Are Environmental Taxes Effective in Curbing Air Pollution? Evidence from the United Kingdom

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Abstract

There is mounting evidence that emissions of greenhouse gases trigger harmful environmental changes which, in turn, exert immense pressure on governments to reduce environmental damage, without impeding the rate of economic growth. Consequently, governments have been employing a variety of instruments, including taxes, at their disposal. In this context, the study examines the empirical relationship between environmental taxes and air pollution for the UK over the period 1997–2017, by employing the Vector Autoregression method and Granger causality tests. The econometric findings indicate that only energy taxes have been successful in curbing air pollution, whereas other environmental taxes, such as transport, pollution and resource taxes, have failed to exert any significant impact on air quality. We argue that factors such as ineffectiveness of the landfill tax, lack of efficient waste management practices and shortcomings in the motor vehicle tax system are offsetting the impacts of pollution and transport taxes.

JEL Classification: H23, Q50, Q53
Keywords: air pollution; environmental taxes; UK; time series analysis

1. Introduction

Climate change is one of the most acute crises facing the earth in current times and there is mounting evidence that emissions of greenhouse gases trigger these harmful changes (Watkiss *et al* 2005; Cassia *et al* 2018). A 2019 UN report (United Nations 2019) states that air pollution is likely to worsen over time, given rapid development and urbanisation. Undoubtedly this challenge is putting further pressure on governments to reduce environmental damage, without impeding the rate of economic growth. For this purpose, the governments have a variety of instruments at their disposal, such as innovation policies, regulations, education programmes, environmental subsidies and taxes. Taxation, in particular, is one of the most important amongst these instruments (OECD 2010).

Environmental taxes have numerous advantages, such as adeptness in raising public revenue, economic efficiency (in terms of directly addressing the failure of markets to account for environmental impacts), environmental effectiveness (by providing consumers and businesses flexibility in terms of determining how to reduce their levels of pollution) and transparency (OECD 2010). There have been previous instances where taxes have been used successfully to tackle various environmental issues, such as waste water disposal (water pollution) (Valero *et al* 2018) and carbon emissions (air pollution) (Lu *et al* 2010). Most of the studies which look at effectiveness of environmental taxes emphasise that the type and structure of environmental taxes are crucial determinants of the effectiveness of those taxes (OECD 2010).

Type and Structure of Environmental Taxes

Introducing taxes with an ambiguously defined environmental justification will not lead to any prospective gains. Instead, the policy introduced should be aimed at successful targeting of the polluter or polluting source. Inadequately targeted environmental taxes will not only lead to an increase in the economic costs of taxation, but also offer little in terms of environmental gains. This problem is apparent between the different types of taxes (Fullerton *et al* 2008):

i) Measured Emission Tax

One of the specifically targeted environmental taxes is where they are based directly upon measured emissions. When polluting emissions rise, the polluter's tax base increases and, as a result, the polluter is required to pay additional tax which is directly proportional to the polluter's rise in emissions. Likewise, the polluter taking any action to reduce their tax liability also ensures a reduction in the polluting emissions. However, the costs of measuring individual emissions are very high, which might deter usage of this form of taxation, especially in cases where only a small number of emission sources are involved or where it is crucial to link the tax incentive directly to the exact amount of emissions. Among developed regions, Denmark, Sweden, Finland, Netherlands and Norway, were the first countries to implement such a tax on emissions (Ghazouani *et al* 2020).

ii) Taxing a market good (which is related to emission production)

This is a form of indirect taxation on emissions, whereby a tax is introduced on the sale of polluting goods or production inputs. For instance, goods and services which cause environmental damage in consumption or production would be taxed heavily. Likewise, goods and services that are believed to benefit the environment would be taxed less than their substitutes (Hammar and Löfgren 2004). This category of environmental taxes is most commonly used as it has numerous benefits. Firstly, these taxes have lower administrative costs than the measured emission tax. Secondly, in some cases it may be possible even to amend the current tax structure and use it for this form of taxation. As

a result, it is less costly than setting up new administrative procedures. Even where setting up new procedures is not possible, a separate tax system based on transaction values has lower administrative costs than its counterparts. The disadvantage of using this kind of tax is that they are less precise than emission-based taxes and, consequently, could encourage inefficient polluter responses (Sandmo 1976; Fullerton *et al* 2008).

iii) Multi-part tax

A more efficient form of taxation would be a combination of multiple indirect taxes so as to be able to replicate the effects of a tax on emissions without the extra administrative cost. It generally includes an excise tax on the sale of a commodity, in addition to a subsidy for clean technology, which together can offer substitution and output effects. For instance, a direct tax on motor vehicle emissions would not be feasible; however, the same effect can be achieved through a combination of instruments such as a tax on petrol, a subsidy on new car purchases or on electric vehicles, a tax on older cars or a tax on cars with low fuel efficiency or high emission rates (Fullerton and West 2002).

A tax targeted on emissions might be difficult to implement if there are substantial costs involved in measuring emissions. However, the same effects can be achieved with a combination of a tax on the output of the firm and a subsidy to purchase pollution abatement technology. Since the sale of output and purchase of inputs are both market transactions, these two instruments together will cost less to administer and would also replicate the tax on emissions (Fullerton *et al* 2008).

There exist several studies that have examined the empirical relationship between air pollution and environmental taxes for an individual country or for a panel of countries (see Section 3 for a detailed review). However, to the best of our knowledge, no quantitative study exists on the UK in this area. Undertaking an investigation on this relationship is vital from a policy point of view because using taxes and emission charges aids in achieving environmental goals cost-efficiently. Economic instruments are able to offer a given level of environmental protection at a lower cost by providing incentives to polluters to choose the most cost-effective abatement mechanism; and by persuading the biggest abatement effort from the polluters for whom it is least expensive. These instruments also usually provide incentives for innovation in pollution control and management technologies (Fullerton *et al* 2008). As a result, it is crucial to understand whether the existing environmental tax instruments in UK are contributing towards pollution abatement efforts or not. This paper therefore extends the literature in the context of the UK.

The rest of the paper is organised as follows. Section 2 gives an overview of the environmental tax structure in the UK. Section 3 reviews the relevant literature, whilst Section 4 discusses the econometric model and data employed in the study. Section 5 presents the empirical analysis and, finally, Section 6 concludes.

2. Overview of the Environmental Tax Structure in the UK

The UK's environmental taxes can be divided into three categories (Office for National Statistics 2015):

i) **Transport Taxes:** This category primarily consists of taxes related to the ownership and use of motor vehicles;

ii) **Pollution and Resource Taxes:** This includes taxes on the extraction of raw materials and on the management of waste; and

iii) **Energy Taxes:** Energy taxes comprise taxes on energy production and on energy products (for example, coal, oil products, natural gas and electricity) used for both transport and stationary purposes.

