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The impact of government expenditure on the environment: An empirical investigation

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ABSTRACT

This paper examines the impact of government spending on the environment using a panel of 77 countries for the time period 1980-2000. We estimate both the direct effect of government spending on pollution and the indirect effect which operates through government spending impact on per capita income and the subsequent effect of income level on pollution. In order to take into account the dynamic nature of the relationships examined, appropriate econometric methods are used. For both sulfur dioxide and carbon dioxide, government spending is estimated to have a negative direct impact on per capita emissions. The indirect effect on sulfur dioxide is found to be negative for low levels of income and then becomes positive as income level increases, while it remains negative for carbon dioxide for the whole income range of the sample. The resultant total effects follow the patterns of the indirect effects, which dominate their respective direct ones for each pollutant. Policy implications, occurring from the paper's results, range according to the level of income of the considered countries.

Keywords: Government expenditure; environment; direct and indirect effects.

JEL Classification Codes: E60; Q53; Q54; Q56.

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1. Introduction

Government expenditure has recently expanded in many countries, as an attempt to alleviate the adverse effects of the 2008 financial and the subsequent economic crisis. Most importantly, a large fraction of a nation's gross domestic product is spent by its government, with a direct impact on different sectors of an economy and society. In addition environmental protection is an area where the private sector has little incentives to invest (Lopez et. al., 2011). However, despite the important influence that public spending may have on the environment, their relationship has not been studied extensively in the literature and has only recently started drawing attention.

The effects of government spending on the environment may be classified as direct and indirect. In particular, the indirect effect operates through the impact of government spending on economic growth and the subsequent relationship between income level and pollution known as Environmental Kuznets Curve (EKC) hypothesis.

Ecological Economics emphasize that the natural environment has an aggregate carrying capacity, which sets a constraint on the maximum sustainable level of economic activity. The level of the current output of an economy in relation to its maximum environmentally sustainable level and the occurring effect of an expansionary fiscal policy on economic activity, are important factors to consider when examining the effect of government expenditure on pollution. Heyes (2000) suggests an augmented Keynesian model that incorporates such a macro-environmental constraint. Abstracting possible factors that could alter the environmental constraint, Heyes concludes that any policy that causes a higher interest rate, like an expansionary fiscal policy, induces substitution towards more environmentally intensive methods of production and thus must be accompanied by a lower aggregate income, if environmental equilibrium is to be sustained.

In an attempt to explicitly address the return to equilibrium, Lawn (2003) proposes the use of tradable resource permits when output exceeds the environmentally sustainable level, for example as the result of an expansionary fiscal policy. As prices for permits increase, reflecting increased demand, the cost of production also increases, generating a contractionary monetary policy that reduces the output level. However, higher resource costs lead to the development of resource-saving technological progress. Thus, the resulting level of output depends on whether the falling costs, due to technological progress, are sufficient to prevent goods prices from rising. In a related paper, Sim (2006) argues that, following an expansionary fiscal policy, the return to equilibrium is triggered by excessive pollution and increased environmental degradation that inflict greater costs to society which lower planned expenditure until the level of output returns to its environmentally sustainable level.

The estimated sign of the direct effect of government size on pollution is indefinite in the empirical literature. Frederik and Lundstrom (2001) investigate the effect of political and economic freedom on the level of CO_2 emissions, using a panel data set of 75 countries for the period 1975-1995. They find that the effect of government size on levels of pollution differs according to the initial government size. In particular, increased economic freedom, in terms of lower government size, decreases CO_2 emissions when the size of government is small but increases emissions when the size is large.

According to Bernauer and Koubi (2006) an increase of the government spending share of GDP is associated with more air pollution and this relationship is not affected by the quality of the government. However, they do not consider quadratic or cubic terms of income in their analysis and they ascribe their finding to the ambiguous hypothesis that higher income leads to both bigger government and better air quality.

More recently, Lopez et. al. (2011) provide a theoretical basis for determining the effect of government expenditure on pollution. Specifically, they stress the importance and estimate empirically the impact of fiscal spending composition on the environment. They argue that a reallocation of government spending composition towards social and public goods reduces pollution. This result is attributed to the combination of four factors occurring from such a shift, namely the scale (increased environmental pressures due to more economic growth), composition (increased human capital intensive activities instead of physical capital intensive industries that harm the environment more), technique (due to higher labor efficiency) and income (where increased income raises the demand for improved environmental quality) effects.

Moreover, they find that increasing total government size, without changing its orientation, has a non-positive impact on environmental quality. However, in a related study, Lopez and Palacios (2010) examine the role of government expenditure and environmental taxes[1] on environmental quality in Europe using disaggregated data for 21 European countries for the period 1995-2006 and report total government expenditure as a negative and significant determinant of air pollution, even when controlling for the composition of public expenditure.

As mentioned above, the indirect mechanism through which the share of government expenditure of GDP may influence pollution depends on both the

[1] For an extended study of the impact of environmental taxes on pollution the reader may refer to Fullerton et. al. (2010).

income - pollution and government - growth relationships. A review of the literature on the former relationship, categorized according to the factors that are regarded as the most important in determining the inverted-U shape of the EKC, is provided by Halkos (2003).

The majority of the studies examining the government size – growth relationship find a negative impact of the former on the latter. Increasing public expenditure may deteriorate economic growth by crowding-out the private sector, due to government inefficiencies, distortions of the tax and incentives systems and interventions to free markets (Barro, 1991; Bajo-Rubio, 2000; Afonso and Furceri, 2008). In addition, the share of government expenditure dedicated to the increase of the productivity of the private sector is typically smaller in countries with big governments (Folster and Henrekson, 2001).

