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Why has Europe Become Environmentally Cleaner? Decomposing the Roles of Fiscal, Trade and Environmental Policies

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Abstract This paper examines the role of fiscal policy, trade and energy taxes on environmental quality in Europe using disaggregated data at the monitoring station level for the 12 richest European countries spanning the period from 1995 to 2008. Our estimations show that fiscal policies and energy taxes are important determinants of pollution through various mechanisms. We find that increasing the share of fiscal spending in GDP and shifting the emphasis towards spending in public goods and against non-social subsidies significantly lower the concentrations of sulfur dioxide and ozone but not nitrogen dioxide. At the same time, energy taxes reduce nitrogen dioxide concentrations but have no effect on ozone and sulfur dioxide. Finally trade openness has a direct effect on sulfur dioxide but no effect on nitrogen dioxide or ozone. Our estimates account for time-varying unobserved heterogeneity.

Keywords Government spending · Spending on public goods · Pollution · Taxes

JEL Classification H50 · H40 · O13 · O44 · Q53

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1 Introduction

This paper provides a decomposition analysis of the observed reductions of the concentrations of sulfur dioxide, nitrogen dioxide and ozone, in the twelve richest European countries. It quantifies the proportion of the reductions that can be attributed to fiscal policies, trade, and energy taxes. We show that fiscal spending policies and increasing trade openness explain the largest portion of the observed reductions of production-related pollutants (e.g., sulfur dioxide) while energy taxes explain most of the observed decreases of pollutants originated mostly in consumption activities (e.g., nitrogen dioxide). This is the first econometric study that compares the effects of fiscal expenditure policies, energy taxes and trade openness on environmental quality in Europe.

This analysis shows that a policy factor that so far has been largely neglected plays a key role in affecting pollution: fiscal spending. The impact of fiscal spending has proven to be important in most areas of the economy.[1] However the relationship between fiscal policies and environmental quality has received little attention in the literature.[2] The study of the impact of fiscal factors is likely to be especially important in Europe where the participation of government spending in the economy tends to be higher than in most other regions of the world (Dewan and Ettlinger 2009).

In addition to fiscal spending, our analysis also examines how increases in trade intensity affect pollution in wealthy countries.[3] Earlier studies (such as Grossman and Krueger 1992; Antweiler et al. 2001; Frankel and Rose 2005) have examined the effect of trade on pollution using samples that include a large proportion of middle income and poor countries. These studies have found that trade reduces pollution. The environmental improvements in middle and low income countries may be due to greater imports of cleaner technologies that already exist in rich countries (Antweiler et al. 2001). However, it is possible that trade may not increase environmental efficiency in rich countries; it may merely induce them to shift production towards cleaner outputs thus displacing their dirty industries to poorer countries. Lastly, we analyze the effect of energy taxes and certain environmental regulations which may increase the incentives in rich countries to produce new and more environmentally efficient technology (Knigge and Görlach 2005).

Empirical studies on trade and environment do not control for the level and composition of government spending and energy taxes. Hence, these studies may be affected by omitted variable bias as recognized by Antweiler et al. (2001). Typically two way fixed effects (TWFE) are used to deal with the bias; however this procedure is not efficient in controlling for country specific time-varying omitted variable bias.

The literature analyzing the effects of energy and environmental taxes on pollution has mainly used simulation exercises, rather than econometric modeling (Baranzini et al. 2000; Fullerton and Heutel 2007; Fullerton et al. 2009). This is mainly due to the lack of suitable data that may capture the variability of institutions, regulations and enforcement variables that may affect pollution (Morley 2010). Another strand of literature has used firm or industry

[1] Studies have focused for example on the effects of public expenditure level and composition on poverty reduction, income distribution and inequality (Kaplow 2006), unemployment (Fougère et al. 2000), education (Hanushek 2003), and many other areas.

[2] Exceptions are the theoretical models of Barman and Gupta (2010) and Gupta and Barman (2009) and López et al. (2011) which include a general equilibrium theoretical model and an empirical application.

[3] Gassebner et al. (2010) survey the literature and find that excluding OECD countries from the sample provides different results; specifically the relationship between GDP growth and pollution loses significance. This suggests that focusing on the richest countries of Europe could provide new insights about the relevance of fiscal policies, trade and energy taxes.

level data (Millock and Nauges 2006; Morley 2010). These studies find that energy and environmental taxes have a negative and significant impact on air pollutants. However, these studies may be affected by the issues concerning time-varying omitted variables.

Our study aims to empirically estimate the effects of the level and composition of government expenditures, trade, and energy taxes on three major air pollutants: sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3). [4] SO_2 is produced by industrial processes and electricity generation and is considered mainly a "production-generated pollutant." A significant part of NO_2 and O_3 is produced by road vehicles implying that both pollutants may be considered as mainly (but not totally) "consumption-generated pollutants."[5] We improve the analysis of pollution determinants regarding two other important aspects:

1. We introduce a method that generalizes the conventional Fixed Country Effects (FCE) approach; a method that we call Time-Varying Country-Specific Effects (TVCE). The TVCE method reduces the risk of spurious correlation between pollution and the explanatory variables of interest caused by time-varying as well as fixed unobserved or difficult-to-measure variables which may be correlated with the latter. While we directly control for certain environmental regulations, there may be other economic and institutional variables that may affect pollution which are either unobserved or difficult to measure, such as regulation enforcement that may change over time and is specific to each country. The TVCE is a parsimonious approach that allows for controlling for omitted variables without measuring them directly.[6]
2. We use a new dataset of air pollution for Europe. The existing empirical estimations have used the GEMS/AIR data which have observations for the period 1971–1996, (Grossman and Krueger 1995; Antweiler et al. 2001; Harbaugh et al. 2002; Bernauer and Koubi 2006). Our sample, using more recent data, has the advantage of including more monitoring stations in each of the countries analyzed, for the 1995–2008 period. The number of observations available for SO_2 (about 16,000 observations distributed over 2,666 monitoring stations in 12 countries), for example, is five times larger than in the old data set. This large number of observations allows us to implement the TVCE method, which, as we shall see, requires us to estimate a large number of auxiliary coefficients.