These are further divided into multiple sub-categories. The following table gives a brief overview of the type and structure of environmental taxes that exist in the UK:

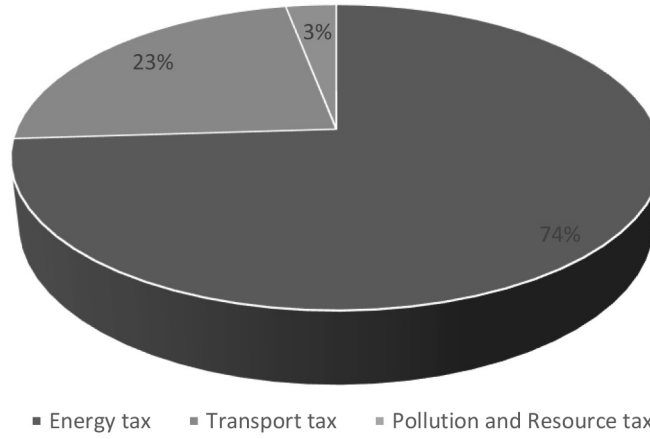
Table 1: UK's Environmental Tax Structure

Type of Tax	*Category of Tax*	*Direct/Indirect tax*
Transport Tax		
Multi-Part Tax	*Vehicle Excise Duty*	Indirect tax
Taxing a market good	*Rail Franchise Premia*	Indirect tax
Taxing a market good	*Air Passenger Duty*	Indirect tax
Pollution and Resource Tax		
Multi-Part Tax	*Landfill Tax*	Indirect tax
Multi-Part Tax	*Aggregates levy*	Indirect tax
Taxing a market good	*Fishing licenses*	Indirect tax
Energy Tax		
Taxing a market good	*Tax on Hydrocarbon Oil*	Indirect tax
Multi-part Tax	*Renewable Energy Obligation*	Indirect tax
Multi-part Tax	*Climate Change Levy*	Indirect tax
Measured Emission Tax	*Emissions Trading Scheme (ETS)*	Indirect tax

Source: Compiled by the authors using information from Leicester (2006).

The highest contribution to environmental tax revenue in 2017 was from energy taxes. It accounted for almost three quarters (74 per cent) of environmental tax revenue. The largest single contributor to energy taxes is the hydrocarbon oil duty. This tax includes diesel and petrol fuels, despite being classified under energy taxes. Hydrocarbon oil duty accounted for 57 per cent of environmental tax revenue in 2017. In the same year, pollution and resource taxes (including extraction of raw materials and management of waste) accounted for 3 per cent of total environmental tax revenues and transport tax accounted for 23 per cent of the same (Office for National Statistics 2018):

Figure 1: UK's Environmental tax revenue, by tax type in 2017



Data source: Office for National Statistics, 2018

3. Review of the Literature

There exists a reasonably large literature which has looked at the relationship between air pollution and environmental taxes. This section has been divided into two parts: the first part explores the theoretical literature and the second part discusses the empirical studies.

3.1 Theoretical Literature

One of the earliest theories of environmental taxes was provided by Pigou (1920). The study shows that taxes, classified as incentive-based mechanisms, are one of the key instruments for addressing environmental issues, such as climate change and pollution. Taxes create the correct incentives for agents to internalise the cost of pollution and prevent them from polluting above the socially optimal level.

However, in reality, it is quite difficult to achieve a socially optimal outcome as there is no correct formula to establish an efficient tax rate, as evidenced in Repetto *et al* (1993). This paper points out that local environmental quality could be improved by raising revenues through environmental charges. However, it is quite possible that the cost of these charges is typically not borne by the individuals or the firms but instead by all users. As a result, when designing these taxes, it is important to ensure that the costs of the damaging activity are distributed uniformly amongst those who cause the damage, but also provide them with enough flexibility to be able to develop appropriate solutions. Furthermore, there are certain pollution issues, such as traffic congestion, carbon emissions and solid waste generation, which are extremely diverse and the nature of the problem changes so quickly that

regulations are usually not kept sufficiently up-to-date to handle these issues.

Eskeland (1993), on the other hand, explains that indirect forms of tax might work better for pollution abatement. The author develops an analytical framework for gasoline in Mexico City to show that an indirect form of environmental tax (that is, taxing a variable input in polluting activities) works better than a direct pollution tax. According to this study, a tax on a variable input like gasoline encourages firms and individuals to forfeit trips when the costs of abatement are higher. This kind of tax mechanism uses privately-held information regarding which trips can be saved at a lower social cost. This study also shows that the appropriate tax rate for a cost-effective pollution control programme is independent of the polluting good's price elasticity of demand. However, the higher the demand elasticity, the higher the costs of not including a tax in the pollution control agency's tool kit.

Sinn (2008) posits that a rapidly rising carbon tax could accelerate greenhouse gas emissions. For instance, consider the problem that a fossil fuel resources owner faces when a rising carbon tax is imposed. If the tax is too high, then it might be rational to leave the fuel in the ground forever. However, if not, then the sooner the fossil fuel is extracted and burned, the less tax will be charged on it. If the tax is rising faster than the rate of interest, then even the present discounted value of the tax will be rising over time, providing an incentive to extract and burn the fuel sooner. This situation is called a 'green paradox', whereby the environmental policy backfires and creates even more harm for the environment by accelerating the rate of global warming.

Another issue to be considered when examining environmental tax design is the multiple externality problem. Parry *et al* (2012) point out that this a significant issue, especially in transportation. For instance, there are four kinds of externalities associated with motor fuel tax (for passenger vehicles). The first is related to carbon dioxide (CO_2) emissions, which are proportional to fuel combustion. Ideally, the level of taxation should equal the CO_2 produced per unit of fuel combustion, times the marginal damage from the emissions. But often, when calculating transport taxes, the marginal damage from CO_2 emissions is not considered. Secondly, fuel taxes can reduce local emissions, but by a lesser amount in proportion to fuel consumption reduction.

Thirdly, in response to higher fuel prices, emissions reduce as people drive less. However, in the long run, emissions-per-mile regulations are ineffective. In response to greater fuel economy, manufacturers in the long run would instead cut back on abatement technologies, because of higher production costs, as fuel prices are higher (Fischer *et al* 2007). Therefore, when calculating corrective fuel taxes, pollution damage estimates need to be considered as well. Finally, the positive externalities of reducing traffic congestion and lowering incidents of traffic accidents should also be considered when designing taxes.

3.2 Empirical Literature

The empirical literature in this field can be categorised into two strands (Miller and Vela 2013): a) the effect of indirect environmental taxes on pollution abatement, focusing on carbon taxes (imposed on fossil fuels and other products according to their carbon content in order to reduce CO_2 emissions); and b) the effect of direct environmental taxes specifically, a carbon tax, on emissions.

Under (a), Bruvoll and Larsen (2004) analyse the effect of carbon taxes on changes in emission rates in Norway, using an applied equilibrium simulation model. The results indicate that carbon taxes reduce emissions per unit of GDP, along with energy intensity and process emissions. Millock *et al* (2004) attempt to look at the effectiveness of environmental taxes on emissions in Sweden and France and conclude that, in France, the taxes had a substantial effect on sulphur dioxide (SO_2) and volatile organic compounds (VOC) emissions, but not on nitrogen oxides (NO_x) emissions. This difference in the effectiveness of taxes could be attributed to French regulations with regards to monitoring procedures. As real emissions are not monitored, the link between the tax base and actual emissions is severed which, in turn, diluted the incentive effect of the tax for NO_x. The study also notes that as Scandinavian environmental taxes are set higher than French taxes on air pollution, it provides a real incentive for Swedish firms to abate and, as a result, the efficiency of the Scandinavian taxes are enhanced.

Millock *et al* (2004) also look at the issues which need to be addressed to improve the incentive effect of carbon taxes on fossil fuels. The study suggests that, for manufacturing, precise monitoring equipment plays a significant role, along with educating engineers about the maintenance of this equipment, as the latter also plays a vital role in monitoring emissions. Further, refunded environmental taxes also seem to be more efficient in reducing emissions as compared to other forms of taxation.

Gerlagh and van der Zwaan (2006) analyse carbon taxes (among other instruments) using a top-down energy demand model. The study finds that recycling carbon taxes as subsidies for non-fossil energy is the cheapest option, compared to subsidies for non-fossil fuel production. Sterner (2007) concludes that fossil fuel taxes in Europe play a critical role in reducing fuel demand and carbon emissions. Yan and Crookes (2009) also find similar results in the context of China, whereby fossil fuel taxes have led to a reduction in the growth of vehicles and energy demand.

