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Περίληψη της Διδακτορικής Διατριβής

Abstract in Greek

Η παρούσα διατριβή μελετά τη σχέση μεταξύ της δημοσιονομικής πολιτικής και της ποιότητας του περιβάλλοντος. Παρά τη μεγάλη σπουδαιότητα των δημοσίων δαπανών και των δημοσίων εσόδων στις διάφορες οικονομίες παγκοσμίως, οι επιπτώσεις της δημοσιονομικής πολιτικής στην ποιότητα του περιβάλλοντος δεν έχουν μέχρι σήμερα μελετηθεί εκτενώς στη βιβλιογραφία. Συνεπώς, σκοπός αυτής της μελέτης είναι να παρουσιάσει μια ανάλυση των επιπτώσεων της δημοσιονομικής πολιτικής στις διάφορες διαστάσεις της περιβαλλοντικής ποιότητας, εξετάζοντας τέσσερις δείκτες ρύπανσης της ατμόσφαιρας, ήτοι τους ρύπους SO_2, N_2O, CO_2 και NOx.

Για το σκοπό αυτό η διδακτορική διατριβή εξετάζει οπτικές αυτής της σχέσης που δεν έχουν αναλυθεί επαρκώς σε προγενέστερες εργασίες. Πρώτον, εκτιμά τόσο την άμεση όσο και την έμμεση επίδραση των δημοσίων δαπανών στην ποιότητα του περιβάλλοντος και παρουσιάζει τη συνολική επίδραση. Συγκεκριμένα, η έμμεση επίδραση σχετίζεται με τις επιπτώσεις των δημοσίων δαπανών στο εισόδημα και την επακόλουθη επίδραση του επιπέδου του εισοδήματος στη ρύπανση του περιβάλλοντος. Δεύτερον, εξετάζει λεπτομερώς τον τρόπο με τον οποίο η άμεση επίδραση των δημοσίων δαπανών μεταβάλλεται για διάφορα επίπεδα οικονομικής ανάπτυξης και ποιότητας των θεσμών σε μια χώρα. Τρίτον, μελετώντας ρυπαντές με διαφορετικά χαρακτηριστικά, όπως αν προέρχονται από την παραγωγική διαδικασία ή την κατανάλωση καθώς και αν οι επιπτώσεις (αρνητικές εξωτερικότητες) τους εντοπίζονται κυρίως σε τοπικό ή διεθνές επίπεδο, παρέχει άμεσα συγκρίσιμες εκτιμήσεις της επίδρασης των δημοσίων δαπανών σε διάφορους δείκτες περιβαλλοντικής υποβάθμισης. Επιπρόσθετα, η χρήση μεθόδων Διανυσματικών Αυτοπαλινδρομήσεων, που βασίζονται

αποκλειστικά σε ελάχιστες υποθέσεις αναφορικά με τα πρόσημα των επιπτώσεων των μακροοικονομικών αιφνίδιων διαταραχών, προσφέρει ενδείξεις αναφορικά με την βραχυπρόθεσμη αλληλεπίδραση μεταξύ της δημοσιονομικής πολιτικής και την ατμοσφαιρική ρύπανση. Τέλος, η αναγκαιότητα και σπουδαιότητα χρήσης δυναμικών οικονομετρικών μεθόδων σε αυτό το πλαίσιο τονίζεται στα εμπειρικά τμήματα της διατριβής και η δυναμική φύση των εξεταζόμενων σχέσεων λαμβάνεται υπόψη.

