monetary values of physical, human, natural and social capital as well as the stock of knowledge. The dataset is found at the World Bank in the World Development Indicators (WDI), which contains all country-level and regional data as estimated by the World Bank (2008).

There was a strong need among academics, researchers and international institutions in particular the World Bank, to establish an indicator that accounts for sustainability in economic development as GDP per capita was an insufficient criterion. The World Bank calculates ANS as: total net national saving and education expenditure minus the resource rents (depletion of energy, minerals and forest) and carbon dioxide (CO_2) damage. Since the ANS index was established numerous discussions have emerged about its properties. Studies such as Hamilton and Clemens (1999) suggest that 'genuine saving' is a useful indicator of sustainability however others like Pillarisetti (2005) argue that environmental sustainability needs to be examined in a global context and that natural capital should be treated independently of physical and human capital. In one recent empirical study by Gnègnè (2009) where he examined ANS and welfare changes, he points out that the World Bank ANS is a step forward in understanding sustainability though more effort is required to improve it.

2.3. Methodology

Although the specific techniques differ, the general approach to Granger non-causality tests, either using time series or panel data, involve the application of cointegration techniques with the subsequent error correction model (ECM) used to test for short and long-run causality (Granger *et al.* 2000)[4]. As noted by Al Sadoon (2009), the concept of Granger non-causality also incorporates a number of related concepts such as cointegration, stability and controllability. When following this approach, the first step involves testing for a panel unit root and in this study the popular Im Pesaran and Shin (IPS) test is used. If the variables are found to be I(1), we then need to test for cointegration, in this case using the Kao (1999) test. This test is initially used, as although it can only be used in a bi-variate context, Gutierrez

[4]There are many examples of panel causality tests which include varying approaches such as Apergis (2004) who uses the cointegration ECM approach, Constantini and Martini, (2010) who use a similar approach to the one adopted here but in a multivariate context. In addition Menegaki (2010) use a random effects approach and causality tests in a similar study but using renewable energy.

(2003) suggests in a homogenous panel it has higher power than other competing tests when, as in this study, the time series component is relatively short. Given the following model:

$$y_{it} = \gamma_0 + \gamma_1 e_{it} + \varepsilon_{it} \tag{1}$$

Where y_{it} is GDP (in logarithms), γ_0, γ_1 are parameters to be estimated and e_{it} is the environmental tax (if testing for causality running the opposite direction, e_{it} would be the dependent variable). The Kao test (1999) is then used to test for cointegration and is based on a panel version of the ADF test on the residual (ε_{it}):

$$\varepsilon_{it} = \rho\varepsilon_{it-1} + \sum_{j=1}^{k}\gamma_j \Delta\varepsilon_{i,t-j} + v_{it} \tag{2}$$

This can be used to produce the following ADF statistic as shown in equation (3), which is a one tailed test and where $\hat{\sigma}_v^2$ is the estimated variance and $\hat{\sigma}_{0v}^2$ is the estimated long-run variance of the error term and follows the standard normal distribution. τ_{ADF} is the ADF statistic for equation (2):

$$ADF = \frac{\tau_{ADF} + \sqrt{6N}\hat{\sigma}_v / (2\hat{\sigma}_{0v})}{\sqrt{\hat{\sigma}_{0v}^2 / (2\hat{\sigma}_v^2) + 3\hat{\sigma}_v^2 / (10\hat{\sigma}_{0v}^2)}} \tag{3}$$

The long-run relationship and consequent error correction term is then based on a dynamic OLS or DOLS model. DOLS involves estimating the long run bi-variate relationship with the inclusion of a lead and lag of the differenced explanatory variable and has better properties than other competing techniques. Then as noted by Granger *et al.* (2000), the long-run causality can be measured by the significance of the error correction term, whilst the short-run causality can be measured by the joint significance of the lagged explanatory variables. This gives the following specification:

$$dy_{it} = \alpha_0 + \sum_{q=1}^{n} \alpha_{iq} de_{it-q} + \sum_{q=1}^{n} \beta_{iq} dy_{it-q} + \delta\varepsilon_{it-1} + \sum \xi TD + u_{1it} \quad (4)$$

$$de_{it} = \phi_0 + \sum_{q=1}^{n} \phi_{iq} de_{it-q} + \sum_{q=1}^{n} \gamma_{iq} dy_{it-q} + \lambda\varepsilon_{it-1} + \sum \zeta TD + u_{2it} \quad (5)$$