Furthermore, related papers by Bergh and Karlsson (2010) and Afonso and Jalles (2011) find that government size correlates negatively with growth and support that countries with big governments can use improvements in institutional quality and globalization to mitigate this negative effect. On the other hand, government expenditure may also have a positive effect on economic performance, due to positive externalities by harmonizing conflicts between private and social interests, providing a socially optimal direction for growth as well as offsetting market failures (Ghali, 1998).

Our paper estimates the direct, indirect and total effects through which government expenditure influences the environment. For that reason, a two equation model was jointly estimated, employing a sample of 77 countries and covering the period 1980-2000 for two air pollutants, sulfur dioxide (SO_2) and carbon dioxide (CO_2). The analysis takes place up to the year 2000 because of limited availability of data on SO_2 after this period. Consequently, for reasons of comparability we also perform the analysis for CO_2 for the same time period. In doing so we take particular care to consider the dynamic nature of the relationships examined, employing appropriate econometric methods for the estimation of dynamic panels, for the first time in this area of research. To the best of knowledge there is no other paper that distinguishes between the direct and indirect impact of fiscal spending on the environment.

The remainder of the paper is organized as follows; section 2 presents the data used in the analysis and section 3 discusses the econometric models proposed in the study. The empirical results are reported in section 4 while the final section concludes the paper.

2. Data

Our sample consists of 77 countries[2] which have a full set of sulfur dioxide, carbon dioxide, share of government expenditure, GDP per capita and other explanatory variables information for the period 1980-2000. The database consists of 1,617 observations per variable[3]. In particular, Government expenditure data are obtained from the Penn World Table and refer to the government consumption share of PPP converted GDP per capita at constant prices, in particular the share of GDP which is left after consumption, investment and net exports are taken into account in any given year.

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[2]Data are for the following countries:
Albania, Algeria, Argentina, Australia, Austria, Belgium, Bolivia, Brazil, Bulgaria, Canada, Cape Verde, Chile, China, Colombia, Cuba, Denmark, Djibouti, Dominican Rep, Equador, Egypt, El Salvador, Finland, France, Germany, Ghana, Greece, Guatemala, Honduras, Hong Kong, Hungary, India, Indonesia, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Lebanon, Liberia, Mauritius, Mexico, Morocco, Mozambique, Nepal, Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Sierra Leone, South Africa, South Korea, Spain, Sri Lanka, Sudan, Sweden, Switzerland, Syria, Thailand, Togo, Trinidad, Tunisia, Turkey, Uganda, United Kingdom, United States, Uruguay, Venezuela

[3] Table A1 of the Appendix provides data sources and descriptions for all variables. Table A2 presents summary statistics of the data.

In order to avoid dependence of results on geographic location characteristics and atmospheric conditions, emissions of the two pollutants were used rather than their concentrations. The main sources of SO_2 and CO_2 pollutants are electricity generation and industrial processes. High concentrations of sulfur dioxide in the atmosphere can result in respiratory illness, alterations in human lung defense and aggravation of existing cardiovascular disease. Sulfur dioxide is among the major precursors of acid rain, which has acidified soils, lakes and streams with harmful effects on plants and animals and accelerated corrosion of buildings and monuments. Before-, during- and after- combustion technologies could be used to remove sulfur. The applicability requirements, the abatement efficiencies, the capital and operating and maintenance costs of each possible abatement option, as well as an estimate of their cost effectiveness are presented in Halkos (1995).

An important distinction between the two pollutants that has to do with their atmospheric life characteristics is their geographical range of effect (Cole, 2007). Considering that two-thirds of sulfur dioxide moves away from the atmosphere within 10 days after its emission, its impact is mainly local or regional and thus, historically, sulfur has been subject to regulation. In contrast, carbon has not been regulated, since its atmospheric life varies from 50 to 200 years and hence its impact is global rather than local.

3. Methodology

In this paper we estimate both the direct and indirect effects of the share of government expenditure of GDP on pollution by employing a similar empirical strategy to that used by Welsch (2004) and Cole (2007) in investigating the effect of corruption on pollution. The model comprises two equations that are jointly estimated, one being a usual formulation of the EKC, augmented with government expenditure and other factors and the second expressing income as a function of government expenditure and other factors. In particular,

$$\ln(P/c)_{it} = \partial_i + \zeta_t + \beta_1 \ln Govshare_{it-1} + \beta_2 \ln(GDP/c)_{it} + \beta_3 (\ln(GDP/c))_{it}^2 + \beta_4 (\ln(GDP/c))_{it}^3 + \beta_5 X_{it} + \varepsilon_{it} \quad (1)$$

$$\ln(GDP/c) = \gamma_i + \delta_t + \alpha_1 \ln Govshare_{it} + \alpha_2 \ln Z_{it} + u_{it} \quad (2)$$

where subscripts i and t represent country and time respectively and all variables are expressed in natural logarithms, unless otherwise stated.

Equation (1) represents a cubic EKC augmented with the share of government expenditure over income along with a standard vector of other explanatory variables that include the share of investment over income, as a proxy for capital stock, and the share of trade over GDP in order to examine whether involvement in international trade affects pollutants. Because the impact of government expenditure may not occur instantaneously, we use the lagged share of government consumption expenditure, which may also mitigate the bias from reverse causality. ∂_i is a country effect which can be fixed or random, ζ_t is a time effect common to all countries and ε_{it} is a disturbance term with the usual desirable properties.

Equation (2) is an augmented Solow model widely used in the growth literature (Mankiw et al., 1992; Barro, 1998). It expresses income as a function of the share of government expenditure of GDP and other explanatory factors like investment and education as proxies for capital and human stock, population growth, inflation rate in order to consider the impact of the macroeconomic environment and a measure of openness to international trade. Finally, γ_i and δ_t represent country and time effects respectively while u_{it} is an error term.