Η μελέτη αυτή παρέχει ενδείξεις ότι η άμεση επίδραση των δημοσίων δαπανών είναι η μείωση, ή τουλάχιστον η μη αύξηση, των διαφόρων δεικτών περιβαλλοντικής ρύπανσης, ενώ αυτό το αποτέλεσμα είναι ακόμα ισχυρότερο σε ανεπτυγμένες χώρες και σε δημοκρατικά καθεστώτα. Επιπλέον, αυτή η άμεση επίδραση είναι μεγαλύτερη σε απόλυτες τιμές και στατιστική σημαντικότητα για ρυπαντές που χαρακτηρίζονται από μικρότερη ατμοσφαιρική διάρκεια ζωής, τοπικές συνέπειες και συνεπώς πιο άμεσες επιβλαβείς επιπτώσεις στην ανθρώπινη υγεία, σε αντίθεση με ρυπαντές με διεθνές αντίκτυπο και μακροπρόθεσμες επιπτώσεις στην ανθρώπινη υγεία. Επιπρόσθετα, η ανάλυση δείχνει ότι η ανωτέρω άμεση επίδραση των κυβερνητικών δαπανών είναι σπουδαιότερη σε στατιστική σημαντικότητα και σε απόλυτη τιμή στους ρύπους που σχετίζονται με την παραγωγική διαδικασία, σε αντίθεση με τους ρύπους που προέρχονται κατά κύριο λόγο από την κατανάλωση. Η εκτιμώμενη συνολική επίδραση των δημοσίων δαπανών στην περιβαλλοντική ρύπανση είναι αρνητική σε χαμηλά επίπεδα εισοδήματος, αν και βαίνει μειούμενη, ενώ γίνεται θετική στις ανεπτυγμένες χώρες. Αναφορικά με τη σύνθεση των δημοσίων δαπανών, τα αποτελέσματα της ανάλυσης επιβεβαιώνουν την υπόθεση ότι η μειωτική άμεση επίδραση των κυβερνητικών δαπανών στη περιβαλλοντική ρύπανση μπορεί να ενισχυθεί σημαντικά αν αυξηθούν συγκεκριμένες κατηγορίες δαπανών, όπως οι δαπάνες που σχετίζονται με την παροχή δημοσίων αγαθών και οι δαπάνες για την προστασία του περιβάλλοντος. Τέλος, η χρήση επεκτατικής δημοσιονομικής πολιτικής στηριζόμενη σε μία μείωση των κυβερνητικών εσόδων σχετίζεται

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με αύξηση των ρύπων CO_2 που προέρχονται από την κατανάλωση, ενώ δεν φαίνεται να επιδρά σημαντικά στους ρύπους που εκπέμπονται κατά την παραγωγική διαδικασία.

Το τελευταίο κεφάλαιο της διατριβής συνοψίζει τα αποτελέσματα της εμπειρικής ανάλυσης και προσφέρει συμπεράσματα και προτάσεις πολιτικής που απορρέουν από την ανάλυση.

Abstract

This thesis explores the relationship between fiscal policy and environmental quality. Despite the immense importance of government expenditure and government revenues in many economies worldwide, little effort has been so far devoted to the study of the impact of such policies on environmental quality. Therefore, the aim of this study is to provide an analysis of the effect of fiscal policy on several aspects of environmental degradation, by considering four different indicators of air pollution, namely SO_2, N_2O, CO_2 and NOx emissions.

In doing so, it aims to examine dimensions of this relationship that have not been sufficiently considered in previous studies. First, it estimates both the direct and indirect effects and reports the total effect of government expenditure on environmental degradation. In particular, the indirect effect operates through the impact of government spending on income and the subsequent effect of the income level on pollution. Second, it explicitly examines how the direct effect of government expenditure on environmental quality may differ conditional on the level of economic development and the quality of institutions in a country. Third, by analyzing pollutants with different characteristics, such as whether they are production- or consumption-generated and whether they are characterized by local or global externalities, it provides estimates of the effect of fiscal policy between the different indicators of environmental pollution, which can be directly compared. In addition, Vector Autoregression methods, which are solely based on minimal hypotheses about the signs of the impacts of macroeconomic shocks are used and offer insights concerning the short-term interrelationships between government expenditure and government revenues with air pollution. Finally, the importance of employing appropriate dynamic econometric techniques

in this framework is emphasized throughout the empirical analysis and the dynamic nature of the examined relationships is explicitly taken into consideration.

The study provides evidence that government expenditure has a negative or non-positive direct effect on the different indicators of environmental degradation, while this alleviating direct effect is significantly reinforced in developed countries and democratic jurisdictions. In addition, the estimated direct effect is greater in significance and in magnitude for pollutants that are characterized by shorter atmospheric life time, local geographical range and therefore more immediate impact on human health, compared to pollutants with externalities that are more global and their impact occurs mostly in the future. Moreover, the analysis shows that the estimated direct effect is greater in significance and magnitude on production-generated pollution, compared to consumption-related pollution. The estimated total effect of government expenditure on environmental degradation is negative for low levels of income, though decreasing in absolute value, and becomes positive in more developed countries. Regarding the composition of government expenditure, the results confirm the hypothesis that the alleviating direct effect of government spending on environmental degradation can be considerably enhanced by spending targeted on specific functional categories, such as spending on public goods and on environmental protection. Finally, an attempt to stimulate the economy through tax-cuts is associated with an increase in consumption-related CO_2 emissions in the short-run, while there is little evidence of an effect on production-generated CO_2 emissions.

The final chapter of this thesis summarizes the research findings, as well as the conclusions and policy implications drawn from these findings.