The remainder of this paper is organized as follows: Sect. 2 discusses conceptual issues, Sect. 3 presents the econometric model, Sect. 4 describes the data, Sect. 5 summarizes the results and Sect. 6 concludes.

2 Conceptual Issues

To analyze the impact of government spending composition, it is important to use a taxonomy of expenditures that is conceptually meaningful and consistent with the available data. López and Galinato (2007) proposed a taxonomy of government expenditures that distinguishes

[4] We select these pollutants because their measurements are reliable and consistent over time, they have the largest number of observations available, they can be regulated, and accepted quality standards exist for them (EPA 2010).

[5] O_3 is the product of the combination of Nitrogen Oxides (NO_x) and volatile organic compounds.

[6] An alternative method to control for time-varying unobservable variables is the so-called Added Controls Approach which sequentially introduces a large number of controls (Altonji et al. 2005). Nevertheless, Altonji et al. (2005) do caution about this methodology: "….[it] is dangerous to infer too much about selection on the unobservables from selection on the observables if the observables are small in number and explanatory power or if they are unlikely to be representative of the full range of factors that determine an outcome". (p. 182).

between expenditures on what they term "public goods," defined as those that alleviate the negative effects of market failures, and expenditures on "private goods," which do little to mitigate market imperfections.[7] Accordingly, government expenditures on public goods include expenditures on education, health, social transfers, environmental protection, research and development (R&D), knowledge creation and diffusion, as well as conventional public goods such as, institutions and law and order. By contrast, government expenditures on private goods are subsidies to special interest groups including credit and input subsidies, farm commodity programs, subsidies to the production and consumption of fossil fuels, industrial subsidies, and others.

Unlike government expenditures on private goods, expenditures on public goods may complement rather than substitute private sector spending. Household subsidies, both direct and indirect via education and health care provision, mitigate the negative effects of liquidity constraints on investments in human capital (e.g. Galor and Zeira 1993) which according to recent studies affect a significant portion of households even in wealthy countries (Zeldes 1989; Jappelli 1990; Grant 2007; Attanasio et al. 2008).[8] Investment in environmental protection, research and development, and creation and diffusion of knowledge, finance activities that otherwise would be under-funded due to generally insufficient market incentives for the private sector to invest in these areas (Dasgupta 1996; Hoff and Stiglitz 2000).

López et al. (2011) develop a theoretical model identifying the channels by which the level and composition of government spending may affect the environment. They find that the reallocation of government expenditure from private to public goods improves environmental quality indicators. They find that increasing the share of public goods expenditures on total government spending contributes to the expansion of aggregate output (or GDP), changes the composition of production towards human capital-intensive industries (and away from physical capital-intensive ones) and promotes investments in R&D. Hence, these factors induce three effects on production-generated pollutants: (1) Scale Effect: the expansion of aggregate output may increase pollution; (2) Composition Effect: a reduction in pollution due to the restructuring of production in favor of human capital-intensive activities that tend to pollute less than physical capital-intensive activities; (3) Technique Effect: increasing investments in R&D and in diffusion of knowledge, which may lead to the development of environmentally cleaner technologies.[9]

Furthermore, reallocating fiscal spending towards public goods may also reduce consumption-generated pollution by shifting consumption towards less polluting goods. For example, raising the share of public goods may entail greater investment in public transportation which substitutes for private transportation which, in turn, often implies less demand for energy and hence less pollution. In addition more investments in R&D increase the supply of fuel efficient cars and energy saving appliances including air conditioning and heating units.

The impact of trade expansion on the environment has also been associated with scale, technique and composition effects (Grossman and Krueger 1992; Antweiler et al. 2001;

[7] Fiorito and Kollintzas (2004) provide a different but related taxonomy based on the relationship between the types of goods provided by the government and private consumption. *Public goods* are defined as those that cannot be provided by the private sector such as defense, public order and justice. *Merit goods* include health, education and others that are in part provided by the private sector but where the public sector may have an important complementary role.

[8] In addition, studies have shown that human capital investments often have spillovers that increase their social value beyond their private returns (Blundell et al. 1999; Fleisher et al. 2010).

[9] Given that the output elasticities of energy (or electricity) range from 0.3 to 1.35 for OECD countries (Adeyemi and Hunt 2007; Liu 2004; Olund 2010), macroeconomic policies such as fiscal spending may have an impact on production related pollution by affecting its sources such as output from electric utilities and industry.

Frankel and Rose 2005). The effects of trade vary depending on the nature of the pollutant and on the economy's level of income. Increases in the volumes of trade may cause an expansion of economic activity (scale effect) thus, ceteris paribus, raising production-generated pollution. Trade may also induce a technique effect on pollution but this effect has been mainly considered to be due to the fact that trade increases income, which in turn may raise the desire for stricter environmental regulations. Hence, if we control for real income, taxes and regulations, the effect of trade should capture mostly the output composition effect. Trade could also affect pollution by facilitating transfers of technology. The increased technology transfer effect is most important for poor countries that tend to be the ones that receive technologies from the more advanced countries. However, given that our sample includes only rich countries which are the ones that generate environmentally cleaner technologies, this effect should be limited in their own environments.