3.1 Econometric issues and estimation

In estimating Equations (1) and (2) we must take into account the unobserved heterogeneity across countries. The standard approach is to use the fixed effects and random effects model formulations, with the choice between the two versions depending on the assumption one makes about the likely correlation between the cross-section specific error component and the explanatory variables. When such correlation is present, then random effects estimators are not consistent and efficient and the use of fixed effects is more appropriate.

For example, in the pollutants' equations these country-specific characteristics may include differences in climate, geography and endowments of fossil fuels, all of them potentially correlated with emissions (Leitao, 2010). In addition, it is very likely that country unobserved characteristics are correlated with income and the other explanatory variables, suggesting that fixed effects estimation is preferred. This assumption is supported by the use of Hausman test statistics, where the random effect model was rejected in favor of the fixed effect model, for both equations (1) and (2).

Since the balanced panel data used in this paper consists of both large N and large T dimensions non-stationarity is a critical issue. In addition, we should take into consideration the dynamic nature of our model. We are particularly concerned about the dynamic misspecification of the pollutants' equations as pointed out by Halkos (2003). If we rely on a static model, then all adjustments to any shock occur within the same time period in which they take place, but this could only be justified if we have an equilibrium relationship or if the adjustment processes are very fast. According to Perman and Stern (1999), that is extremely unlikely to be the case and, on the contrary it is expected that the return to long-run equilibrium emission levels is a rather slow process.

In that context, in order to estimate a non-stationary dynamic panel we employ three alternative estimators developed by Pesaran and Smith (1995) and Pesaran et al. (1997, 2004). The first one is a dynamic fixed effects (DFE) estimation in which we assume that intercepts differ across countries but the long-run coefficients are equal across countries. However, if equality of the slope coefficients does not hold in practice this technique yields inconsistent estimators. These assumptions may be tested by the use of a Hausman test.

An alternative estimation method that fits the model for each country individually and calculates the arithmetic average of the coefficients is the mean-group estimator (MG). This method is less restrictive than DFE since intercepts, slope coefficients and error variances are all allowed to differ across countries. Finally, the pooled mean group (PMG) estimator combines the DFE and MG methods by allowing the intercept, short-run coefficients and error variances to differ across groups while assuming equality of the long-run coefficients. Martinez-Zarzoso and Bengochea-Morancho (2004) applied the PMG estimator in order to test the existence of EKC for CO_2 for a group of OECD countries and point to the existence of an N-shaped, cubic, EKC for the majority of those countries.

For equation (1), adopting the formalization by Blackburne III and Frank (2007), we set up an initial general autoregressive-distributed lag model AD ($p,q_1,\ldots,q_k$) of the form

$$y_{it} = \sum_{j=1}^{p} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta_{ij}^{'} X_{i,t-j} + \mu_i + \varepsilon_{it} \tag{3}$$

where the number of countries $i = 1, 2, ..., N$; the number of periods $t = 1, 2, ..., T$, for sufficiently large T; X_{it} is a $k \times 1$ vector of explanatory variables; and μ_i is a country-specific effect.

If the variables in equation (3) are integrated of order one, that is if they are I(1), and cointegrated, then the error term is an I(0) process for all i. A principle feature of cointegrated variables is their responsiveness to any deviation from the long-run equilibrium. Hence, it is possible to specify an error correction model in which deviations from the long-run equilibrium affect the short-run dynamics of the variables. We can then form the error correction equation as

$$\Delta y_{it} = \varphi_i (y_{i,t-1} - \theta_i^{'} X_{it}) + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta y_{i,t-1} + \sum_{j=0}^{q-1} \delta_{ij}^{'*} \Delta X_{i,t-j} + \mu_i + \varepsilon_{it} \qquad (4)$$

where

$\varphi_i = -(1 - \sum_{j=1}^{p} \lambda_{ij}), \theta_i = \sum_{j=0}^{q} \delta_{ij} / (1 - \sum_k \lambda_{ik}), \lambda_{ij}^{*} = -\sum_{m=j+1}^{p} \lambda_{im} \;\; j = 1, 2, ..., p-1,$ and

$\delta_{ij}^{*} = -\sum_{m=j+1}^{q} \delta_{im} \;\; j = 1, 2, ..., q-1$.

Nonlinearity in the parameters requires that the models are estimated using maximum likelihood. The likelihood may be written as the product of each country's likelihood, which expressed in logarithmic form, is

$$l_T(\theta^{'}, \varphi^{'}, \sigma^{'}) = -\frac{\mathrm{T}}{2} \sum_{i=1}^{N} \ln(2\pi\sigma_i^2) - \frac{1}{2} \sum_{i=1}^{N} \frac{1}{\sigma_i^2} [\Delta y_i - \varphi_i \xi_i(\theta)]' \mathrm{H}_i [\Delta y_i - \varphi_i \xi_i(\theta)] \qquad (5)$$

for $i = 1, ..., N$, where $\xi_i(\theta) = y_{i,t-1} - X_i \theta_i$, $H_i = I_T - W_i (W_i^{'} W_i) W_i$, I_T is an identity matrix of order T, and $W_i = (\Delta y_{i,t-1}, ..., \Delta y_{i,t-p+1}, \Delta X_i, \Delta X_{i,t-1}, ..., \Delta X_{i,t-q+1})$.

The main econometric concern for equation (2) is the possible bias occurring from the endogeneity between income and government spending. The exact relationship between GDP and government spending is an active area of research but there is empirical and anecdotal evidence that governments often alter the amount and composition of fiscal spending in order to deal with the effects of the business cycle.

To address this reverse causality problem we use two different approaches, namely a Two Stage Least Squares (2SLS) generalization of panel data estimators and the Arellano - Bond (1998) Generalized Method of Moments (GMM) in order to also take into account dynamics. Our aim is to exploit an exogenous source of variation in the government spending share of GDP. To that end we use as instrumental variable the weighted average government spending in other countries, weighting by the inverse of the distance between the two countries[4].