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Introduction

1. The importance of fiscal policy

The role of government as an essential component of civilized communities, albeit in its extreme form of absolutism for the sovereign, has been pointed out by Thomas Hobbes (1651). On the other hand, Adam Smith (1776) has argued that governments should limit their tasks to fundamental functions such as protecting property rights and ensuring the rule of law and order, otherwise economic growth and welfare would be significantly deteriorated. Nevertheless, he has warned against the complete confinement of the state, since this would lead to detrimental effects and social disorder. Moreover, Adolf Wagner's law suggests that the size of government tends to increase with the level of income in order to maintain the same level of administrative and law enforcement functions, as well as to ensure the necessary provision of public goods and the alleviation of market failures[1].

Nowadays, in most countries a large part of Gross Domestic Product (GDP) is being spent through government consumption and investment. In particular, the share of government expenditure in GDP increased in most developed countries during the period 1970–1995, in an attempt to alleviate the effect of business cycles and achieve income equality. This trend reverted during the period 1995 – 2005, in order to confine increasing public debt ratios, but subsequently increased again, as several governments have followed expansionary macroeconomic policies to support and expedite the recovery of their economies in response to the economic crisis that initiated in 2008. The evolution of the size of government expenditure from 1970 to 2013, for a sample of 28 OECD countries, is depicted in Table 1.

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[1] For related studies that empirically confirm this hypothesis see Rao (1989) and Martinez-Mongay (2002).

Despite renewed recent attempts to reduce government expenditure, still an average of more than 45% of GDP is spent by governments.

Table 1: Total public expenditure as a % of GDP (General government)

	1970	1980	1990	1995	2000	2005	2010	2013	Changes in pp			
									05-70	05-95	10-05	13-10
Australia	25.9	33.2	35.7	38.3	34.8	34.9	36.8	36.6	9.0	-3.4	1.9	-0.2
Austria	39.7	49.4	51.5	56.0	51.4	49.9	52.7	50.8	10.2	-6.1	2.8	-1.9
Belgium	41.0	54.7	52.2	51.9	49.0	49.8	52.3	54.5	8.8	-2.1	2.5	2.2
Canada	36.0	41.6	48.8	48.5	41.1	39.3	43.3	40.7	3.2	-9.2	4.0	-2.6
Czech Republic	..	..	..	54.0	41.7	43.6	43.0	42.0	..	-10.3	-0.6	-1,0
Denmark	..	53.6	55.9	59.5	53.9	52.8	57.1	57.1	..	-6.7	4.3	0.0
Finland	30.9	40.1	48.0	61.5	48.3	50.1	54.8	57.6	19.2	-11.4	4.7	2.8
France	39.2	45.6	49.4	54.4	51.6	53.9	56.4	57.0	14.7	-0.6	2.5	0.6
Germany	38.4	46.9	43.6	48.3	45.1	46.8	47.1	44.1	8.4	-1.5	0.3	-3.0
Greece	26.5	32.1	49.2	50.1	51.2	46.7	52.2	60.1	20.1	-3.5	5.5	7.9
Hungary	..	..	..	55.4	46.6	49.9	49.8	49.8	..	-5.5	-0.1	0.0
Iceland	31.1	35.7	41.5	42.7	42.1	43.4	49.4	44.1	12.3	0.7	6.0	-5.3
Ireland	44.8	54.6	43.1	41.3	31.6	34.1	..	39.6	-10.7	-7.1	..	..
Italy	32.5	40.8	52.9	52.5	46.1	48.2	49.9	50.9	15.8	-4.2	1.7	1.0
Japan	20.8	32.1	31.8	36.5	39.2	37.0	40.7	42.3	16.2	0.5	3.7	1.6
Korea	..	21.2	20.0	20.8	23.9	29.1	31.0	31.8	..	8.2	1.9	0.8
Luxembourg	..	..	37.7	39.7	37.6	43.2	43.8	42.6	..	3.5	0.6	-1.2
Netherlands	43.7	54.2	52.9	50.0	44.0	45.5	48.2	46.4	1.7	-4.6	2.7	-1.8
New Zealand	..	..	53.2	42.0	39.6	38.2	47.4		..	-3.8	9.2	..
Norway	39.1	46.1	54.0	51.5	42.7	42.8	45.0	44.0	3.7	-8.7	2.2	-1.0
Poland	..	..	..	47.7	41.0	42.7	45.9	42.2	..	-5.0	3.2	-3.7
Portugal	..	34.2	40.3	43.1	43.1	47.7	51.8	49.8	..	4.7	4.1	-2.0
Slovakia	..	..	..	47.0	51.7	37.1	42.0	41.0	..	-9.9	4.9	-1.0
Spain	23.0	33.5	42.6	44.2	39.0	38.2	45.6	44.3	15.2	-6.0	7.4	-1.3
Sweden	43.9	64.1	61.3	67.1	56.8	56.3	52.0	53.4	12.4	-10.8	-4.3	1.4
Switzerland	..	..	30.0	34.5	33.9	36.2	32.9	33.5	..	1.6	-3.3	0.6
United Kingdom	42.0	46.4	42.4	44.9	37.5	44.9	48.7	45.5	2.8	-0.1	3.8	-3.2
United States	32.3	34.3	36.3	37.3	38.3	39.3	42.9	38.5	7.0	2.0	3.6	-4.4
Minimum	20.8	21.2	20.0	20.8	23.9	29.1	31.0	31.8	8.3	8.2	1.9	0.8
Maximum	44.8	64.1	61.3	67.1	56.8	56.3	57.1	60.1	11.5	-10.8	0.8	3.0
Simple average	35.0	42.6	44.8	47.3	43.1	43.8	47.4	45.9	9.1	-3.5	2.8	-0.6