Carbone *et al* (2013) predict that a $50 per tonne carbon tax, starting in 2015 and held constant in real terms, should reduce US greenhouse emissions by roughly 23 per cent below a business-as-usual (BAU) baseline in 2025. Miller and Vela (2013) analyse the effectiveness of environmental taxes by examining the environmental performance of 50 countries. Using a cross-sectional regression and a dynamic panel regression, they find that countries with higher revenues from these types of taxes also exhibit greater reductions in CO_2 emissions and particulate matter (PM10) emissions. Hafstead and Kopp

(2015) find that a $45 per tonne carbon tax, starting in 2016 and rising at 2 per cent per year in real terms, would reduce US emissions by almost 36 per cent in 2030.

Ionescu (2019) examines the relationship between pollution tax, climate policies and carbon pricing in the US using structural equation modelling. The results indicate that introducing a green energy default nudge reduces support for a carbon tax. Instead, if governments reinvest in society to support issues surrounding climate change, this might influence society more to favour carbon taxes. Moreover, as there are contradicting emission reduction targets worldwide, domestic climate policies may be ineffective in lowering consumption based CO_2 emissions throughout a supply chain comprised of global fractions.

Under the latter strand (the effect of direct carbon taxes on emissions), Nakata and Lamont (2001) examine the effects of carbon and energy taxes on carbon emissions from the Japanese energy system and conclude that these taxes are a suitable instrument for reducing emissions. Using a difference in differences approach, Lin and Li (2011) find that carbon taxes play a significant role in reducing emissions in Finland, but not in the Netherlands, Denmark or Sweden. Andersson (2019) analyses the impact of a carbon tax and a value-added tax (on transport fuel) in Sweden and finds evidence of emissions reductions of 11 per cent. Metcalf (2019) estimates difference-in-difference regressions using Canadian province data for British Columbia and establishes that a carbon tax reduced emissions by five to eight per cent since its introduction in 2008. Metcalf and Stock (2020) consider the impact of the taxes on emissions reductions in 31 European countries (including the former EU member, the UK) that are part of the EU wide emissions trading system (EU-ETS) and find a cumulative reduction of the order of four to six per cent for a tax of $40 per tonne of CO_2.

Certain studies report no effect of environmental taxes on pollution because of poor tax structure, incorrect tax exemptions and inadequately planned refund systems. For instance, Morley (2012) conducts a study which looks at whether environmental taxes play a role in affecting levels of pollution in EU countries and Norway. The author finds that despite there being a significant negative relationship between taxes and pollution, taxes have a limited effect on the use of natural resources. The study points out that, for environmental taxes to be effective for pollution abatement, the structure of the environmental tax as well as other tax levels play a significant role. Similarly, Vehmas (2005) studies Finland's experience with environmentally based energy taxes and finds that fiscally motivated deviations from the optimal level of environmental tax have weakened the actual purpose of the tax, again pointing towards an improper tax structure.

As can be seen from the above discussion, there are numerous studies that have looked at the relationship between environmental taxes and pollution, but none of the studies are based on the UK. There are studies, such as Morley (2012), which tests the tax-pollution nexus for a panel of EU countries including

the UK, but one of the main shortcomings of panel studies is that these results only provide an estimate of the average relationship between variables for the entire sample. To formulate effective and relevant policies, one needs to know the country-specific characteristics and, in this context, the current study aims to contribute to the debate by undertaking a time-series analysis on the UK. Moreover, having now left the EU, the UK needs to formulate its own environmental policies, which adds further relevance to this research. Finally, most of the studies have only looked at one form of tax, however in this study, all three categories of the UK's environmental tax system (energy taxes, transport taxes, and pollution and resource taxes) will be considered when analysing the relationship between taxes and air pollution.

4. Methodology and Data

Past studies have put forward several variables as potential determinants of pollution. Following Miller and Vela (2013), we have considered revenues from various environmental taxes as the proxy for environmental taxes. One may argue that higher revenues do not necessarily imply higher tax rates and, furthermore, a more effective tax may diminish the base of the environmental tax, thereby reducing total revenue from environmental taxes. Nonetheless, the existing empirical evidence suggests that countries with higher revenues from environmental taxes do generally have higher tax rates (OECD 2006).

The 2013 study also argues that industrial intensity represents the weight of the polluting sectors in the economy. Hence, we incorporate a measure for the size of the manufacturing sector as a control variable in our econometric model. The variable also acts as a proxy for the size of the economy of the country in consideration. However, please note that we have also used overall economic size (GDP, in constant 2010 US$) as an alternate proxy for economic activities in our re-estimation of the econometric model (under robustness checks). Following Lin and Li (2011), a measure of urbanisation (population density) has been considered. Auerbach and Flieger (1967) and Karatas and Karatas (2016) suggest that higher education leads to more awareness about the environment which, in turn, results in less pollution. Consequently, we incorporate a measure of 'Education' in our model as a control variable. Finally, an institutional control variable (Ruleoflaw) has been included in the model as past studies have shown that political institutions tend to influence environmental outcomes including air quality (Congleton 1992; Bernauera and Koubi 2009).

A regulatory quality control variable has also been incorporated in the econometric model. As regulatory quality is a multi-dimensional variable and is difficult to quantify (Brunel and Levinson 2013), therefore, natural resource rent (as a percentage of GDP) has been considered as a proxy for this. Basu Roy (2019) has shown that natural resource rent affects pollution levels through its impact on the regulatory quality of pollution. If natural resources rents for a country are high it implies that the environmental regulations are weak and, consequently, this should potentially lead to an increase in pollution.

In its basic form, the econometric model estimated in this study can be expressed as:

$$\text{Pollution}_t = \beta_0 + \beta_1\text{Taxes}_t + \beta_2\text{Manufacturing}_t + \beta_3\text{Education}_t + \beta_4\text{RuleofLaw}_t + \beta_5\text{Rent}_t + \beta_6\text{Population}_t + e_t \quad (1)$$

where, in time 't', 'Pollution' denotes air pollution, defined as total greenhouse gas emissions (kt of CO_2 equivalent), 'Taxes' represent three types of taxes, namely, energy taxes (proxied by real government revenue from energy taxes in the UK in million pounds, variable name: *Energytaxes*), transport taxes (real government revenue from transport taxes in the UK in million pounds, variable name: *Transporttaxes*), and pollution and resource taxes (real government revenue from pollution and resource taxes in the UK in million pounds, variable name: *Pollutiontaxes*). Each tax variable enters the model separately.

We also incorporate other control variables in our model: 'Manufacturing', which is defined as total value added manufacturing (constant 2010 US$), 'Education' stands for the number of UK, EU and non-EU undergraduate students in the UK, 'RuleofLaw' is a governance variable which measures the extent to which agents have confidence in and abide by the rules of society, in particular, the quality of contract enforcement, the police, and the courts, as well as the likelihood of crime and violence, 'Rent' represents natural resources rents, calculated as the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents as a percentage of GDP, 'Population' denotes population density (people/km^2) and, finally, 'e' is the error term. Please see Table A1 in the Appendix for sources of all the variables used in the analysis.

Table A2 in the Appendix presents the descriptive statistics of the key variables. The revenues from the three broad categories of environmental taxes show an incremental trend over the last two decades (see Figure A1 in the Appendix). Energy taxes are the source of the majority of the revenue from environmental taxes in the UK (as discussed in Section 2), followed by transport taxes. Over the time period considered, as Figure A2 indicates, air pollution (as measured by total greenhouse gas emissions) has registered an overall downward trend in the UK, declining from 716,185 kt of CO_2 equivalent in 1997 to 460,200 kt of CO_2 equivalent in 2017. Now, the question is whether there exists causality between this decline in air pollution and the increase in environmental tax revenues.