Where dy_{it} is the differenced real per capita GDP and is equivalent to economic growth, de_{it} is the differenced environmental tax. The tax data is with respect to both GDP and total taxes, the use of the latter measure ensures that the results are not due to having GDP on both sides of the equation. TD are time dummy variables taking the value of 1 for a particular year and zero otherwise. The use of the Arellano-Bover approach allows the inclusion of fixed effects into the model, to remove the problem of unobserved heterogeneity, where any effects not captured by the explanatory variables are controlled for. The use of orthogonal deviations, which is similar to differences from the mean approach, removes the unobserved heterogeneity in the cross section, the time dummy variables then control for unobserved heterogeneity in the time series. The ε_{it} is the error term from the DOLS estimate and represents the error correction term, which is assumed to be negative. As with Granger *et al.* (2000), long-run causality is measured by the standard t-statistic, whilst the lagged explanatory variables measure short-run causality, in this case using a t-test as only a single lag is included, due to the data being annual. Bond (2002) suggests the Arellano-Bover approach may have some advantages over other approaches to dynamic panel models.

In addition we expect the error correction term to be negative to ensure the model is stable and the coefficient represents the speed of adjustment following an exogenous shock. To test the overidentifying restrictions imposed by the use of GMM, we use the Sargan test. In addition we use time dummy variables to model the time series fixed effects, as in part this controls for the business cycle and also it models the rapid changes in environmental regulations in the EU recently. A test of joint significance of these dummy variables shows they are highly significant.

The final sets of tests are conducted on a multivariate model in which the population and a proxy for environmental subsidies are included. As this is a multivariate model the Kao approach to cointegration is as explained earlier not applicable, instead the Pedroni approach has been applied specifically to determine whether the addition of other factors to the bi-variate model affect the result. The Pedroni approach (1999) suggests seven tests for cointegration which include the panel *v*-statistic, panel rho statistic, panel ADF-statistic, panel PP-statistic, group rho-statistic, group ADF-statistic and group PP-statistic. As before in the event of no consistent evidence of cointegration, the standard Granger causality models are estimated without an error correction model[5].

3. Results and Discussion

The EU panel consists of twenty five countries all from the European Union[6]. All the EU data is taken from *Eurostat* at the *European Communities,* consisting of environmental taxes as a percentage of GDP as well as total tax revenue. In addition we have used transport taxes again as a percentage of GDP and total taxes, to compliment the OECD database of diesel and gasoline taxes (IEA, 2008). The GDP is real per capita. Other explanatory variables include population and a proxy for environmental subsidies namely for the EU data this is renewable energy data which is the percentage of electricity generated from renewable sources. This is used because there is not sufficient data on environmental subsidies. The OECD dataset consists of all OECD countries where there was sufficient data (See Table 2), the diesel and gasoline taxes are also taken from the OECD where the taxes are defined as the level of tax in dollars per litre of gasoline/diesel (See Table 3). The adjusted net savings data is as explained earlier taken from the World Bank (World Bank, 2008).

[5] When there is no cointegration, the error correction terms are not included in the ECMS as they are I(1) in the event of no cointegration and all variables in the ECM need to be I(0). In general when added they were not significant.

[6] The countries used are listed in Tables 2 and 3. They are limited by the data availability for some countries, particularly the time series element where we have just 12 years of data. However the data includes transition economies too, who were required to improve their environments as a condition for joining the EU during the 1990s and 2000s. European data is used as it is compatible across all the countries chosen and the variables used are defined in a similar way across these countries.

Table 2 includes the summary statistics for both transport and total environmental taxes relative to GDP and total tax revenue, both follow a similar pattern overall. As is evident the countries that use environmental taxes the most tend to be Scandinavian. Denmark relies on these taxes more than any other country, with about 5% of GDP and 10% of total tax revenue being collected in the form of environmental taxes. Transport taxes tend to make up about 1% of GDP and 2% of total tax revenue, with a relatively low variance across the EU. In general some of the Eastern European countries collect the lowest proportions, with the Baltic states being the lowest. The same pattern is followed with the OECD dataset as shown in Table 3, in that the UK, Switzerland and Norway have the highest average taxes on its fuel, with the USA not surprisingly having the lowest.