Environmental regulations and environmental taxes may have an effect on the environment mostly through the technique effect, by reducing the level of emissions per unit of goods produced or consumed (Knigge and Görlach 2005). Environmental and energy taxes directly increase the costs of "dirty" inputs or of dirty consumption goods such as fuels or gasoline, thus inducing their savings and substitution. While these policies may also induce some output composition effect by increasing the relative price of outputs that use dirty inputs more intensively, this effect is likely to be weak. As Karp (2011) argues, one possible explanation for the weakness of the composition effect of environmental policies is that the costs of complying with environmental regulations account for only a small share of total production costs, creating little incentives to relocate production of dirty goods. Thus, unlike economy-wide policies, energy taxes and regulations are likely to have first order effects on techniques and the structure of consumption goods and only a second order effect on production composition.

Controlling for the scale effect (as we do in this paper), given the sample of rich countries that we use and the type of pollutants considered in our analysis, it is expected that energy taxes and environmental regulations mostly amplify the technique effect; trade mostly influences the composition effect in the case of production pollutants and has little effect on pollution produced by consumption activities. Fiscal policies may affect pollution via both the technique and output composition effects.

3 Econometric Model

We assume that the annual average pollutant concentration at monitoring station i, in country j at time t, Z_{ijt}, is determined by a vector reflecting the stocks of public and private goods provided by the government, $\mathbf{G_{jt}}$, trade intensity, TI_{jt}, country-specific energy taxes, M_{jt}, and environmental regulations at the country level, R_{jt}. In addition, we control for the 3 year moving average of per capita household final consumption expenditure (as a proxy for permanent per capita income), Y_{jt}. Additional controls include temperature (heating degree days), E_{jt}, and monitoring station characteristics, $\mathbf{X_{ij}}$. Finally, the model controls for unobserved monitoring station effects and time-varying unobserved country effects.

$$Z_{ijt} = \tilde{\psi}_{ij} + a_1\mathbf{G_{j,t-1}} + a_2 TI_{j,t} + a_3 M_{j,t} + a_4 R_{jt} + a_5 Y_{j,t} + a_6 E_{jt} + a_7 \mathbf{X_{ij}} + \zeta(\tau)_{jt} + \tilde{\varepsilon}_{ijt} \quad i \in \{1, 2, \ldots, I\}, j \in \{1, 2, \ldots, J\}, t \in \{1995, \ldots, 2008\}, \quad (1)$$

where $\tilde{\psi}_{ij}$ is an unobserved monitoring station effect that can be fixed or random; $\zeta(\tau)_{jt}$ is a function of time that controls for fixed and time-varying country-specific effects;

$\tau = t - 1995$; and $\tilde{\varepsilon}_{ijt}$ is an idiosyncratic error that is assumed to be independent and identically distributed with zero mean and fixed variance.

While we have data on government expenditure flows for various key components we do not have reliable measures of their respective stock levels, $\mathbf{G_{jt}}$. We thus write Eq. (1) below in differences so that the annual differences of the government stocks can be approximated by the lagged level of corresponding government expenditure flows. We then have,

$$z_{ijt} = \psi_{ij} + \alpha_1 \mathbf{g_{j,t-1}} + \alpha_2 ti_{j,t} + \alpha_3 m_{j,t} + \alpha_4 r_{jt} + \alpha_5 y_{j,t} + \alpha_6 E_{jt} + \upsilon_{jt} + \varepsilon_{ijt} \quad (2)$$

where, $z_{ijt} \equiv Z_{ijt} - Z_{ij,t-1}$; $\mathbf{g_{j,t-1}} \equiv \mathbf{G_{jt}} - \mathbf{G_{j,t-1}}$; $ti_{jt} \equiv TI_{jt} - TI_{j,t-1}$; $m_{jt} \equiv M_{jt} - M_{j,t-1}$; $r_{jt} \equiv R_{jt} - R_{j,t-1}$; $y_{j,t-1} \equiv Y_{jt} - Y_{jt-1}$; $\upsilon_{jt} \equiv \zeta(\tau)_{jt} - \zeta(\tau)_{jt-1}$; ψ_{ij} is an unobserved monitoring station effect; $\tilde{\varepsilon}_{ijt}$ is an idiosyncratic error that is assumed to be independent and identically distributed with zero mean and fixed variance.[10]

The ν_{jt} effect corresponds to the TVCE. We approximate the ν_{jt} effect by a $(T-2)$th order (country-specific) polynomial function of time,

$$\nu_{jt} = b_{0j} + b_{1j}\tau + b_{2j}\tau^2 + b_{3j}\tau^3 + \cdots + b_{T-2,j}\tau^{T-2} + \mu_{jt} \quad (3)$$

where, $b_{0j}, b_{1j}, b_{2j}, \ldots, b_{T-2,j}$ are country-specific coefficients of the polynomial function of τ; μ_{jt} is the residual; T is the maximum number of observations for a country. Using (3) in (2) we obtain the estimating equation where the new disturbance term is $\varepsilon_{ijt} \equiv \tilde{\varepsilon}_{ijt} + \mu_{jt}$. The $(T-2)$th order (country specific) polynomial function of time in Eq. (3) is the maximum order of approximation that allows for sufficient degrees of freedom to estimate the effects of observed country variables on pollution.

The TVCE method is related to methods used in the literature (Cornwell et al. 1990; Jacobsen et al. 1993; Friedberg 1998; Wolfers 2006). However, these studies choose up to a second order polynomial of time to capture individual or region-specific slow moving omitted variables. The main advantage of the TVCE model proposed here is that it does not arbitrarily restrict the degree of approximation to a second order polynomial as the earlier studies cited did. Instead the degrees of freedom in the data determine the limit of the time trend polynomial in the estimation. This approach allows for a much more flexible approximation of the omitted variables impact and hence reduces significantly the risks of omitted variable biases affecting the coefficients of the variables of interest.