The income level in a small country relative to the regional and world economy should have no effect on the government spending in these other countries, making the weighted average spending share of GDP elsewhere a good instrument for the local government spending share. An advantage of using the weighted average spending share of GDP in other countries as an instrument is that its lags can also be used as an instrument depending on the preferred exogeneity assumptions. Moreover, we are not restricted in using only a random effects specification as would be the case if we were employing time invariant instruments, which would prevent the potential correlation between country-specific effects and the explanatory variables. Finally, the Arellano-Bond GMM procedure accounts for the inertia that may exist in the determination of income. It mitigates also potential reverse causality biases by using both predetermined and exogenous variables as instruments in a systematic way.

[4] Lee and Gordon (2005) used a similar approach in examining the effect of tax structure on economic growth.

3.2 Capturing the effects of government expenditure on pollution

Given the direct and indirect effects, the total effect of government spending on pollution can be expressed as follows

$$\frac{d(P/c)}{dGovshare} = \frac{\partial(P/c)}{\partial Govshare_{t-1}} + \frac{\partial(P/c)}{\partial(GDP/c)}\frac{\partial(GDP/c)}{\partial Govshare}$$

(6)

where the first expression is the direct effect and the latter is the indirect effect via government's expenditure impact on prosperity. It should be noted that while the direct effect remains constant throughout the whole income range, the indirect and thus the total effect depend on the level of per capita income because of the inclusion of quadratic and cubic income terms in equation (1). In addition, also from equation (1), it occurs that the direct effect of government expenditure on pollution takes place in the next period rather than in the same year, since we use the lagged share of government consumption expenditure. In contrast, the indirect effect is contemporaneous.

4. Results

Table 1 presents the coefficient estimates of per capita income, Eq. (2), by applying different estimation methods. We use the Huber-White-Sandwich estimator of the variance-covariance matrix to estimate the standard error of the coefficients in order to account for autocorrelation and heteroskedasticity. All estimates yield negative and statistically significant effects for the government expenditure share of GDP, as expected, at the 1% level regardless of the method used.

Instrumenting government share in the third column has the effect of increasing the magnitude of its coefficient. A Hansen test of overidentifying restrictions is reported[5] which is asymptotically distributed as χ^2. The test fails to reject the null hypotheses that the instruments are uncorrelated with the error term and that the specification is correct. The test does not reject the overidentifying restrictions and there is no evidence against the null that the instruments, as a group, are exogenous. In addition, the Cragg-Donald F-statistic of 153.23 is much greater than the Stock-Yogo weak ID test critical value at the 10% maximal IV size, 16.38, indicating that the instrument used is not weak. The estimates imply that increasing the share of government spending in GDP by 1%, holding all other explanatory variables constant, may result in a 0.799% reduction of per capita income.

Table 1: Econometric results of the impact of government share on per capita income

Model	OLS (1)	FE (2)	2SLS (3)	GMM A-B (4)	DFE (5)
Log government share	-0.144***	-0.216***	-0.799***	-1.350***	-0.888***
	(0.045)	(0.069)	(0.275)		(0.329)
Log investment	0.820***	0.140***	0.053	0.685***	0.428*
	(0.047)	(0.038)	(0.068)		(0.226)
Population growth	-0.256***	-0.013**	-0.013*	-0.160***	-0.257***
	(0.039)	(0.006)	(0.0069)		(0.078)
Trade openness	0.002***	0.003***	0.003***	0.020***	0.006*
	(0.0005)	(0.0009)	(0.001)		(0.0035)
Constant	6.711***	8.485***			
	(0.252)	(0.239)			
R^2	0.473	0.1986			
F test	0.000	0.000	0.000		
Wald test				0.000	
Hausman FE v. RE		0.000			
Cragg-Donald F-stat			153.23		
Hausman PMG v. DFE					1.000
Hansen test			0.410	0.118	
A-B test of AR(1)				0.000	
A-B test of AR(2)				0.062	
Nobs/Countries/IVs	1,617	1,617/77	1,540/77	1,463/77/60	1,540/77

Note: Robust standard errors are in brackets. All tests' values reported are probabilities.
*Significant at 10%.
**Significant at 5%
***Significant at 1%.

[5] The Sargan statistic is not reported since it is not robust and shows a tendency to over-reject when heteroskedasticity and/or autocorellation are present in the model (Arellano and Bond, 1991).

In the fourth column, applying the Arellano-Bond two-step[6] procedure GMM estimator, government share is still treated as endogenous but now dynamics are also taken into consideration. The significance of the lagged dependent variable (p-value = 0.000) suggests that the dynamic specification should be preferred. We report long-run estimates, calculated by dividing each estimated short-run coefficient by one minus that short-run coefficient. The estimated impact of government expenditure on GDP is even greater in that case, suggesting that an increase of 1% in the share of government spending of GDP, ceteris paribus, reduces per capita income by 1.35%. To obtain robust standard errors the Windmeijer's finite-sample correction for the two-step covariance matrix is used. We use the Arellano-Bond estimates as benchmarks, therefore subsequent analysis and the estimation of equation (1) is based on fitted values of real per capita income from the GMM estimation.

It should be noted that in our analysis the assumption of uncorrelated u_{it} is important, so tests for first- and second-order serial correlation related to the residuals from the estimated equation are reported in column (4). These tests are asymptotically distributed as normal variables under the null hypothesis of no-serial correlation. The test for AR(1) is rejected as expected, while there is no evidence to suggest that the assumption of serially uncorrelated errors is inappropriate at least for the 1% and 5% significance levels.

The estimates of the DFE method are presented in the fifth column. The estimated coefficient of government expenditure is still significant at the 1% level and equal to -0.888, suggesting that consideration of dynamics increases the estimated impact of government share on per capita income, even without accounting for endogeneity.

[6] Since there is evidence of heteroskedasticity the more appropriate two-step version of Arellano-Bond procedure is applied.