The results for the IPS panel unit root tests are presented in Table 4 and show that overall all the variables contain a unit root, suggesting the need to difference these variables before testing for non-causality[7]. The cointegration tests are contained in Table 5 for the EU dataset and Table 6 for the OECD dataset, as with Granger *et al.* (2000) we test for cointegration in both directions, with both variables acting as the dependent variable. The Kao test for cointegration results on the EU dataset show evidence of a stable long-run cointegrating relationship only when taxes are the dependent variable and taxes are as a proportion of GDP. However, when GDP is the dependent variable there is no evidence of a long-run relationship. Nevertheless with the OECD dataset, there is evidence of a stable long-run relationship between environmental taxes and GDP, but only when the tax variable is the dependent variable and gasoline taxes are used.

Based on these results we conclude that although there is some evidence of a stable long-run relationship when the taxes are the dependent variable, there is no evidence for it when GDP/ANS are the dependent variables. Where there is evidence of cointegration, the error correction term will be included in the non-causality tests, but excluded where there is no evidence as in Granger *et al.* (2000).

[7] Although population appears to be I(2) with the IPS test, other panel unit root tests such as the Phillips-Perron Fisher test indicate it is I(1), the difference in the latter test is that Newey-West adjusted standard errors are used to overcome autocorrelation instead of adding lags of the dependent variable..

Table 7 contains the results from the Pedroni (2004) test for cointegration[8] with the multivariate model including renewable energy and population. The results are mixed with different results giving varying conclusions, but in general the null of no cointegration is not rejected in the majority of cases. This suggests that the error correction term should not be included in the models in which the Granger non-causality is conducted.

Tables 8 contains the results from the GMM estimation of the ECMs using the Arellano-Bovver approach and the results indicate little evidence of any short-run causal effect running from the environmental taxes or transport taxes[9] to economic growth, as evidenced by the lack of significance of the lagged explanatory variable. The exception is environmental taxes relative to total taxes which significantly affects output. This offers tentative support for other studies which find either little or ambiguous evidence of the environmental taxes affecting economic growth, as noted in Bosquet (2000) and Anger *et al*, (2010). However there is evidence of short-run causality from GDP to environmental taxes with respect to GDP and transport taxes relative to total taxes, but it is negatively signed, which may be due to overall tax revenue rising during times of economic growth, so requiring less need for the environmental taxes.

In Table 10 using the OECD dataset, the significant error correction term backs up the evidence of long-run causality running from GDP to gasoline taxes, suggesting as countries become richer, they are more inclined to use environmental taxes. The Sargan test of the overidentifying restrictions indicates the null is not rejected in all cases, suggesting the instruments used in the GMM estimation are acceptable. In

[8] Although the dataset does not lend itself to the use of the Pedroni approach as mentioned earlier, we have followed Narayan and Smyth (2008) whom include the results from the Pedroni test, despite it not suiting their methodology. As with their approach the failure to find cointegration in this study could be due to the lack of a long-run relationship between the variables or due to the short period in this dataset.

[9] Energy and pollution tax data was also available, but produced similar results to transport taxes so are not included. Results available from the authors on request.

addition the F-test on the joint significance of the time dummies, suggests all are jointly significant so need to be included in the causality tests.

The models in which the population (po) and renewable energy (re) measures are also included in Table 9 and tend to offer less support for the previous bi-variate results as many of the previously significant lags are no longer significant with regard to the taxes and GDP growth. However there is evidence of Granger causality from renewable energy, proxying environmental subsidies to economic growth, although it is negatively signed, suggesting expenditure on environmental protection as yet has not produced the technological spillovers and subsequent increase in growth. In addition in the case of transport taxes, changes in population Granger cause the transport tax, suggesting countries with higher population growth have lower levels of transport taxes, which is not as expected although this could simply reflect the fact that high levels of population growth have been associated with lower economic growth, which indirectly would reduce the tax revenue.

Using the OECD dataset[10], the results are presented in Table 10 and the significant error correction terms suggests there is long-run causality running from GDP to the gasoline and diesel taxes, which again backs up the cointegration tests. There is also a positive short-run effect from GDP to diesel taxes, which may suggest as the economy grows, the use of freight increases, which increases the tax taken from diesel. The adjusted net savings data suggests much the same as GDP, although there is evidence of short run causal effects from the gasoline taxes to the net savings, which is negative. This suggests that in the short term greater use of gasoline taxes may harm aspects of the economy.