In time series analysis, we start by checking the order of integration (or, a test of stationarity) of the variables. If the variables come out to be non-stationary, applying Ordinary Least squares (OLS) will lead to the problem of spurious regressions and, thus, the results will be unreliable and unfit for drawing meaningful inferences (Stock and Watson 2007). Instead, more advanced econometric techniques will need to be applied (as outlined below). The Augmented Dickey-Fuller (ADF) unit root test has been employed to test for

stationarity. All variables have been expressed in their natural logarithms for ease of interpretation because taking logarithm converts the changes in variables into percentage changes (Stock and Watson, 2007).

Table 2: ADF test results

Variable	*Level*	*1st Difference*	*Conclusion*
Air Pollution	0.10	–3.60**	I(1)
Energy Taxes	–2.30	–4.70***	I(1)
Transport Taxes	–2.81	–3.89**	I(1)
Pollution and Resource Taxes	–0.95	–3.68**	I(1)
Manufacturing	–2.96	–4.16**	I(1)
Education	–2.70	–3.91**	I(1)
RuleofLaw	–3.51*		I(0)
Population	–3.21	–4.43***	I(1)
Rent	–2.71*		I(0)

Note: *, ** and *** represent statistical significance at 10%, 5% and 1% respectively

The ADF test results indicate that all variables, except 'RuleofLaw' and 'Rent', are I(1) i.e. they are stationary in 1st differences. Next, we examine the possible existence of co-integration (or, a long-run relationship) between air pollution and the taxes. The Johansen test results confirm that there exists no relationship between the two in the long run (these results not presented here but are available upon request). Consequently, we attempt to estimate the short-run relationship by employing Vector Autoregression (VAR).

Moreover, there is ample evidence in the literature that there may exist reverse causality from pollution towards environmental taxes (e.g. Fredriksson 2001). The variable 'Rent' (natural resources rents), which measures the contribution of natural resources to economic output, can also be endogenous and depend on pollution, taxes and RuleofLaw. It is the profits earned above the cost of extracting these resources. Rents from non-renewable resources are an indication of a country's capital stock liquidation. As a result, when countries use these rents to sponsor current consumption rather than trying to substitute what is being used up, they are borrowing against their future. As a result, if rents for a country are high, it implies regulations or institutions are weak. This further implies that rents have a relationship not only with pollution but also taxes and rule of law (Basu Roy 2019).

If there is any reverse causality in our data then OLS regression estimates will be biased and, again, VAR would be a more effective approach in dealing with such endogeneity or reverse causality issues (Ghosh Dastidar 2015). The VAR system of equations with air pollution as the dependent variable and government revenue from energy taxes ('EnergyTaxes') looks as follows. The optimal number of lags is 2, as determined by the Akaike Information Criterion (AIC). We have treated pollution, taxes and the rent variables as "endogenous" and the rest of the variables as exogenous.

$$\Delta Pollution_t = \beta_0 + \beta_1 \Delta Pollution_{t-1} + \beta_2 \Delta Pollution_{t-2} + \beta_3 \Delta EnergyTaxes_{t-1} + \beta_4 \Delta EnergyTaxes_{t-2} + \beta_5 Rent_{t-1} + \beta_6 Rent_{t-2} + \beta_7 \Delta Manufacturing_t + \beta_8 \Delta Education_t + \beta_9 RuleofLaw_t + \beta_{10} \Delta Population_t + e_{1t} \quad (2)$$

$$\Delta Energytaxes_t = \beta_0 + \beta_1 \Delta Pollution_{t-1} + \beta_2 \Delta Pollution_{t-2} + \beta_3 \Delta EnergyTaxes_{t-1} + \beta_4 \Delta EnergyTaxes_{t-2} + \beta_5 Rent_{t-1} + \beta_6 Rent_{t-2} + \beta_7 \Delta Manufacturing_t + \beta_8 \Delta Education_t + \beta_9 RuleofLaw_t + \beta_{10} \Delta Population_t + e_{2t} \quad (3)$$

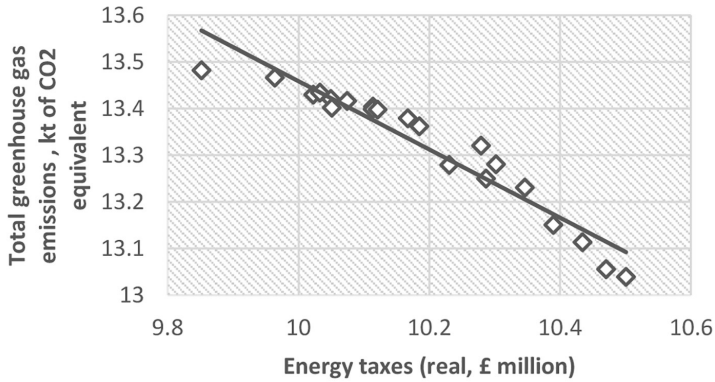
$$Rent_t = \beta_0 + \beta_1 \Delta Pollution_{t-1} + \beta_2 \Delta Pollution_{t-2} + \beta_3 \Delta EnergyTaxes_{t-1} + \beta_4 \Delta EnergyTaxes_{t-2} + \beta_5 Rent_{t-1} + \beta_6 Rent_{t-2} + \beta_7 \Delta Manufacturing_t + \beta_8 \Delta Education_t + \beta_9 RuleofLaw_t + \beta_{10} \Delta Population_t + e_{3t} \quad (4)$$

Similarly, estimating equations with other tax variables (Transport and Pollution and Resource taxes) will be specified. The analysis has been conducted for the time period 1997–2017. Earlier and more recent years could not be incorporated in the analysis, given data limitations. We also perform robustness checks (in Section 5) to ensure that our findings are not sensitive to different model specifications and to different proxies for economic factors or institutional quality.

5. Empirical Analysis

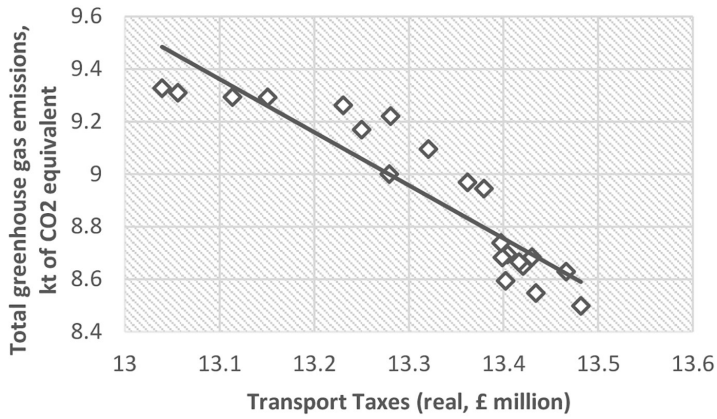
We start by looking at the correlation between air pollution and various environmental taxes. The scatter diagrams (Figures 2–4) presented below indicate that there exists a very strong negative association between greenhouse gas emissions and all three types of environmental taxes, especially energy and transport taxes, where the correlation coefficients are –0.959 and –0.917 respectively.