The signs and significance of the coefficients associated with the other control variables are all plausible and consistent with the literature. The impact of capital stock, represented by the share of investment in GDP, is positive and significant across all methods of estimation except from 2SLS. Population growth has a consistent negative and significant effect, while the coefficient of trade openness is also found to be significant and with the expected positive sign.

We have also considered the use of years of schooling as a proxy for human capital and inflation in order to capture the macroeconomic environment, but they were both excluded from the final estimated model since they were not statistically significant and did not alter the parameter estimates of government expenditure and their importance[7].

Before turning to the estimation of per capita pollution emissions we should examine the time series properties of the main variables of the model. Testing for unit roots in panel data requires both the asymptotic behavior of the time series dimension, T, and the cross-section dimension, N, to be taken into consideration. Specifically, whether N and/or T converge to infinity is critical in determining the asymptotics of the unit root tests used in each case. The tests proposed by Hadri (2000), Breitung (2000) and Breitung and Das (2005) are based on a sequential limit, where first T tends to infinity for fixed N, and subsequently N tends to infinity. Harris and Tzavalis (1999) and Im et. al. (2003) suggest tests that are asymptotically normal for $N \to \infty$ and fixed T. Tests that may be employed when both $N \to \infty$ and $T \to \infty$, are the ones proposed by Levin et al. (2002) and the Fisher-type tests assuming that the number of panels that do not have a unit root grow at the same rate as N.

[7] The estimated impact of government share was also found to be robust to the incremental inclusion of the explanatory variables.

Since the panel data set we examine consists of both $N \rightarrow \infty$ and $T \rightarrow \infty$ dimensions, the tests of stationarity performed are based on the Fisher-type Phillips-Peron unit root test. The test allows heterogeneity of the autoregressive parameter and although in its general form does not allow for cross-sectional dependence, it is more powerful than Levin et al. (2002) in that case[8]. Table 2 presents the results of the Phillips-Perron unit root tests on the variables of interest. As can be seen, there is evidence against stationarity in levels since in all cases our variables are I(1) i.e. they are stationary in first differences and non-stationary in levels for any level of statistical significance.

Table 2: Panel data unit root tests

Variable	no trend c-s means	no trend minus c-s means	with trend c-s means	with trend minus c-s means
Log SO_2/c	0.063	0.763	0.367	0.526
Δ(Log SO_2/c)	0.000	0.000	0.000	0.000
Log CO_2/c	0.383	0.093	0.000	0.000
Δ(Log CO_2/c)	0.000	0.000	0.000	0.000
Log Government share	0.821	0.511	0.464	0.527
Δ(Log Government share)	0.000	0.000	0.000	0.000
Log GDP/c	1.000	0.980	1.000	1.000
Δ(Log GDP/c)	0.000	0.000	0.000	0.000
$(\text{Log GDP/c})^2$	1.000	0.998	1.000	1.000
$\Delta(\text{Log GDP/c})^2$	0.000	0.000	0.000	0.000
$(\text{Log GDP/c})^3$	1.000	1.000	1.000	1.000
$\Delta(\text{Log GDP/c})^3$	0.000	0.000	0.000	0.000
Log Trade openness	0.924	0.022	0.345	0.137
Δ(Log Trade openness)	0.000	0.000	0.000	0.000

Note: Fisher-type Phillips-Perron unit root tests performed on each panel including one Newey-West lag. All values reported are probabilities. C-s means stands for cross-sectional means.

In addition, application of the DFE method requires that the variables included in the model are cointegrated i.e. there is a long-run relationship among

[8] We also compute the mean of the series across panels and substract this mean from the series (columns 2 and 4 in Table 2), in order to mitigate the impact of cross-sectional dependence according to Levin, Lin, and Chu (2002)

them. Table 3 presents the Pedroni Cointegration Tests for the two pollutants equations.

Table 3: Pedroni residual cointegration test

	SO_2/c		CO_2/c	
	Statistic	Probability	Statistic	Probability
Panel v-statistic	0.012	0.495	-1.120	0.869
Panel rho-statistic	3.069	0.999	2.402	0.992
Panel PP-statistic	-1.850	0.032	-6.207	0.000
Panel ADF-statistic	-4.848	0.000	-5.200	0.000
Group rho-statistic	4.461	1.000	4.781	1.000
Group PP-statistic	-8.207	0.000	-12.096	0.000
Group ADG-statistic	-6.802	0.000	-5.200	0.000

For each pollutant, in four of the seven cases we reject the null hypothesis of no-cointegration at the conventional statistical significance level of 0.05. However, in terms of raw power of the statistics for relatively small values of T the rho and panel-v statistics are the most conservative and show a tendency to over-reject (Pedroni, 2004), suggesting that evidence of cointegration is even stronger than that depicted in Table 3.

Table 4 provides the estimates of per capita pollution emissions utilizing the results of the GMM estimates of equation (2). For each pollutant we report both the FE and DFE estimates. In both models we used a proxy of capital stock and trade openness as control variables. Capital stock was not found to be statistically significant nor did it alter the main findings and hence has been excluded from the results in Table 4.

It has already been mentioned that in our model, according to the Hausman test, FE is preferred to RE. Based on FE estimates (columns 1 and 3) the lagged government share of GDP is found to have a negative statistically significant direct effect on per capita SO_2/c and a negative but not significant relationship with CO_2/c. In addition, both pollutants have a statistically significant cubic relationship with per capita income while trade openness is found to be a negative determinant in both cases but significant only for per capita SO_2.