There are a number of possible omitted variables that the function ν_{jt} may control for. The main omitted variables which we are concerned about are regulations and especially their degree of enforcement. There are several characteristics about regulations that do not lend themselves to be easily accounted for. They tend to suffer from constant revisions over time, for instance, existing regulations may include more sectors or new regulations may be proposed and adopted. The stringency of regulation enforcement might increase over time (but not necessarily linearly). Also, the evolution of enforcement of the same regulations may differ across countries. All these factors make regulation stringency and enforcement difficult to measure and therefore hard to control.

Regulations and their enforcement are specifically a concern for this study since they may follow similar patterns over time as the share of public expenditures over total government spending in many countries, which suggests a positive correlation between the omitted regulation and our variables of interest. This in turn implies that failing to control for the effect of the time-varying omitted variables may bias the coefficients of the relevant explanatory variables upwards (more negative).

[10] The fixed station characteristics $\mathbf{X_{ij}}$ vanish as a consequence of first differencing.

Including our proposed TVCE approach, there are a few other candidate specifications for dealing with omitted variables bias. These specifications include (i) the standard country fixed effects model (FCE), (ii) country by year fixed effects which consists of fully interacted country and time dummies (iii) country specific trends which is essentially country dummies interacted with a time trend and (iv) the TVCE approach proposed above.

The limitation of the standard country fixed effects approach (i) is that it does not account for time varying omitted variables. Most of the potential omitted variables mentioned such as regulation stringency and enforcement are not fixed for each country and tend to vary over time. In contrast, our proposed TVCE approach, do control for time-varying omitted variables as long as the omitted variables exhibit some degree of systematic variations over time.

To fully control for the effects of the omitted variables it would be necessary to use the complete matrix of country-year dummies, which is approach (ii). There are two potential advantages of the TVCE approach with respect to using the country by year fixed effects model. Estimating a $(T-1)$th order polynomial function of time for each country is equivalent to using the complete matrix of country-year dummies because in this case we would estimate T independent parameters for each country (the country-specific constant term or fixed effect plus $T-1$ parameters corresponding to the slopes of the polynomial), in total $T \times J$ independent parameters. Thus the TVCE specification that estimates a $(T-2)$th order polynomial has the advantage of estimating fewer parameters than approach (ii). The second and most important advantage of the TVCE approach over the country by year fixed effects is that in the latter it is impossible to estimate the effect of any observed countrywide variables as all variation in these explanatory variables is eliminated. For the TVCE approach we can use the $(T-2)$th order approximation which means that the TVCE approach comes close to a full country by year fixed effects model but also allows to estimate the effects of country-wide explanatory variables.[11]

Finally, the use of country specific time trends (iii) imposes a linear functional form of the omitted variables while the TVCE approach allows for a more flexible functional form using country specific polynomials of the time trend. It is also important to note that the TVCE approach is a generalization of both the standard FCE (i) and the country-specific time trends approach (iii).[12]

The TVCE method is indeed a generalization of the standard fixed-country effects model. It can be assumed that the FCE apply to estimations in levels and thus taking first differences, as in Eq. (2), would wipe them out. More generally, we may apply the FCE to a regression in differences instead of one merely in levels.[13] Applying FCE to first differences can be

[11] The TVCE approach indeed follows the tradition of classical regression analysis of using prior information (or assumptions) as a means of economizing the number of parameters. For example, in pure cross-country regressions the full use of country effects would not allow estimating the effects of the (observed) variables of interest, and thus a common approach is to use regional effects instead of country effects. The prior information or assumption is that the countries within the region may have common unobserved effects.

[12] While our assumption that the unobserved time patterns can be fully captured by the $(T-2)$th polynomial approximation is not certain, we can test whether the μ_{jt} residuals (and therefore the $\varepsilon_{ijt} \equiv \tilde{\varepsilon}_{ijt} + \mu_{jt}$ error term) are time-independent. If the hypothesis that the residuals are time-independent is not rejected, then the $(T-2)$th order polynomial approximation may be sufficient to uncover the full time pattern of omitted variable effects on the endogenous variable. Hence, the TVCE approach would be effective in mitigating time-varying country-idiosyncratic biases caused by omitted variables. By contrast, rejection of the hypothesis of time-independent residuals would suggest that the effects of omitted variables are not fully controlled for.

[13] The inclusion of the FCE in regressions in differences has often been used in literature examining the determinants of economic growth (defined as log difference of per capita GDP), in which FCE are used to

interpreted as a first order approximation of the unobserved country effects.[14] In cases where the total number of time observations per country is greater than 3, the $(T-2)$th order approximation of the TVCE method is more general allowing for the FCE-in-differences estimators to be nested within the TVCE estimators. That is, the FCE-in-differences model can be tested as a special case of the TVCE by parametrically testing the following restrictions, $b_{1j} = b_{2j} = \cdots = b_{T-2,j} = 0$ for all $j \in \{1, 2, \ldots, J\}$, while $b_{oj} \neq 0$, for at least some j.

4 Data

The air pollution data consist of annual averages for SO_2, NO_2 and O_3 observations, measured at a large number of monitoring stations in the 12 richest European countries for the 1995–2008 period. These air quality measures are taken from the AirBase dataset maintained by the European Environmental Agency. The complete list of countries is provided in Table A.1 in ESM Appendix A.

Government expenditure, household final consumption and trade data are obtained from the EUROSTAT database. We use the functional classification of government expenditures at the general government level.[15] The government expenditures on public goods include expenditures on public order and safety, environment protection, housing and community amenities, health, recreation, culture and religion, education and social protection. Trade intensity is defined as the sum of exports and imports of goods and services as proportion of GDP.