Source: Afonso and Furceri, 2010-p.10 (extended using OECD stats and own calculations)

The economic implications of government expenditure have been shown to be significant and broad, however the empirical evidence concerning the qualitative characteristics of these relationships remain inconclusive. In particular, government spending has been shown to enhance long-run economic growth by increasing the level of human capital and Research and Development (R&D) expenditure, and by improving public infrastructure (Ram, 1986; Ghali, 1998; Dalamagas, 2000; Agenor and Neanidis, 2006). In contrast to the above, there is

evidence that a greater size of government spending may be less efficient and therefore not necessarily associated with a better provision of public goods and higher levels of economic growth (Afonso and Furceri, 2010; Bergh and Karlsson, 2010).

Moreover, it is likely that the size of government expenditure and its composition are associated with key aspects of the quality of growth, such as income inequality and environmental sustainability (Lopez et al., 2010). Calbick and Gunton (2014) suggest that policy factors alone account for much of the variation in emissions among developed countries. This relationship is of great interest since, if a positive relationship between government expenditure and environmental quality can be established, it will provide reassurance to macroeconomic policy makers that a fiscal spending expansion does not induce pollution and in fact may lead to a significant alleviating effect on environmental degradation. In such a case, fiscal spending could complement the efforts to improve environmental quality, rendering environmental policy easier and more cost efficient. Despite the potentially significant implications of fiscal spending on the environment, it is surprising that this relationship had been neglected in the literature and only recently there is a burgeoning body of theoretical and empirical studies that have systematically started to explore it (Lopez et al. 2011; Halkos and Paizanos, 2013; Bernauer and Koubi, 2013; Galinato and Islam, 2014).

At the same time, a large body of empirical literature posits a relationship between economic growth and pollution. This literature focuses on the possibility of the existence of an inverted-U shaped relationship between per capita income and pollution, commonly known as the Environmental Kuznets Curve (Grossman and Krueger, 1995; Halkos, 2003). By affecting per capita income, government spending is expected to indirectly influence environmental quality.

Therefore, the framework for this dissertation is related to three bodies of literature: (i) the literature linking fiscal policy to long-term growth and short-term income fluctuations; (ii) the literature on the growth-pollution relationship; and (iii) a small but growing literature on the effects of fiscal policy on the environment. However, since the literature examining the fiscal policy-growth and growth-pollution relationships is already well developed, the research undertaken for this thesis focuses on how fiscal policy affects environmental quality.

2. Exploring the effect of fiscal policy on the environment

The empirical literature provides controversial evidence concerning the sign of the effect of government size on pollution. In an early study, Frederik and Lundstrom (2001) suggested that greater economic freedom, in terms of lower government size, reduces CO_2 emissions when the size of government is small, but increases emissions when the initial size of government is large. In a related work, Bernauer and Koubi (2013) found that an increase in the government spending share of GDP is associated with more air pollution and this relationship is not affected by the quality of the government. In addition, several studies provide a theoretical basis for determining the effect of government expenditure on pollution, emphasizing the importance of fiscal spending composition (Lopez et al., 2011; Galinato and Islam, 2014). In particular, these studies have shown that a reallocation of government spending composition towards social and public goods reduces pollution while increasing total government size, without changing its orientation, has a negative or non-positive effect on environmental pollution. Given this background, the present thesis aspires to contribute to this literature, by explicitly examining several dimensions of this relationship that have not been sufficiently considered in previous studies.