Table 4: Estimates of per capita pollution emissions

	SO_2/c		CO_2/c	
	FE	DFE	FE	DFE
Log government share lagged	-0.327**	-0.482*	-0.100	-0.236*
	(0.147)	(0.246)	(0.098)	(0.124)
Log GDPc	-35.02**	-63.98***	-20.14***	-16.26**
	(16.52)	(14.98)	(6.669)	(7.709)
(Log GDPc)^2	4.621**	8.429***	2.620***	2.119**
	(2.110)	(1.897)	(0.788)	(0.915)
(Log GDPc)^3	-0.198**	-0.364***	-0.107***	-0.087**
	(0.0890)	(0.0796)	(0.031)	(0.0357)
Log trade openess	-0.188***	-0.135	-0.070	0.052
	(0.0567)	(0.126)	(0.069)	(0.071)
Constant	82.64*		47.96**	
	(42.80)		(18.60)	
Error correction term		-0.213		-0.219
		(0.072)		(0.032)
Turning Points	685/8,342	831/6,088	489/25,109	501/22,471
R^2	0.170		0.395	
F test	0.000		0.000	
Hausman FE v. RE	0.001		0.000	
Hausman MG v. PMG		0.961		0.978
Hausman MG v. DFE		1.000		1.000
Nobs/Countries	1,540/77	1,463/77	1,540/77	1,463/77

Note: Robust standard errors are in brackets. All tests' values reported are probabilities.
*Significant at 10%.
**Significant at 5%
***Significant at 1%.

Dynamics are taken into account in the estimates reported in columns 2 and 4 of Table 4. Since the DFE and PMG estimators constrain the long-run coefficients to be equal across all panels, this 'pooling' across countries yields efficient and consistent estimates when the restrictions are true and the true model is not heterogenous. The test of difference in these models is performed with the use of a Hausman test. Comparing the MG and PMG estimators we see that the PMG estimator, the efficient estimator under the null hypothesis, is preferred and thus pooling is more appropriate in our panel.

However, before suggesting the DFE model as the more appropriate in that case, we should take into account the possible simultaneous equation bias from endogeneity between the error term and the lagged dependent variable, a condition that may be tested with the use of a Hausman test. Results indicate that the simultaneous equation bias is minimal in our panel and we conclude that the FE model is preferred over the MG model.

Government share of income still possesses a negative relationship with SO_2/c and CO_2/c which is significant at the 0.052 and 0.058 significance levels respectively. A statistically significant cubic relationship is confirmed between the pollutants and per capita income.

Concentrating on DFE results, the estimated turning points of the EKC at its maximum (i.e. the level of income above which pollution declines) is within the sample for both pollutants, at \$ 6,088 and \$ 22,471 for SO_2/c and CO_2/c respectively and greater for CO_2/c, a usual result in the literature. The estimated effect of trade openness on both pollutants is estimated to be negative but not statistically significant.

As a side note, it is worth mentioning that the speed of adjustment rate for each pollutant is similar in magnitude and negative, implying an analogous return to long-run equilibrium values.

Table 5 provides the direct, indirect and total effect of government share of GDP on pollution based on the FE and DFE estimates in Table 4. Since the indirect and thus the total effect depend on the level of income, the effects in Table 5 are calculated at the sample median level of income.

Table 5: The impact of government spending on the pollutants (elasticities)

	SO_2/c		CO_2/c	
	FE	DFE	FE	DFE
Direct Effect	-0.327	-0.482	-0.100	-0.236
Indirect Effect	-0.887	-0.660	-1.652	-1.361
Total Effect	-1.214	-1.142	-1.766	-1.579
Change of sign point	9,738	7,094	27,770	28,912

Note: The indirect effect is calculated at the sample median level of per capita income ($4703).

A negative direct effect of government share of income on pollution is estimated by all models, as it has already been indicated by the results in Table 4. In detail, increasing the share of government spending of GDP by 1%, holding income and trade openness constant, may result in a 0.482% reduction of per capita SO_2 emissions and a 0.236% decrease in per capita CO_2 emissions according to the DFE estimates. The indirect effects are also negative at the median income level, leading to a negative total effect. The negative sign of the indirect effect occurs from the positive relationship between income and pollution at the median income level. Explicitly, at the median level of income, an increase in the government share of GDP leads to a reduction in income and, consequently, to a reduction in emissions. In addition, the estimated indirect effects are notably larger than the direct effects.

Figures 1 and 2 show the direct, indirect and total effects of government share of income on emission levels against per capita income. For both pollutants the estimated direct effect is negative and constant for any income level. In contrast, the indirect effect increases with per capita income, since $\frac{\partial(GDP/c)}{\partial(Govshare)}$ = - 1.35 and $\frac{\partial(P/c)}{\partial(GDP/c)}$ falls from 0.36 to – 5.05 for SO_2/c and from 0.68 to 0.03 for CO_2/c throughout the sample income range. These patterns largely depend on the relationship between pollution and the income level described by the EKC.

Consequently, the total effect of government share on SO_2/c is negative for low levels of per capita income and then turns to positive. On the other hand, the total effect on CO_2/c is also negative but becomes positive only for very high levels of income. Table 5 presents the estimated income level at which the total effect changes from negative to positive. In particular, DFE estimates indicate that this level is \$ 7,094 for SO_2/c and \$ 28,912 for CO_2/c i.e. the total effect of government share of income on CO_2/c is negative through the whole sample income range. From the figures it becomes clear that the pattern of the total effect is determined by the shape of the indirect effect.