Figure 2: Air Pollution and Energy Taxes Scatterplot, 1997–2017



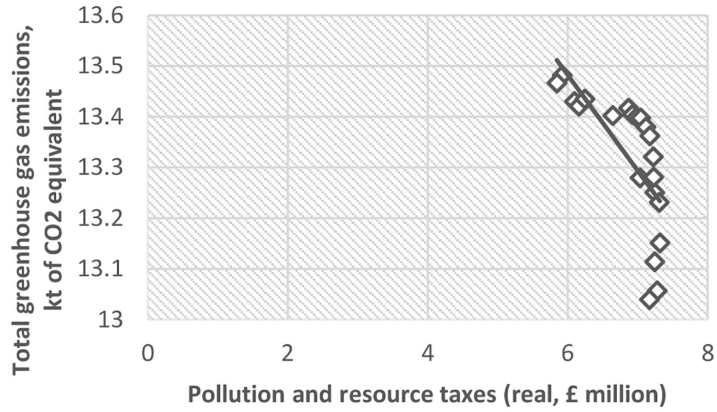
Note: Authors' own calculations based on data from the World Development Indicators (WDI) and the Office for National Statistics (ONS). Correlation coefficient = –0.959. Both variables have been expressed in their natural logarithms.

Figure 3: Air Pollution and Transport Taxes Scatterplot, 1997–2017



Note: Authors' own calculations based on data from the WDI and ONS. Correlation coefficient = –0.917. Both variables have been expressed in their natural logarithms.

Figure 4: Air Pollution and Pollution Taxes Scatterplot, 1997–2017



Note: Authors' own calculations based on data from the WDI and ONS. Correlation coefficient = –0.698. Both variables have been expressed in their natural logarithms

This finding is not surprising as, over the past two decades, greenhouse gas emissions have fallen drastically in the UK. At the same time, government revenues from energy, transport and pollution and resources taxes have increased by 91.4 per cent, 129.3 per cent and 248.5 per cent respectively. Subsequently, we examine whether this strong correlation translates to causality with the help of a VAR model (Table 3) and Granger causality tests (Table 4).

For the convenience of the reader and for the sake of brevity, we only present the VAR estimation results with 'pollution' as dependent variable (Equation 2 in context of energy taxes as the environmental tax) and do not report the same for the VAR equations with 'Taxes' and 'Rent' as dependent variables (Equations 3 and 4 in the context of energy taxes).[3] The justification behind this decision is the fact that the primary goal of the paper is to investigate the impact of environmental taxes on pollution. However, we do report the Granger causality test results of reverse causality flowing from pollution towards taxes. Column I, II and III present the VAR results with energy tax, transport tax and pollution tax as proxy for environmental taxes respectively.

Table 3: VAR Estimation Results

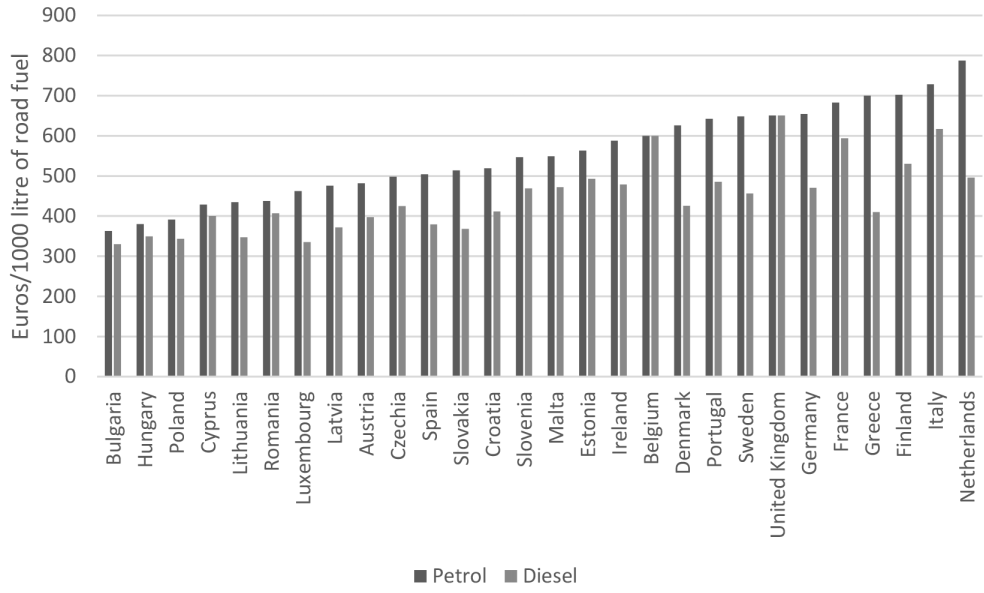
X variable	*Energy Taxes (I)*	*Transport Taxes (II)*	*Pollution & Resource Taxes (III)*
	Coefficient	*Coefficient*	*Coefficient*
$L.\Delta Pollution_{t-1}$	–0.835***	–0.679***	–0.555***
$L2.\Delta Pollution_{t-2}$	–0.048	–0.046	0.132
$L.\Delta Energytaxes_{t-1}$	–0.597**		
$L2.\Delta Energytaxes_{t-2}$	–0.306		
$L.\Delta Transporttaxes_{t-1}$		0.016	
$L2.\Delta Transporttaxes_{t-2}$		–0.201*	
$L.\Delta Pollutiontaxes_{t-1}$			–0.016
$L2.\Delta Pollutiontaxes_{t-2}$			0.096
$L.Rent_{t-1}$	0.102***	0.121***	0.053
$L2.Rent_{t-2}$	–0.043	–0.042	0.004
$\Delta Manufacturing_t$	0.891***	0.699***	0.646***
$RuleofLaw_t$	–0.280***	–0.260***	–0.178*
$\Delta Education_t$	0.012	0.022	–0.007
$\Delta Population_t$	–5.256	–1.947	–7.831
constant	0.452***	0.367***	0.272*
LM test for autocorrelation	Lag 1: P value=0.25	Lag 1: P value=0.27	Lag 1: P value=0.11
H_0: No autocorrelation at lag order	Lag 2: P value=0.32	Lag 2: P value=0.13	Lag 2: P value=0.15

Note: Dependent Variable=$\Delta Pollution_t$. L and L2 denote 1st and 2nd lags respectively. The VAR system satisfies the stability condition as all the eigenvalues lie inside the unit circle. *, ** and *** represent statistical significance at 10%, 5% and 1% respectively.

The econometric findings indicate that the effectiveness of taxes in curbing air pollution has not been uniform and there is clear evidence that some taxes have been more successful than others. Only energy taxes seem to have played a significant role in this regard. To be specific, everything else held constant, if the rate of growth in government revenues from energy taxes increases by 1 percentage point this year, greenhouse gas emissions growth falls by about 0.84 percentage points next year. As reported in Table 4, there is a unidirectional causality flowing from energy taxes towards air pollution as we reject the null hypothesis 'Energy taxes do not granger cause Air pollution'.

Energy taxes in UK have five components, but given data unavailability for each of the five components, it was not possible to conduct a comprehensive analysis regarding the effectiveness of each of the components. However, as the tax on hydrocarbon oils (fuel duty) accounted for 83.4 per cent of all income from energy taxes in 2015 (Office for National Statistics 2015), we can safely assume that the fuel duty component is likely to be the most efficient in pollution abatement. In fact, as evidenced in Figure 5 below also, the UK also has one of the highest fuel excise duty rates among European countries and the US.

Figure 5: Road fuel excise duties in the EU-27 and UK (2019)



Source: European Environment Agency, 2019

Figure 5 also demonstrates that the fuel excise duty on diesel in the UK is equal to that on petrol, unlike its European counterparts (except Belgium), where the tax on the former is lower. This taxation strategy is followed in the EU despite evidence that the environmental externality costs of diesel vehicles are higher than those of petrol vehicles. As a result, in recent decades, there has been a shift from petrol to diesel vehicles in most EU member states (European Environment Agency 2019). On the contrary, in the UK, there was a 30 per cent fall in registered diesel vehicles in 2018 compared to 2017. It was the second successive year of decline as, in 2016, diesel cars accounted for 47 per cent of all new car registrations, falling to 31 per cent in 2018 (Department for Transport 2019).