The implicit tax rate on energy is obtained from EUROSTAT Statistical Books (2010). The temperature indicator (heating-degree-days) is obtained from the EUROSTAT database.[16] Table A.2 in ESM Appendix A presents the description and source of data, while Table A.3 in ESM Appendix A provides summary statistics of the variables used in the regressions.

In the sample there is high variation in SO_2 concentrations among monitoring stations and over time. Some stations have reported reductions in SO_2 concentrations of up to 50 % over the period. NO_2 concentrations have not decreased as much as SO_2. However NO_2 concentrations have high variation across monitoring stations and countries. Ozone concentrations have increased in some stations located in Southern and Central Europe. See Table A.4 in ESM Appendix A for measures of variability of the pollutants and Tables A.5, A.6 and A.7 in ESM Appendix A for the annual averages of each pollutant across countries and years.

The main explanatory variables show a large degree of variation over time and across countries as shown in Figures A.1 and A.2 in ESM Appendix A. The share of public goods in total government expenditure has increased over time for most of the countries. Germany and Denmark have the highest shares reaching values of 0.78–0.79 in some years; while

Footnote 13 continued
control for unobserved time-invariant country specific characteristics (see for example, Fölster and Henrekson 2001; Afonso and Furceri 2010).

14 If country effect in the level equation is $b_{00j} + b_{0j}\tau$ then by first differencing the regression, the level FE (b_{00j}) vanishes and the FCE applying to differences becomes b_{0j}.

15 This classification, organizes government expenditures in ten general categories, according to their objectives or purposes, which is of the government's administrative or organizational structure. The categories are: (i) general public services, (ii) defense, (iii) public order and safety, (iv) economic affairs, (v) environmental protection, (vi) housing and community amenities, (vii) health, (viii) recreation, culture and religion, (ix) education and (x) social protection (Jacobs et al. 2009).

16 We control for heating degree days in our estimation, but are unable to account for cooling degree days due to lack of data. However, this omission may not be so serious given that most countries in our sample have only small windows of time in the summer when air conditioners may be used, and even then their incidence is low. In contrast, heaters are used more intensively in the winters.

Belgium and the Netherlands exhibit the lowest shares of the period with values as low as 0.65. Similarly, the share of total government expenditure over GDP varies significantly across countries and within countries during the sample period. The countries with the lowest share of total expenditure over GDP are Spain and the United Kingdom, with shares as low as 0.38 in some years, and the countries with the highest shares include Sweden, Finland and Denmark with shares as high as 0.62.

5 Estimation and Results

We estimate equation (2) after normalizing the total government expenditures by GDP and the government expenditures on public goods by total government expenditures. We also normalize trade intensity (exports plus imports) by GDP. These normalizations are convenient because they yield unit free measures of the variables, which diminish the problems of comparing currency values and inflation across time and countries.

We use a sixth order polynomial approximation for the time-varying country effects (Eq. 3). The reason for limiting the approximation to the sixth order is that in our unbalanced panel data there are countries for which we have only 8 years of observations. This effectively implies that we can estimate a maximum of seven coefficients per country to capture the ν_{jt} effect (the b_{0j} and the six b_{tj} coefficients for each country) in order to preserve sufficient degrees of freedom to estimate the variables of interest.

The monitoring station effect ψ_{ij} may be uncorrelated with the observed explanatory variables in which case we can use a random station effects model. Alternatively, we may allow for arbitrary correlation between the unobserved monitoring station effect and the observed explanatory variables in which case we would need to use fixed monitoring station effects. We use both random station effects and fixed station effects in combination with time-varying country-specific effects (RSE-TVCE and FSE-TVCE, respectively). We present the results obtained using RSE-TVCE in Table 1 while Table 2 shows the FSE-TVCE estimators.[17] If the station effects are correlated with the explanatory variables, the FCE-TVCE would be consistent and the RSE-TVCE may not. However, the results from both estimators are statistically similar which means that both are consistent. Given that the RSE-TVCE estimators use both the within and between variation while FCE-TVCE only rely on within country variations, the former are more efficient (Kennedy 2003; Wooldridge 2002). We use the RSE-TVCE estimators for the subsequent analysis.

5.1 Specification Tests

5.1.1 Testing the Fixed Country Effect model

We test the null hypothesis that $b_{1j} = b_{2j} = b_{3j} = b_{4j} = b_{5j} = b_{6j} = 0$ for all j which, as discussed earlier, is a test for the validity of the fixed country effects model. As indicated at the bottom of Table 1, the restricted model is rejected at the 1 % level of significance in favor of the TVCE model for each of the three pollutants, meaning that the often used fixed country effect specification is statistically rejected.[18]

[17] The standard errors in all the estimates are robust to heteroskedasticity and autocorrelation.

[18] Additionally, we test whether the residuals from the RSE-TVCE estimations are time independent by regressing them on a time trend τ ($\varepsilon_{ijt} = constant + \beta\tau$).The null hypothesis that the residuals are time

Table 1 Random monitoring stations effects with time varying country effects (RSE-TVCE)