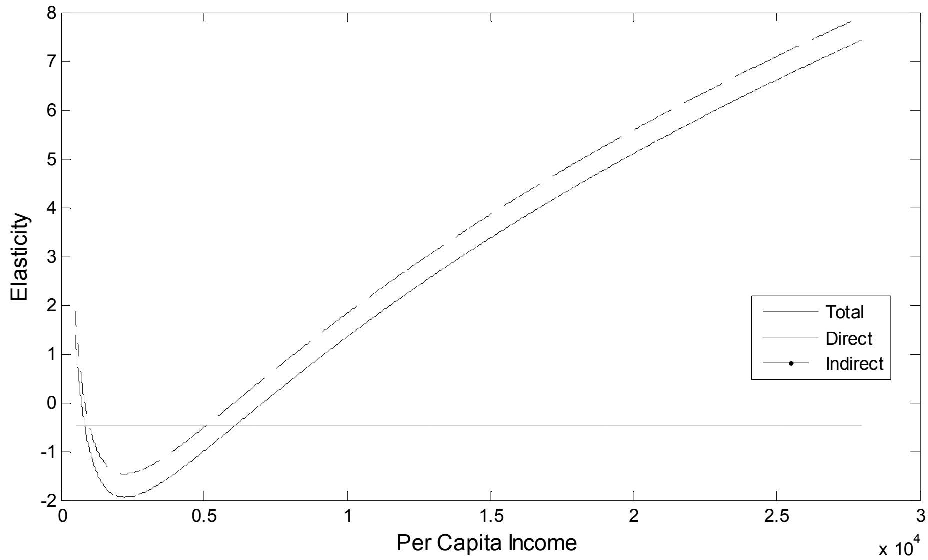

Figure 1: The effect of government share on SO_2/c

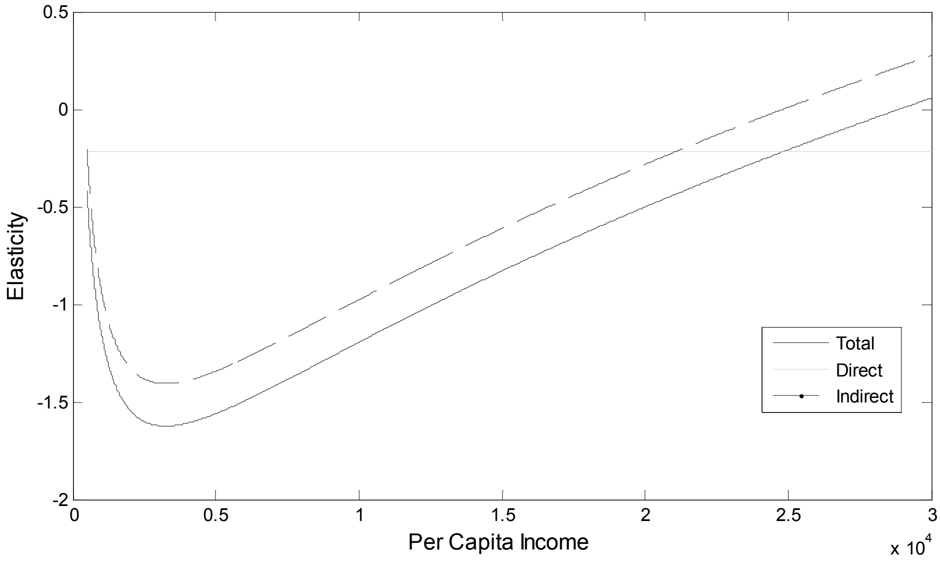

Figure 2: The effect of government share on CO_2/c

By further examining the results of Table 5, it becomes apparent that the estimated direct effect of government spending on pollution is considerably larger, in absolute values, for SO_2 than CO_2. That finding comes as no surprise when one takes into consideration both pollutants impact on human health as well as the technological capabilities of reducing their levels in the atmosphere and hence the environmental degradation associated with them. In particular, SO_2 emission externalities are local and immediate while CO_2 emission externalities are global and occur mostly in the future. Consequently, there are more incentives to incur the abatement costs associated with reduced SO_2 emissions and thus SO_2 is a pollutant that has been historically regulated to a larger extent than CO_2. Moreover, existence of local environmental degradation, as in the case of SO_2, increases demand for technological improvements to diminish that impact. On the other hand, when the cost of pollution is uncertain, more global and affects future generations relatively more, there is little demand for technological innovations that reduce environmental degradation (Shafik, 1994). As a result, substitution away from coal or high sulfur coal is easier than substitution away from fossil fuels mostly associated with CO_2 (Stern and Common, 2001).

The difference in magnitude between the estimated direct effects of government expenditure on SO_2 and CO_2 could also be explained by how the different sectors of the economy respond to certain policies, as pointed out by Cole (2007), since industries and sectors that produce large quantities of SO_2 per unit of output do not necessarily emit large quantities of CO_2, and vice versa. However, the indirect effect of government share on emissions is larger for CO_2 than SO_2 since the former's relationship with income has a greater positive slope over the sample income range than for SO_2.

4.2 Sensitivity analysis

We have already seen that the estimates of government's effect on both pollutants are robust across two different estimation approaches. In this section we further check the robustness of our results in order to confirm that the estimated coefficients are not dependent on particular model specifications and data points.

We present the estimated total effect of government share on both pollutants as well as the level of income where this effect changes from negative to positive, when extreme observations are dropped from the analysis. Firstly, the model was estimated without the top and bottom 1% of government share expenditure data and then a similar approach was followed with the pollutant measures. Comparing the results on Table 6 with those of Table 5, it can be seen that the magnitude of the total effect and the estimate of the change of sign point are robust across the different datasets, indicating that the results are not determined by a small number of observations.

Table 6: Robustness checks of the estimates on the total effect of government share on the pollutants

	SO_2/c		CO_2/c	
	FE	DFE	FE	DFE
Bottom 1% of government share dropped	-1.664	-0.721	-2.234	-2.169
	(7,854)	(5,766)	(20,814)	(25,694)
Top 1% of government share dropped	-1.598	-1.395	-2.391	-2.345
	(9,406)	(6,786)	(25,806)	(31,218)
Bottom and top 1% of government share dropped	-2.143	-1.110	-3.308	-3.168
	(7,494)	(5,866)	(20,892)	(25,352)
Bottom 1% of pollutant dropped	-1.138	-0.696	-1.648	-1.605
	(8,904)	(6,430)	(23,720)	(27,168)
Top 1% of pollutant dropped	-1.078	-1.024	-1.624	-1.577
	(9,902)	(7,266)	(24,652)	(29,128)
Bottom and top 1% of pollutant dropped	-1.023	-0.729	-1.639	-1.597
	(9,218)	(6,990)	(23,648)	(27,230)
Democracy used as instrument	-1.545	-1.303	-2.234	-2.118
	(9,140)	(6,674)	(24,496)	(28,300)

Note: The indirect effect is calculated at the sample median level of per capita income ($4703). Effects presented are based on the DFE and FE estimations of the EKC equation. Change of sign points in parentheses.