We assume that as the current fuel tax rates are encouraging consumers to shift from diesel vehicles to other fuel/electric vehicles, which has led to a fall in the UK's carbon emissions, making the energy tax effective. It also needs to be noted that a few papers, such as Wellings (2012), recommend reducing fuel duty as it is inefficient for addressing road congestion levels, accidents and infrastructure costs. Parry and Small (2004) also support reducing the current fuel duty in UK as it is more than twice the estimated optimal level (considering congestion as the largest externality). We, however, argue that to control carbon emissions, fuel duty tax rates work the best (as evidenced by this study) and, in fact, it should rise with inflation, which would further provide incentives to the consumers to move away from polluting fuels. In fact, to address congestion (as it can also lead to higher emissions), instead of reducing or abolishing fuel duty tax, peak time pricing could be introduced throughout the country and should not only be restricted to Central London.

The findings display a gloomy picture as far as the performance of the other taxes are concerned. Pollution and resource taxes are estimated to be completely ineffective in controlling air pollution in the UK; if anything, there is a reverse causality from air pollution towards pollution and resource taxes.

Table 4: Granger Causality Test Results

Null Hypothesis	*P-value*
Energy taxes do not granger cause Air pollution	0.032
Transport taxes do not granger cause Air pollution	0.130
Pollution & Resource taxes taxes do not granger cause Air pollution	0.281
Air Pollution does not granger cause Energy taxes	0.195
Air Pollution does not granger cause Transport taxes	0.814
Air Pollution does not granger cause Pollution & Resource taxes	0.023

As mentioned in Section 1, the pollution and resource taxes have three components. The literature suggests that of the three, the effectiveness of the landfill tax component, which makes the largest contribution towards this category of taxes, has been questioned time and again (ECOTEC 1998; HM Customs and Excise 1998; ACBE 2001). In 2014, the landfill tax represented 75.8 per cent of all income from pollution and resource taxes (Office for National Statistics 2015), thus we can safely conclude that this component is not working efficiently. Further, the environmental externalities of landfill lead to, among other things, emissions of methane, drinking water contamination and groundwater pollution (Martin and Scott 2003), which in turn leads to a rise in air pollution, thereby reinforcing our results.

An earlier theoretical assessment of the UK's landfill tax by the 2003 paper points out that, when it comes to municipal waste going to landfill, the tax has been unable to provide sufficient incentives for using alternative waste management practices. As a result, the total amount of municipal disposal waste has been increasing at a fast pace. Although there is evidence that levels of

recycling have been increasing, its rate of growth has been too slow to counterbalance the growth in municipal disposal waste in landfills. This is in contrast with construction wastes entering landfill sites, which has seen a sharp decline after the introduction of the tax. However, this cannot be heralded as a success story, as much of this construction waste is instead being spread on golf courses and farms for landscaping and soil improvement purposes respectively, which is leading to a rise in abusing licensing exemptions (ENDS 2001).

The main concern with the ineffectiveness of the landfill tax (particularly for municipal waste, which is the bigger environmental threat because of its organic content) is insufficient incentive for waste minimisation. The biggest contributors of municipal disposal waste are domestic households and non-construction based small and medium-sized enterprises. In the case of the former, the combination of landfill tax with council tax is charged at a flat rate, providing households with no incentives to reduce waste production. Similarly, for businesses, the current tax rate offers a negligible cost to force a change in behaviour. Additional disposal charges are also not strongly linked to weight of waste produced. Consequently, there is inadequate incentive for waste minimisation (Martin and Scott 2003). To increase the incentive, the government has been increasing landfill tax rates over time but, given the insignificant impact of the pollution tax coefficient, it can be safely assumed that the tax rates do not provide a sufficient incentive for waste minimisation yet. The results indicate that the tax needs to be redesigned (either through higher taxes or re-structuring), so that individuals and businesses feel its impact.

We obtained some evidence of a weak negative effect of transport taxes on air pollution (–0.201) but the overall impact of the tax has been insignificant, as indicated by the causality analysis. As mentioned before, the UK's transport tax also has three components. Of these, motor vehicle taxes (or, vehicle excise duty (VED)) account for the largest contribution to transport taxes (Office for National Statistics 2015). For instance, VED accounted for 47.6 per cent of total transport tax revenue in 2014. Therefore, it can be concluded that if transport tax is ineffective in pollution abatement, it is probably because of shortcomings in the VED tax system.

The UK's current tax measures on vehicle purchases include an annual circulation tax which depends on CO_2 emissions (Ekins *et al* 2010), but the VED reform which was introduced in 2017, on its own, has not been a very efficient policy measure to influence car purchase decisions. This lack of efficiency could be attributed to the fact that, under the new VED system, first year VED payments are related to CO_2 emissions (for cars registered after 2017), but subsequent payments are not. Ideally then, this tax should provide enough of an incentive to lead to a fall in motor vehicles with high CO_2 emissions and an increase in electric and hybrid vehicles which would lead to lower levels of air pollution.

However, in reality, the story is quite different, as economic incentives are necessary but not sufficient to encourage behavioural change (Lane and Potter

2007). Firstly, for car buyers in the UK, the 2007 study reports that environmental considerations are their least important concern. Secondly, the high purchase price and extended pay back times for low carbon vehicles act as major barriers in shifting to environmentally friendly vehicles. For instance, in the UK, the lease cost of a Toyota Prius Hybrid car has a significant premium over conventional models. The difference is because of the high servicing costs associated with hybrid cars. Thirdly, consumers are only likely to adopt products which are convenient to use and would not require the users to familiarise themselves with the product's technical requirements (such as charging of electric vehicles). Lastly, numerous drivers (especially, among young car drivers) in the UK view their car as a status symbol and are less likely to consider the environmental implications when choosing a car (Lane and Potter 2007; Hobbs and Harriss 2013). Therefore, it can be concluded that certain attitudes can lead to unsustainable and irrational behaviours among car users which can negate the incentive effects of the VAT tax system. Consequently, the transport tax also does not seem to affect air pollution levels in the UK.

Among the other control variables, an acceleration in manufacturing (value added) growth leads to an increase in air pollution growth. The coefficient comes out to be statistically significant in all three estimating equations. The finding is similar to that obtained by studies such as Ang (2007) and Liu *et al* (2018). The 2007 study reports that economic growth exerts a causal influence on the growth of energy use and growth of pollution in France, whilst the latter concludes that manufacturing agglomeration aggravates haze pollution significantly, in the context of China. In line with the findings of past studies like Castiglione *et al* (2015) and Clark *et al* (2019), institutions also seem to play a major role in curbing air pollution in the UK. Moreover, the impact of 'rule of law' is robust as it is not sensitive to different model specifications. There is also some evidence that the higher the natural resource rent, the higher will be the pollution, similar to the results found in Basu Roy (2019).

Robustness Checks

We subject our model and the findings obtained above to a series of robustness checks in order to ensure that the results are not sensitive to model specifications. Firstly, we replace the 'ruleoflaw' variable with other measures of institutional quality and/or governance ('Government Effectiveness' and 'Voice and Accountability') from the World Bank and re-run the model. This is because the term 'governance' has numerous definitions (Malito, 2015). Governance has been defined differently throughout the literature, ranging from 'order and disorder' (Levi-Faur 2012) to 'forms of collective action' (through media or civil society) (Lynn 2013).

Governance and/or Institutional quality is a significant factor when designing frameworks for pollution abatement policies and regulations.

Regulations, when enforced fairly, can ensure effective implementation of environmental strategies (Harman 2005). However, for these regulations to be enforced fairly, governance and institutional quality are critical. Hence, it is imperative that we test whether the other dimensions of governance (besides rule of law) have also played a role in UK's efforts in pollution abatement.