[10] With the OECD dataset, we also attempted to use population and a variable proxying environmental subsidies, which in this case was the research and development expenditure on the environment. However using the Pedroni approach to panel cointegration, there was no evidence of cointegration in any test and also in the Granger causality tests, there was no evidence of any causality, so the results have not been reported. We also tried using the gasoline and diesel taxes as a percentage of the cost of a litre of fuel, but these measures did not work as well as the total cost of the tax, possibly because the cost of a gallon of fuel differs substantially across the countries tested. The base used is the same for all countries.

The error correction terms are negative when causality runs to the environmental taxes indicating stability although the speed of adjustment depends on the measure used, being between 20 and 50% of adjustment back to the long-run in a year. These results accord with other studies that suggest results are sensitive to the measurement of the environmental variables (See Jeppesen *et al,* 2002), although diesel and gasoline taxes tend to be more significant than the general environmental tax measures used by the EU.

4. Conclusions

These results provide some evidence of a long-run causal effect from GDP and net adjusted savings to environmental and/or transport taxes, however there is little evidence of long-run causality in the other direction with the EU or OECD environmental and transport taxes data. This result does not change substantially when other factors are considered, such as population and proxies for environmental subsidies. This suggests there is little evidence that an expansion of environmentally friendly tax policies will enhance economic growth. The policy interpretation is that more smart approaches for efficient instruments to promote sustainable economic growth and at the same time managing the natural resources and controlling pollution levels efficiently is required. Hence, the link between environmentally related taxes and environmental development in association with revenue recycling is important. For instance, in some OECD countries, the motor fuel and motor vehicles taxes are spent on the construction or maintenance of roads and other activities such as: installation of noise-protection walls, development of bicycle lanes and improvement in public transport (OECD, 2006). Hence, future research can assess the magnitude of such revenue recycling in environmental development against the levels of the tax burden for countries.

Also, with the OECD data, both diesel and gasoline taxes have no long-run causal effect on output. There is also no causal relationship from gasoline or diesel taxes to adjusted net savings, suggesting that our failure to find support for the positive effects of environmental taxes on growth is not due to limitations with GDP as a measure of welfare. Unfortunately, there is no data on the use of biofuels over this time period, which is an important area for future research as more data becomes available. Overall the evidence suggests richer countries are more able to afford the costs associated with the environmental taxes, although as with other results the effect is sensitive to the measure of the environmental policy used.

The policy implications of this study suggest that for country's to meet their pollution targets, environmental taxes and the associated increase in renewable energy will probably need to continue but it is imperative to link these actions to economic development. The evidence here suggests that increasing environmental taxes does not appear to have any substantial impact on the economy. Also, it does not indicate any harmful impact from the increase of taxes, which is important for the transition economies to improve their environmental standards.

Moreover, future research will need to concentrate on other larger economies, specifically that of the USA and China and over longer time periods as the data becomes available for the exploration of the underlying effects of changes in environmental taxes to environmental externalities. Also of importance is the addition of more disaggregated data and other explanatory variables, as the data becomes available, in particular the effects of environmentally related technology, which could include specific data on patents. In addition the relationship between environmental taxes and other personal and corporate taxes could be included as further factors effecting growth. The study attempts to control for the endogeneity problem using GMM estimation techniques, however it would be interesting to use alternative sets of instruments to the ones used in this study, again as suitable data becomes available.

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Table 1. Description of Variables

Variable	Description
Y	real GDP per capita
Taxt	Total environment taxes to total taxes(%)
Taxy	Total environment taxes to GDP(%)
Trantaxt	Transport taxes to total taxes(%)
Trantaxy	Transport taxes to GDP(%)
ANS	Adjusted net saving
DTax	Diesel tax
Gtax	Gas Tax
Populat	Population
RE	Renewable energy (% of energy from renewable sources)

Table 2. Summary Statistics regarding tax revenue for EU (%)