We also examine the sensitivity of the model to the instrumental variable used. We replace our strictly exogenous instrument for the government expenditure in the estimation of Eq. (2), with democracy. There are many empirical studies suggesting a relationship between public expenditure and the level of democracy in a country[9]. Boix (2003) suggests that a large share of the public sector depends on the level of democracy, while according to Aidt et al. (2006) cutting down socio-economic restrictions to the voting system leads to larger public share of GDP, mainly through increasing spending on infrastructure and internal security. In another study, Martin and Plümper (2003) find that there is a U-shaped relationship between the level of political participation and the spending behavior of opportunistic governments. In particular they claim that for low levels of democratic participation,

[9] It should be mentioned, however, that there is also a number of studies that find no causal relationship between democracy measures and public spending (see Profeta et al. 2010).

government spending is high in order to meet the demand of rents by the elites while for high levels of democracy public spending is high due to growing demand for public goods. In contrast, none of these pressures relate to medium levels of political participation. In addition, there is a lack of sufficient empirical evidence about the existence of a significant relationship between income level and democracy (Barro, 1996; Acemoglu et al., 2005). The results in the last row of Table 6 indicate that the estimation of the total direct effect is also robust to the use of a different instrumental variable in the model.

5. Conclusions

In this paper, we have used a sample of 77 countries for the period 1980-2000, in order to empirically test the impact of government size on pollution. For that reason, a two equation model was jointly estimated taking particular care to consider the dynamic nature of the relationships examined.

The direct effect of government expenditure was found to be negative for both SO_2 and CO_2 per capita emissions and occurring with one year lag. Moreover, as a result of the relationship of income with the pollutants as well as with the government size, a contemporaneous indirect impact was also estimated. The estimated total effect is largely determined and follows the pattern of the more dominant indirect effect. In particular, for SO_2, the total impact is negative, although decreasing in absolute value, for low levels of income and then becomes positive for more developed countries. In contrast, for CO_2, the total effect was found to be negative and decreasing in absolute value for all levels of income in our sample. The reported results are robust to extreme observations dominance and to the use of an alternative instrumental variable for Eq. (2).

The estimation of a non positive direct effect of government size on pollution is in line with recent findings by Lopez et. al. (2011) and Lopez and Palacios (2010). However, the estimation of the indirect effect is considered for the first time in this paper. Our results confirm the theoretical and empirical developments on the existence of a relationship between income and pollution as well between government size and economic performance.

Policy implications, occurring from the paper's results, differ according to the level of income of a country. For countries with GDP lower than $ 7,094, decreasing the government expenditure share of GDP tends to increase income but could also hinder environmental quality in terms of SO_2 emissions. Since economic growth is an important factor for improving well-being and the results suggest that increases of government size are associated with the deterioration of economic performance, expansionary fiscal policies should be undertaken with particular care. In particular, in developing countries a cut in government expenditure should be undertaken together with the establishment of appropriate environmental regulation. However, in high income countries, a reduction of government size is found to be even more beneficial since it leads to improvements in both economic performance and environmental quality. These implications bear some resemblance to the EKC. In particular, countries with income level at the decreasing area of the EKC are more likely to have already established the environmental legislation and to have undertaken public expenditures for the improvement of environmental quality, thus they are susceptible to diminishing returns from a further increase in government size. On the other hand, when considering CO_2 emissions with a more global ecological impact, a reduction of government expenditure leads to environmental degradation in all levels of income[10], and should therefore be accompanied by appropriate legislation along with the establishment of international environmental treaties.

APPENDIX

Data description and sources

Variable	Description	Source
SO_2/c	Sulfur dioxide emissions per capita, thousands of metric tons of sulfur	Stern(2005)
CO_2/c	Carbon dioxide emissions per capita, metric tons of carbon	Boden, Marland, Andres (2011)
Government share	Government share of Real GDP per capita	Penn World Table(2009)
GDPc	GDP per capita (Constant US$ 1990)	Maddison(2010)
Investment	Investment share of Real GDP per capita	Penn World Table (2009)
Trade openess	Share of imports and exports in GDP	Penn World Table (2009)
Population growth	Annual growth rate of pupulation	Maddison(2010)
School	Primary school enrollment (% gross)	World Bank(2011)
World government share	Weighted avarage of government share of Real GDP per capita in other countries	Authors' calculations
Democracy	Degree of democracy, scaled -10 to 10	Polity IV(2010)

Summary statistics of variables used in the estimations, 1990 values

Variables	Mean	Std. Dev	Min	Max
SO_2/c (thousands of metric tons)	0.0147	0.0188	0.00044	0.11288
CO_2/c (metric tons)	1.208	1.222	0.0091	5.3197
Government share (%)	17.278	8.870	4.082	54.279
GDPc ($1990)	7,312	6,502	585	23,201
Investment(%)	21.332	10.425	4.13	48.93
Trade openess(%)	63.979	40.337	10.185	252.609
Population growth(%)	1.523	2.091	-12.249	8.051
School(%)	98.625	17.240	35.833	140.924
World government share(%)	18.094	2.395	15.785	30.632
Democracy (-10 to 10)	4.176	6.698	-9	10

[10] All levels of income of countries included in our sample.

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