The variable 'Government Effectiveness', obtained from the World Development Indicators database, captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. The index ranges from approximately –2.5 (weak) to 2.5 (strong) governance performance. 'Voice and Accountability' captures perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media. As in the case of government effectiveness, the index ranges from –2.5 to 2.5. The estimation results have been presented in Tables 5 and 6 below.

Table 5: VAR Estimation Results with 'Government Effectiveness' (Govt)

X variable	*Energy Taxes (I)*	*Transport Taxes (II)*	*Pollution & Resource Taxes (III)*
	Coefficient	*Coefficient*	*Coefficient*
$L.\Delta Pollution_{t-1}$	–0.909***	–0.719***	–0.566**
$L2.\Delta Pollution_{t-2}$	–0.090	–0.023	0.130
$L.\Delta Energytaxes_{t-1}$	–0.605**		
$L2.\Delta Energytaxes_{t-2}$	–0.299		
$L.\Delta Transporttaxes_{t-1}$		0.024	
$L2.\Delta Transporttaxes_{t-2}$		–0.187*	
$L.\Delta Pollutiontaxes_{t-1}$			–0.021
$L2.\Delta Pollutiontaxes_{t-2}$			0.087
$L.Rent_{t-1}$	0.098***	0.116***	0.056
$L2.Rent_{t-2}$	–0.040	–0.037	0.003
$\Delta Manufacturing_t$	0.797***	0.663***	0.645***
$Govt_t$	0.046	0.029	0.011
$RuleofLaw_t$	–0.288***	–0.262***	–0.187*
$\Delta Education_t$	0.006	0.018	–0.006
$\Delta Population_t$	–3.418	–1.258	–7.322
constant	–3.417	0.314**	0.265*
LM test for autocorrelation	Lag 1: P value=0.16	Lag 1: P value=0.12	Lag 1: P value=0.39
H_0: No autocorrelation at lag order	Lag 2: P value=0.16	Lag 2: P value=0.74	Lag 2: P value=0.28

Note: Dependent Variable=$\Delta Pollution_t$. L and L2 denote 1st and 2nd lags respectively. The VAR system satisfies the stability condition as all the eigenvalues lie inside the unit circle. *, ** and *** represent statistical significance at 10%, 5% and 1% respectively.

Table 6: VAR Estimation Results with 'Voice and Accountability' (VM)

X variable	*Energy Taxes (I)*	*Transport Taxes (II)*	*Pollution & Resource Taxes (III)*
	Coefficient	*Coefficient*	*Coefficient*
$L.\Delta Pollution_{t-1}$	–0.893***	–0.770***	–0.592**
$L2.\Delta Pollution_{t-2}$	–0.095	–0.025	0.114
$L.\Delta Energytaxes_{t-1}$	–0.537**		
$L2.\Delta Energytaxes_{t-2}$	–0.323		
$L.\Delta Transporttaxes_{t-1}$		0.021	
$L2.\Delta Transporttaxes_{t-2}$		–0.191*	
$L.\Delta Pollutiontaxes_{t-1}$			–0.029
$L2.\Delta Pollutiontaxes_{t-2}$			0.075
$L.Rent_{t-1}$	0.099***	0.113***	0.057
$L2.Rent_{t-2}$	–0.034	–0.027	0.008
$\Delta Manufacturing_t$	0.797***	0.576***	0.605***
VM_t	0.083	0.117	0.068
$RuleofLaw_t$	–0.225**	–0.185*	–0.152*
$\Delta Education_t$	0.004	0.011	–0.009
$\Delta Population_t$	–8.221	–6.140	–9.947
constant	0.259	0.099	0.145
LM test for autocorrelation	Lag 1: P value=0.15	Lag 1: P value=0.68	Lag 1: P value=0.15
H_0: No autocorrelation at lag order	Lag 2: P value=0.36	Lag 2: P value=0.18	Lag 2: P value=0.48

Note: Dependent Variable=$\Delta Pollution_t$. L and L2 denote 1st and 2nd lags respectively. The VAR system satisfies the stability condition as all the eigenvalues lie inside the unit circle. *, ** and *** represent statistical significance at 10%, 5% and 1% respectively.

Our key findings stay unaltered. In other words, the new estimation results also indicate that only energy taxes have been instrumental in curbing air pollution in the UK. There is again some evidence of the effect of transport taxes on pollution, but the impact is marginal. As far as the institutional variables are concerned, we find that rule of law matters when it comes to effectiveness of environmental measures. In other words, the law and order situation in the country and quality of contract enforcement play an instrumental role in this regard.

Secondly, we take the overall economy size, GDP (in constant 2010 US$), as a proxy for economic activities (instead of just manufacturing) and re-examine the pollution-environmental taxes nexus (Table 7). The rationale behind the inclusion of this variable is to also incorporate the possibility of the impact of pollution from other economic sectors (like agriculture) as well. Moreover, previous studies such as Cole and Elliott (2003) and Morley (2012) have also used a GDP measure as potential determinant of pollution.

Table 7: VAR Estimation Results with GDP (constant 2010 US$) as proxy for economic activities

X variable	*Energy Taxes (I)*	*Transport Taxes (II)*	*Pollution & Resource Taxes (III)*
	Coefficient	*Coefficient*	*Coefficient*
$L.\Delta Pollution_{t-1}$	–0.877***	–0.807***	–0.728**
$L2.\Delta Pollution_{t-2}$	–0.001	0.001	0.079
$L.\Delta Energytaxes_{t-1}$	–0.337**		
$L2.\Delta Energytaxes_{t-2}$	–0.105		
$L.\Delta Transporttaxes_{t-1}$		0.066	
$L2.\Delta Transporttaxes_{t-2}$		–0.136	
$L.\Delta Pollutiontaxes_{t-1}$			–0.009
$L2.\Delta Pollutiontaxes_{t-2}$			0.044
$L.Rent_{t-1}$	0.080**	0.105***	0.066
$L2.Rent_{t-2}$	–0.023	–0.032	–0.005
ΔGDP_t	1.286***	1.206***	1.174**
$RuleofLaw_t$	–0.301**	–0.276***	–0.248**
$\Delta Education_t$	–0.004	0.011	–0.010
$\Delta Population_t$	1.975	2.382	–0.238
constant	0.402***	0.337***	0.313**
LM test for autocorrelation	Lag 1: P value=0.88	Lag 1: P value=0.17	Lag 1: P value=0.16
H_0: No autocorrelation at lag order	Lag 2: P value=0.19	Lag 2: P value=0.65	Lag 2: P value=0.34

Note: Dependent Variable=$\Delta Pollution_t$. L and L2 denote 1st and 2nd lags respectively. The VAR system satisfies the stability condition as all the eigenvalues lie inside the unit circle. *, ** and *** represent statistical significance at 10%, 5% and 1% respectively. GDP data comes from the World Development Indicators.

Nonetheless, our key finding with respect to the association between environmental taxes and air pollution stays unchanged. In line with our main findings, the robustness results also highlight the ineffectiveness of transport and pollution taxes. Energy taxes again come out to be the only category that is working as desired, as far as the UK's air pollution scenario is concerned. As expected and in line with the literature, GDP comes out with a positive and statistically significant coefficient, which implies that the volume of economic activities exerts a damaging impact on air quality.

6. Conclusions and Policy Recommendations

This study examines the causal relationship between environmental taxes and air pollution in the UK over the time period 1997–2017, by employing Vector Autoregression (VAR) and Granger causality tests. The econometric results indicate that only energy taxes have been successful in curbing air pollution, whereas the other environmental taxes, such as transport and pollution and resource taxes, have failed to exert any significant impact on air quality. This finding is robust and is not sensitive to different model specifications. We argue

that factors such as ineffectiveness of the landfill tax, lack of efficient waste management practices and shortcomings in the motor vehicle tax system are offsetting the impacts of pollution and transport taxes.