	Ln Diff SO_2	Ln Diff NO_2	Ln Diff O_3
Share of expenditures in public goods over total government expenditures (lagged)	−5.33** [1.27]	−0.19 [0.49]	−1.69** [0.52]
Share of total government expenditures over GDP (lagged)	−5.52** [1.78]	−0.37 [0.71]	−1.73* [0.77]
Time difference of energy tax rate	−0.11 [0.06]	−0.18** [0.03]	0.057 [0.04]
Time difference of regulation over large plants	−0.49** [0.07]		
Time difference of regulation over NO_x		−0.34 [0.51]	1.54 [0.83]
Time difference of log of trade (X+M)/GDP	−1.13** [0.40]	−0.41 [0.25]	−0.21 [0.43]
Time difference of 3-year moving average of Ln of household final consumption per capita	0.053** [0.02]	0.004 [0.01]	0.026* [0.01]
Number of observations	16,222	19,374	15,282
No. of monitoring stations	2,666	3,176	2,274
Overall R-squared	0.11	0.06	0.10
Specification tests:			
Testing the fixed country effects-random site effects model: log likelihood ratio test Ho: $b_{1j} = b_{2j} = \cdots = b_{T-2,j} = 0$	426**	322**	316**

Robust standard errors in brackets
Not reported in the table are 77 coefficients for each equation for the variables that capture the TVCE, 12 coefficients for year effects and one coefficient for heating degree days
* Significant at 5 %; ** significant at 1 %

The coefficients $b_{1j}, b_{2j}, b_{3j}, b_{4j}, b_{5j}, b_{6j}$ are jointly significant at the 1 % level of significance and the majority of them are individually significant. This, in conjunction with the relatively large impact that including these effects has on the coefficient estimates of the key variables, reflects the importance of the RSE-TVCE approach.[19]

5.1.2 Reverse Causality

Consistent with the econometric model presented in Sect. 3, the normalized government expenditures are lagged in the model. This may avoid the direct reverse causality between these variables and the pollutant, often a source of biases in the estimated coefficients. In principle it would still be possible that such lagged expenditures are correlated with other

Footnote 18 continued
independent is not rejected at any reasonable level for any of the pollutants; *p* values for the associated nulls are all above 0.99 (these results are available from the authors).

[19] Table C.1 in ESM Appendix C presents a summary of the analysis of the predicted values of the TVCE function. In most countries the effect of the omitted variables has been negative for SO_2, and has changed sign over time for NO_2 and O_3. The majority of predicted values of the TVCE function are non-monotonic and have at least 2 turning points.

Table 2 Fixed monitoring stations effects with time varying country effects (FSE-TVCE) regressions

	Ln Diff SO_2	Ln Diff NO_2	Ln Diff O_3
Share of expenditures in public goods over total government exp (lagged)	−5.92**	−0.27	−1.68**
	[1.34]	[0.54]	[0.58]
Share of total government expenditure over GDP (lagged)	−6.17**	−0.12	−1.61
	[1.91]	[0.79]	[0.86]
Time difference of energy tax rate	−0.14*	−0.20**	0.05
	[0.07]	[0.034]	[0.04]
Time difference of regulation over large plants	−0.47**		
	[0.08]		
Time difference of regulation over NO_x		−0.55	1.70
		[0.66]	[1.06]
Time difference of log of trade (X+M)/GDP	−1.09*	−0.37	−0.23
	[0.48]	[0.27]	[0.48]
Time difference of 3 year moving average of Ln of household final consumption per capita	0.06*	0.04**	0.05**
	[0.02]	[0.01]|	[0.01]
Number of observations	16,222	19,374	15,282
No. of monitoring stations	2,666	3,176	2,274
Overall R-squared	0.12	0.07	0.13
Specification tests:			
1. Testing the fixed country effects-random site effects model: log likelihood ratio test Ho: $b_{1j} = b_{2j} = \cdots = b_{T-2,j} = 0$	463**	361**	403**

Robust standard errors in brackets
Not reported in the table are 66 coefficients for each equation for the variables that capture the TVCE, 12 coefficients for year effects and one coefficient for heating degree days
* Significant at 5 %; ** significant at 1 %

concurrent omitted variables which would bias the coefficients. However, as we argued earlier, the country-specific time-varying effects largely minimize such a risk as these effects control for omitted variables.

It may be argued that reverse causality could be an issue for energy taxes as the tax variable is not lagged. Higher levels of pollution may be a factor that induces governments to raise energy taxes in which case there would be an upward (less negative) bias on the energy tax coefficient. However, it is unlikely that the level of energy taxes is influenced much by variations in local pollution as energy tax policies are mostly motivated in renewable energy and climate change policies rather than in local pollution-related objectives (Newberry 2005; Biermann and Brohm 2005; Decker and Wohar 2007). But even if reverse causality were indeed an issue, the finding of a negative effect of the energy tax on pollution, as we do when using the RSE-TVCE estimates, would merely make such estimates a lower bound measure of the true effect and would not alter the sign of the estimates. That is, if we corrected for reverse causality bias, the estimates of the energy tax effect would be even more negative than the ones obtained in the estimations.

5.2 Analysis of the Estimates

5.2.1 Impact Analysis

The estimates indicate negative and significant effects of the government spending level and composition on SO_2 and O_3, and negative but not statistically significant effects on NO_2, as

Table 3 Elasticities and sample quantitative effects

	SO_2	NO_2	O_3
Elasticity of the share of public goods	−3.91**	n.s.	−1.25**
Change in the pollutant when the share of public goods increases by one standard deviation (% of SD of pollutant)	−22.70 %**	n.s.	−19.45 %**
Elasticity of the ratio of total government expenditure over GDP	−2.63**	n.s.	−0.82*
Change in the pollutant when the ratio of total government expenditure over GDP increases by one standard deviation (% of SD of pollutant)	−35.10 %**	n.s.	−31.37 %*
Elasticity of the energy tax rate	n.s.	−0.31**	n.s.
Change in the pollutant when the energy tax rate increases by one standard deviation (% of SD of pollutant)	n.s.	−12.32 %**	n.s.
Elasticity of trade	−1.13**	n.s.	n.s.
Change in the pollutant when trade increases by one standard deviation (% of SD of pollutant)	−49.23 %**	n.s.	n.s.

n.s. non-significant
* Significant at 5 %; ** significant at 1 %

shown by the coefficients of the share of expenditures in public goods over total government expenditure and the share of total government expenditure over GDP in Table 1. Trade shows a negative and significant effect on SO_2 concentrations but not on the other pollutants, and energy taxes exert a negative and significant effect on NO_2 but not on the other contaminants.