	Total environmental taxes				Transport Taxes			
	% of GDP		% of total tax		% of GDP		% of total tax	
Country	mean	var	mean	var	mean	Var	mean	Var
Austria	2.44	0.05	5.66	0.25	0.79	0.01	1.82	0.04
Belgium	2.34	0.01	5.20	0.06	0.66	0.00	1.47	0.01
Czech	2.57	0.02	7.30	0.07	0.29	0.01	0.83	0.05
Cyprus	3.02	0.26	9.92	1.02	1.93	0.06	6.51	2.11
Denmark	5.23	0.17	10.66	0.64	2.04	0.04	4.14	0.13
Estonia	1.77	0.20	5.50	2.72	0.17	0.01	0.53	0.06
Finland	3.13	0.02	6.93	0.12	1.06	0.02	2.35	0.10
France	2.56	0.04	5.85	0.20	0.61	0.00	1.40	0.02
Germany	2.38	0.03	5.93	0.27	0.37	0.00	0.92	0.00
Greece	2.53	0.19	8.01	2.69	0.82	0.01	2.57	0.09
Hungary	2.99	0.06	7.72	0.30	0.37	0.02	0.97	0.13
Ireland	2.69	0.10	8.61	0.52	1.25	0.01	3.99	0.06
Italy	3.16	0.09	7.59	0.50	0.45	0.00	1.09	0.03
Latvia	2.29	0.22	7.59	2.74	0.22	0.02	0.74	0.28
Lithuania	1.80	0.12	6.12	1.38	0.66	0.04	2.26	0.47
Luxembourg	2.87	0.01	7.51	0.14	0.13	0.00	0.33	0.00
Malta	3.48	0.10	11.94	3.55	2.13	0.06	7.36	2.23
Netherlands	3.82	0.02	9.79	0.17	1.34	0.01	3.43	0.02
Poland	2.21	0.12	6.55	1.68	0.22	0.00	0.64	0.04
Portugal	3.19	0.06	9.41	0.97	1.00	0.01	2.94	0.09
Spain	2.12	0.02	6.22	0.31	0.41	0.00	1.21	0.00
Sweden	2.85	0.01	5.72	0.05	0.33	0.00	0.66	0.00
UK	2.83	0.06	7.82	0.51	0.54	0.00	1.51	0.03

Notes: Var is the variance.

Table 3. Summary Statistics for OECD (in US$ per litre)

	Diesel taxes		Gas taxes	
Country	mean	variance	mean	variance
Austria	0.36	0	0.69	0.01
Belgium	0.37	0	0.82	0.01
Czech	0.31	0.01	0.54	0.01
Finland	0.36	0	0.85	0.01
France	0.45	0	0.89	0.01
Germany	0.46	0.01	0.83	0.01
Greece	0.31	0	0.57	0.02
Hungary	0.40	0.02	0.80	0.05
Ireland	0.41	0.01	0.68	0.01
Italy	0.48	0	0.86	0.01
Netherlands	0.42	0	0.94	0.02
Norway	0.53	0.01	0.95	0.01
Poland	0.25	0	0.50	0.01
Portugal	0.41	0.01	0.74	0.03
Slovak	0.40	0.01	0.57	0.01
Spain	0.35	0	0.62	0.01
Sweden	0.39	0	0.81	0.01
Switzerland	0.57	0	0.61	0.01
UK	0.75	0.01	0.89	0.02
USA	0.13	0	0.12	0

Notes: These values represent the amount of tax in a litre of fuel in US dollars.

Table 4. IPS Unit root tests

	EU			OECD	
Variable	Level	Differenced		level	differenced
Y	4.126	-2.663**	Y	2.414	-2.271**
taxt	0.785	-5.993**	Ans	3.614	-2.866**
taxy	0.278	-5.879**	Dtax	0.775	-2.246**
trantaxt	-0.212	-8.383**	Gtax	1.395	-1.657**
Trantaxy	-0.171	-8.131**			
Re	1.955	-7.794**			
populat	8.540	5.339 (69.036**)			

Notes: ** indicates significance at the 5% level (one tailed test). Lag length determined by modified Akaike Information Criteria. Value in parentheses is Fisher chi-sq Philips-Perron test statistic.

Table 5. Tests for Cointegration in EU Dataset

Test Statistic	tax→y	y→tax
Y/taxy	1.732	-2.973**
Y/taxt	1.846	-1.374
Y/trantaxt	2.136	0.661
Ytrantaxy	1.833	-1.096

Notes: ** indicates rejection of the null hypothesis of no cointegration at the 5% level. In the first and second columns, the dependent variable in the cointegrating relation is first followed by the explanatory variable.