The landfill tax (the biggest component of pollution and resource taxation) has largely been ineffective in changing the waste producing behaviour of domestic households and non-construction SMEs. With regard to households, the landfill tax paid as part of their Council Tax is made a flat rate, independent of how much waste is being produced by every household. Consequently, it has not been able to alter the behaviour of households. We recommend redesigning the landfill tax, using a variable rate instead, whereby every household should be charged according to the number of people living in the house or according to the weight of household waste produced per month. This would ensure that every household is accountable for every kilo of waste they produce. This, in turn, will provide them with enough incentives to change their behaviour. Similarly, for non-construction SME's, disposal charges need to be linked to the weight of waste produced.

Ineffectiveness of transport taxes, on the other hand, can be attributed to failure of the VED system in altering car buyers' behaviour. To address the attitudinal barriers, educational tools and promotional activities (especially for electric vehicles, which requires users to be well-acquainted with the technical knowledge about charging, among others) could be introduced. Secondly, there exist several monetary incentives to encourage buyers to shift to low emission vehicles (such as low or zero VED), however these are not working efficiently. To address this, more effective incentives need to be introduced, such as, lower interest rates for green vehicles or annual tax rebates on car servicing (as hybrid cars are usually associated with higher maintenance costs).

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Appendix

Table A1: Data sources

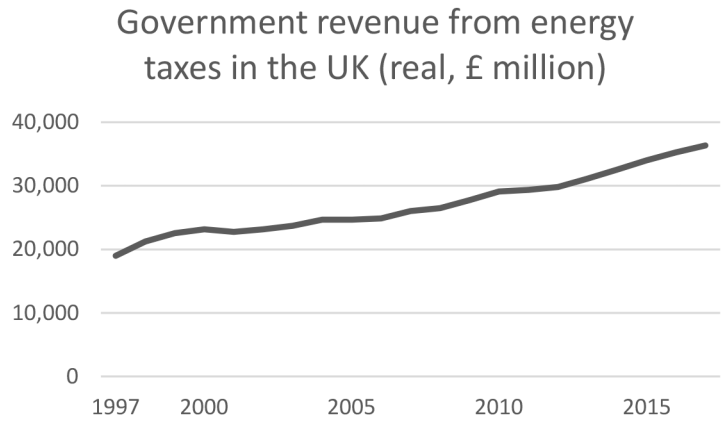
Variable Name	*Source*
Pollution	World Development Indicators database, World Bank
Manufacturing	World Development Indicators database, World Bank
Rent	World Development Indicators database, World Bank
RuleofLaw	World Development Indicators database, World Bank
Taxes (Energy taxes, Transport taxes & Pollution and Resource taxes)	Office for National Statistics
Population	Office for National Statistics
Education	GOV.UK
Voice and Accountability	World Development Indicators database, World Bank
Government Effectiveness	World Development Indicators database, World Bank
GDP	World Development Indicators database, World Bank

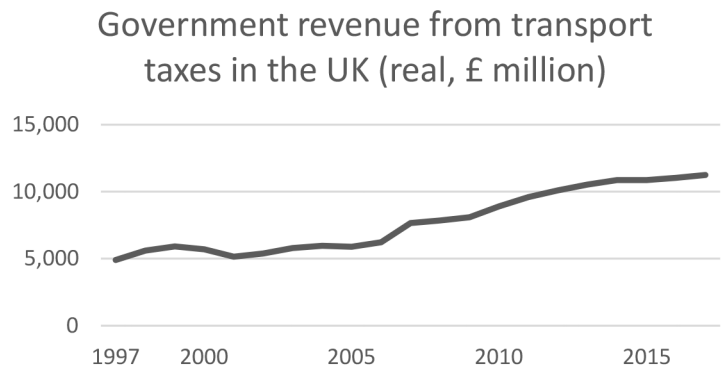
Table A2: Descriptive Statistics

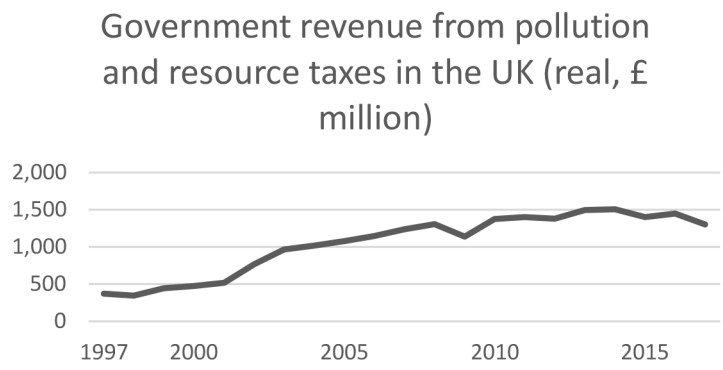
Variable	*Mean*	*Standard Deviation*	*Kurtosis*	*Skewness*
Total greenhouse gas emissions (kt of CO_2 equivalent) (air pollution)	614145.44	77716.16	–0.56	–0.77
Government revenue from energy taxes (real £ million)	27026.38	4808.61	–0.67	0.45
Government revenue from transport taxes (real £ million)	7778.57	2300.71	–1.62	0.32
Government revenue from pollution and energy taxes (real £ million)	1053.52	401.97	–1.01	–0.71
Number of undergraduates (Education)	912852.95	545127.82	–1.46	0.11
Population Density	255.76	10.83	–1.32	0.23
Rent (% of GDP)	0.76	0.29	–0.34	–0.29
Manufacturing (real US$)	245098163379.4	6546892413	2.07	1.16
GDP (real US$)	2450000000000	293000000000	–0.7	–0.25

Source: Authors' own calculations

Figure A1: Government revenues from Environmental taxes in the UK

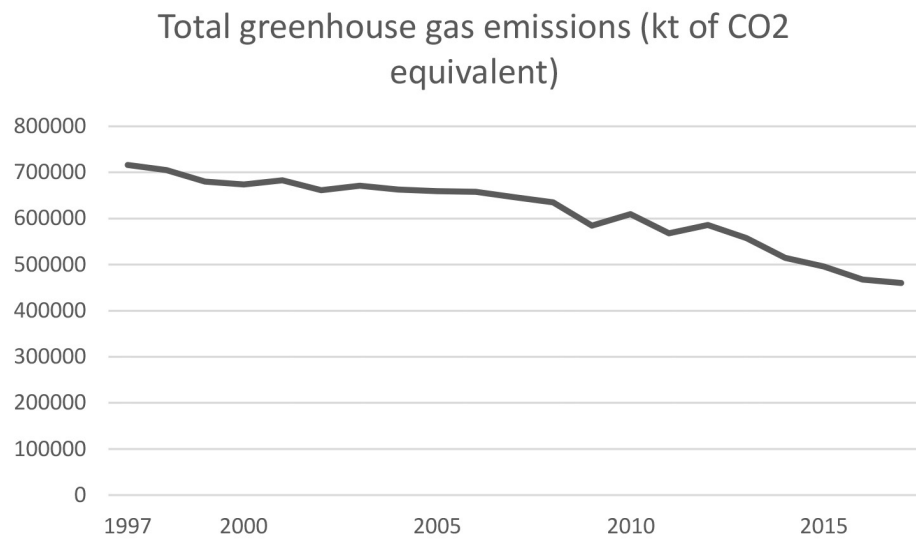






Source: Authors' own calculations based on data from the ONS

Figure A2: Air Pollution in the UK



Source: Authors' own calculations based on data from World Bank

Endnotes

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3. The full set of VAR results are available upon request.

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