In Table 3 we show the elasticities for the main determinants of each pollutant. The importance of each of these effects is also expressed by the relative changes within the sample (impact of changing the explanatory variables in one standard deviation, expressing it as proportion of the sample standard deviations of the pollutant). Increasing the share of government expenditures on public goods by 1 %, holding total government expenditure constant, may result in a 3.9 % reduction of SO_2 concentrations and a 1.25 % decrease in O_3 concentrations. Increasing the share of expenditures on public goods by one standard deviation reduces SO_2 concentrations by 22.7 % and O_3 by 19.4 % of their respective standard deviations.

The concentrations of SO_2 and O_3 may be reduced by 2.6 % and 0.82 % respectively, if total government expenditure increases by 1 %. The increase of one standard deviation of the share of total expenditure with respect to GDP may result in a standard deviation reduction of 35.1 % for SO_2 and 31.7 % in the case of O_3.

We find that the elasticity of energy taxes is −0.31 for NO_2. If the energy tax rates increase by one standard deviation, the concentration of NO_2 may be reduced by 12 % of its standard deviation.[20] The estimated effects of energy taxes are not significant for SO_2 which is caused mainly by industrial processes and electricity generation. We did not find statistically significant effects of energy taxes on O_3 which is formed by certain precursor

[20] These findings are consistent with the elasticity estimates in a few studies that have measured these effects. Millock and Nauges (2006) estimate elasticities of energy taxes on NO_2 and SO_2 that vary from −2.7 to −0.2 depending on the industry analyzed.

gases in combination with weather conditions.[21] Our results suggest that energy taxes only affect pollution levels caused mainly by road and off-road fuel consumption.

Trade has a negative and significant effect on SO_2 but does not have a significant effect on neither NO_2 nor O_3 concentrations. The estimates imply that increasing trade intensity by 1 % may result in a 1.1 % reduction of SO_2 concentrations. If trade intensity is increased by one standard deviation, SO_2 concentrations are reduced by 49 % of its standard deviation. Hence, as predicted by our conceptual analysis, trade affects "production" pollutants most likely through the composition effect but does not affect "consumption" pollutants.

The coefficients for the level of per capita household consumption are positive in our estimates and mostly significant while most existing empirical studies for high income countries obtain a negative effect on local pollutants (Antweiler et al. 2001; Bernauer and Koubi 2006; Deacon and Norman 2007). This divergence may stem from our effort to mitigate the omitted variable biases by controlling for energy taxes, environmental regulation and other unobserved economy-wide variables that may be positively correlated with per capita income or consumption and that have a negative impact on pollution. The standard estimates are likely to attribute the effects of these variables to per capita income and thus conclude that increasing per capita income or household consumption may reduce pollution. By contrast our estimates isolate the pure effect of income or consumption on pollution.

5.2.2 Comparison Across Different Specifications

In the conceptual section we justified the use of the TVCE model and indicated its advantages over alternative specifications. Tables B.1, B.2 and B.3 in ESM Appendix B present the results of RSE, RSE with Fixed Country Effects (RSE-FCE), and RSE-TVCE with the full range of orders of approximation from 1 to 6.[22] The sign and significance of the results of our main coefficients are retained as they stabilize with higher polynomials of the time trend. A few results are however worth noting. As we control for time varying omitted variables and increase the order of approximation, both the magnitude and significance of the share of government expenditures on public goods increase. This may imply that the higher order approximations of the TVCE are capturing unobserved country level variables that are correlated with spending and pollution . Similarly, we find that in our base estimations trade has no significant effect on NO_2 and O_3 pollutants. However, using simple RSE-FCE estimations the effect of trade becomes negative and significant. This may imply that our TVCE approach may be capturing country-wide omitted variables such as the degree of regulations enforcement which may be biasing upward the RSE-FCE estimations of the impact of trade on NO_2 and O3.

5.2.3 Sensitivity Analysis

In addition to the specification tests reported earlier, we performed a series of sensitivity analyses to ascertain the robustness of the estimators. We checked for extreme data points

[21] One of the reasons energy taxes do not have a significant effect on O_3 concentrations might be the nature of this pollutant since it is not emitted directly by any source and it is rather formed by the combination of certain precursor gases especially under hot and sunny weather conditions (EEA 2007). Another possible reason might be the positive effect of energy taxes over the participation of diesel vehicles on the automobile fleet (data that is not available for all countries and time periods); diesel vehicles tend to emit three times more ozone-precursor gases than gasoline vehicles. Vestreng et al. (2008) has shown that this is true in the countries where systematic data on the participation of diesel vehicles are available.

[22] The results for the Fixed Monitoring Stations Effects with Time Varying Country Effects (FSE-TVCE) alongside alternative specifications are available from the authors.

that may dominate the sign and significance of key estimates and looked for individual country dominance.

We conducted two types of dominance tests. In order to account for extreme data points, we first re-estimated the model by excluding observations in the top and bottom 1 % of the share of government expenditures on public goods. The same procedure is followed by re-estimating the model without observations in the top and bottom 1 % of the energy tax rate, pollutant concentration and trade intensity. The parameters are robust to the sample changes, except for the case of trade when dropping the bottom 1 % of SO_2 observations. This result indicates that the effect of trade is weak even on production pollutants, once we control for energy taxes, environmental regulations, fiscal expenditure as well as other unobserved factors. Signs, significance and magnitudes of the parameter estimates from these models are shown in Tables C.1 to C.6 in ESM Appendix C.