Table 6. Tests for Cointegration in OECD Dataset

Test Statistic	tax→y	y→tax
Y/Dtax	-0.694	-1.535
Y/Gtax	-0.143	-6.180**
ANS/Dtax	1.550	2.896
ANS/Gtax	1.524	2.312

Notes: See Table 3.** indicates rejection of the null hypothesis of no Cointegration at 5% level of significance

Table 7. Results of Pedroni Cointegration Tests including population and renewable energy

Test Statistic	Taxt	Taxy	Trantaxt	Trantaxy
Panel *v*-statistics	-0.437	-3.318	-0.727	-0.874
Panel rho-statistics	2.370	-0.100	2.575	2.707
Panel PP-statistics	-0.822	-15.183**	-0.944	-0.075
Panel ADF-statistics	-2.870**	-11.079**	-2.089**	-2.612**
Group rho-statistics	4.481	3.461	3.741	3.644
Group PP-statistics	-6.226**	-11.424**	-7.217**	-5.546**
Group ADF-statistics	-6.173**	-7.965**	-6.723**	-6.585**

Notes: ** indicates rejection of the null of no cointegration at the 5% level of significance (one tailed test). Lag length determined by Schwarz-Bayesian Information Criteria

Table 8. Granger Causality Tests with EU Data

Causality direction	ECT (t-statistic)	Lag coefficient (t-statistic)	F-test (time dummies)	Sargan (p-value)
TAXT→Y		-0.005(3.848)**	48.153**	0.244
Y→TAXT		-0.443 (0.368)	69.828**	0.298
Y→TAXY	-0.360(5.994)**	-0.938 (2.140)**	69.242**	0.712
TAXY→Y		-0.011 (3.531)	56.060**	0.318
TRTAXT→Y		-0.047 (0.039)	25.447**	0.485
Y→TRTAXT		-0.017 (4.524)**	3.871**	0.290
TRTAXY→Y		-1.174 (0.302)	19.167**	0.497
Y→TRTAXY		0.0003 (0.146)	5.290**	0.178

Notes: ECT is the error correction term. The instruments used in the GMM estimation were the second lag of the dependent variable and the yearly dummies. The fourth column is a F-test on the joint significance of the time dummies and the fifth column contains the p-value for the Sargan test for overidentifying restrictions. ** indicates it is significantly different to 0 at the 5% level of significance.

Table 9. Granger causality with EU dataset and including population and renewable energy.

Direction of Causality	Taxt(-1)/ Y(-1)	RE(-1)	Populat (-1)	F-test (time dummies)	Sargan (p-value)
TAXT→Y	-0.000 (0.020)	-0.004** (3.415)	-1.450 (0.683)	44.433**	0.233
Y→TAXT	-0.931 (0.539)	-0.006 (1.055)	-21.256 (1.280)	12.832**	0.270
Y→TAXY	0.552 (0.877)	0.003 (0.619)	7.753 (0.352)	25.896**	0.147
TAXY→Y	-0.007 (0.263)	-0.004** (2.838)	-1.602 (0.664)	44.433**	0.229
TRTAXT→Y	-0.005 (0.230)	-0.004** (3.790)	-1.273 (0.706)	35.300**	0.206
Y→TRTAXT	-0.875 (0.980)	-0.008 (0.634)	-59.048** (5.236)	3.461**	0.291
TRTAXY→Y	-0.032 (0.426)	-0.004** (3.600)	-1.415 (0.761)	37.648**	0.209
Y→TRTAXY	-0.100 (0.345)	0.004 (0.698)	-20.451** (4.001)	3.247**	0.399

Notes: See Table 6, RE is the differenced renewable energy and populat is the differenced population.
** indicates it is significantly different to 0 at the 5% levels of significance.

Table 10. Granger Causality Tests with OECD Data

Causality direction	ECT (t-statistic)	Short-run causality	Sargan test (p-value)	F-test (time dummies)
DTAX→Y		-0.003 (0.084)	0.252	84.021**
Y→DTAX		-0.340 (0.233)	0.331	82.710**
GTAX→Y		0.029 (1.418)	0.242	103.805**
Y→GTAX	-0.457 (4.951)**	-0.069 (0.114)	0.473	174.00**
DTAX→NS		0.194 (0.981)	0.361	49.841**
NS→DTAX		-0.201 (0.501)	0.420	108.714**
GTAX→NS		-0.335 (2.497)**	0.501	25.491**
NS→GTAX		-0.008 (0.083)	0.126	67.510**

Notes: The instruments used in the GMM estimation were the second lag of the dependent variable and the yearly dummies. The fourth column contains the p-value for the Sargan test for overidentifying restrictions, the fifth column a F-test on joint significance of the time dummies. ** indicates it is significantly different to 0 at the 5% level of significance.