The second type of tests focuses on the effect of potential country dominance. We re-estimated our benchmark models, dropping one country at a time, to check whether they alter the parameter estimates of the share of public goods (for the SO_2 and O_3 regressions), of the energy taxes (for the NO_2 regressions) and of trade (for SO_2). As shown in Figures C.1 to C.4 in ESM Appendix C, removing one country at a time does not affect the sign and significance of the estimated parameters, with the exception of share of public goods over government expenditure in the O_3 regression, which seems to be dependent on Italy.[23]

5.3 Decomposition Analysis

Table 4 shows the average annual changes in all pollutants for the analyzed period and the decomposition of fiscal, trade and environmental policy effects on each one of them. SO_2, mainly a production pollutant, has decreased very rapidly over the period at an annual rate of 8.5 % but NO_2 and O_3, considered mainly consumption pollutants, have not improved nearly as much. NO_2 concentrations have fallen by only 1.4 % per annum and O_3 concentrations have increased in almost all countries showing an average annual rate of increase of 0.9 %.

As mentioned in the conceptual section, we expect fiscal policies to mostly affect air pollution concentration via the composition and technique effects, with trade having a larger effect through the former on production pollutants and a negligible effect through the latter on consumption pollutants. We also expect that environmental policies and energy taxes would affect consumption pollution mainly via the technique effect. As can be seen in Table 4, these predictions are fully corroborated by the empirical results.

SO_2 reductions are mostly explained by trade and fiscal policies, which together explain practically all the observed reductions, meaning that without those policies SO_2 levels would have increased over the analyzed period. The large contribution of trade and of the increased share of expenditures in public goods over total government expenditure and of the share of total government expenditure over GDP may be the result of the production shift towards cleaner, possibly more human capital-intensive industries. Environmental regulation, specifically the "Large Combustion Plant Directive" (see Table A.2 in ESM Appendix A for a detailed description of this regulation), also contributes to the reduction in SO_2 concentrations possibly through a technique effect.

In the case of NO_2, energy taxes explain a major part of the observed modest reduction; about 52 % of this reduction is most likely due to their direct effect causing higher energy

[23] It is worth noting that Italy includes a large number of observations, more than 1,500 observations or about 8 % of the total. This does not necessarily indicate a lack of robustness of the estimators; it is indeed remarkable that the coefficients are robust to the exclusion of all other countries even if dropping individual countries often entails removing 7 % or more of the total observations.

Table 4 Decomposition analysis of the effect of the various factors

	Observed annual average rate of growth of the pollutant (%)	Annual average contribution (in percentage points)				
		Fiscal policy		Environmental policy		Trade policy
		Share of expenditures in public goods over total government expenditures	Share of total government expenditures over GDP	Regulation	Energy taxes	
SO_2	−8.51	−5.56*	−2.27*	−3.79*	n.s.	−2.76*
NO_2	−1.37	n.s.	n.s.	n.s.	−0.58*	n.s.
O_3	0.91	−0.39*	−0.71*	n.s.	n.s.	n.s.

The rates of growth used to create this table were calculated as the annual average growth. In the case of the pollutant the annual rate of growth of each monitoring station was calculated, and then a country average was taken for each country and finally the average over all of the years available in the sample. For the rest of the variables at the country level, first the rate of growth with respect to the previous year was calculated then the average of the whole period

* Significant to at least 5 %

prices and hence less consumer demand for energy. They may also induce a technique effect that reduces pollution. This suggests that energy taxes are an effective instrument to reduce this type of pollutant, and reflects the European countries' demand (on average) for less NO_2 emissions per unit of goods consumed.

Fiscal policies associated with an increased participation of government spending in GDP and progressive shifts towards the provision of public goods have a strong (unintended) effect towards reducing ozone. In fact, the combined effect of the observed fiscal spending policies in Europe has been to induce a reduction of ozone concentrations by more than 1 % per annum. That is, if Europe had not increased the share of government spending in GDP and if it had not changed the spending composition towards public goods, ozone would have increased twice as fast as what was actually experienced. The European fiscal spending policies may explain why in these countries O_3 concentrations have not increased nearly as much as in other regions of the world. Additionally, fiscal policies are the only policies considered that have any effect on ozone, which is probably the most difficult to control among the measured pollutants.

6 Conclusion

This study finds that fiscal, trade and energy tax policies implemented by the twelve richest European countries are important determinants of pollution through various mechanisms. Large and increasing public sector participation and increasing prioritization of public goods over private goods in the European countries analyzed have had a hitherto ignored effect by reducing the concentrations of sulfur dioxide and ozone but not nitrogen dioxide. In addition, we find that the high energy tax policy adopted by the majority of the European countries over the last few decades have substantially contributed to reduce the concentrations of nitrogen dioxide but have no effect on ozone and sulfur dioxide. Finally, trade openness has a direct effect on sulfur dioxide but no effect on nitrogen dioxide or ozone.

These results should be regarded as an added incentive for EU countries to at least persist if not increase the emphasis on fiscal policies and energy taxes that trigger the development of new technologies. The study may also present an argument for other countries which have not yet adopted these policies to implement them. The results have implications for several non-European countries including the USA and large developing countries which currently have much lower energy taxes and fiscal spending policies that are heavily oriented to provide private goods instead of public goods. Pursuing fiscal policies as adopted by some European countries may potentially have a large unintended environmental payoff.

To the best of our knowledge this is the first paper that systematically examines the role of fiscal spending policy, trade and energy taxes on Europe's environmental quality, using a methodology that obtains estimates mostly free from time-varying omitted variable biases.

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