First, as already mentioned, there is established evidence on the link between fiscal policy and growth, as well as on the relationship between growth and pollution. These relationships imply that fiscal policy, to the extent that it affects economic growth, might also indirectly influence environmental quality through this channel. However, existing research ignores this mechanism and therefore the reported results in the literature capture only part of the effect of government expenditure on pollution. As such, in this dissertation both the direct and indirect effects are taken into consideration and the total effect of government expenditure on pollution is estimated.

In addition, it is well documented that environmental quality is influenced by various other factors, apart from fiscal policy and economic growth, including political institutions, population, trade and investment (Grossman and Krueger, 1995; Halkos, 2013a; Bernauer and Koubi, 2009; Zhu and Peng, 2012; Cole and Elliott, 2003). Some of these characteristics may interact with government expenditure and influence its effect on environmental quality. In this regard, it is highly unlikely that the effect of government spending on pollution is independent from country specific characteristics. For example, Galinato and Islam (2014) have given credibility to the hypothesis that the magnitude of the direct effect of government expenditure on pollution depends on whether a specific country has a democratic or autocratic regime. Furthermore, the level of economic development might also affect the magnitude of the relationship between fiscal spending and environmental degradation. Nevertheless, all but one[2] of the studies that examine the direct effect of government expenditure on environmental quality, report a unified estimate based on a world sample of countries. Since this approach may lead to omitted variable bias, the research in this thesis identifies and estimates three distinct channels that may influence the direct effect of government spending on pollution.

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[2] Galinato and Islam (2014).

Another interesting aspect to explore is how the effect of fiscal policy varies according to the different characteristics of the pollutants. The mechanisms through which fiscal policy affects pollution might differ according to the source of pollution, i.e. whether pollution is production- or consumption-generated (McAusland, 2008; Lopez et al., 2011; Galinato and Islam 2014). Furthermore, depending on the atmospheric life characteristics and geographical range of the effect of different pollutants, emissions externalities may range from local and immediate to those that are global and occur mostly in the future (Shafik, 1994; Cole, 2007). However, only one study (Islam and Lopez, 2015) takes into account these important distinctions and reports estimates on both production- and consumption-generated pollutants, however all the pollutants used in that work refer to local environmental degradation. The analysis for this thesis examines several indicators of environmental degradation and therefore reports estimates, on each of the aforementioned categories of pollutants, which can be directly compared.

All the empirical studies dealing with the effect of fiscal policy on the environment use reduced-form models and estimate the long-term effect of government spending. Thus, implicitly they make strong assumptions about the lack of correlation between government expenditure and other fiscal variables which are excluded from the model, assumptions that would appear unlikely to hold in general, as pointed out by Blanchard and Perotti (2002). To alleviate such concerns, the research undertaken in this thesis draws structural conclusions using Vector Autoregression methods which are solely based on minimal hypotheses about the signs of the impacts of certain shocks (Faust, 1998; Canova and de Nicolo, 1998; Uhlig, 2005; Mountford and Uhlig; 2009). This approach has the additional advantage to provide insights regarding the short-term interrelationships between fiscal policy and environmental degradation. In addition, application of this method to the U.S. economy, allows the use of a tax revenues variable, which is not possible in global sample panel data sets due to the

paucity of relative data. Therefore, this analysis also offers indications regarding the effect of a tax-cut based fiscal expansion on the environment.

Finally, it should be mentioned that throughout the empirical analysis of this dissertation, appropriate econometric techniques are employed in order to take into account the dynamic nature of the examined relationships. In particular, due to the large N and T dimensions of the data used, non-stationarity and the potential dynamic misspecification of the pollutants equations should be explicitly considered (Halkos, 2003; Christopoulos and Tsionas, 2004). Static models, which are used in the majority of the works in this literature, assume that adjustments to any shock occur instantaneously, however this could only be justified in equilibrium or if the adjustment mechanism is rapid and is highly unlikely, considering that the return to long-run equilibrium emission levels can be relatively slow (Perman and Stern, 1999).

3. Structure of the thesis

This dissertation is structured as follows:

Chapter 1 provides a brief review of the theoretical and empirical literature on the relationship between fiscal policy and economic activity, both in terms of long-run economic growth and short-term output fluctuations.

Chapter 2 presents the theoretical underpinnings and the findings of empirical research on the link between economic growth and environmental quality. Furthermore, it presents the theoretical and empirical framework of the relationship between fiscal policy and pollution by reviewing the relevant literature.

The empirical part of this dissertation is presented in Chapters 3–5 and consists of three distinct studies which examine different dimensions of the relationship between fiscal policy and environmental quality. In particular, *Chapter 3* emphasizes the significance of the indirect effect of government expenditure on environmental quality, which operates through the effect of fiscal policy on economic growth. It reviews the relevant literature and explains the econometric approach that has been used. It also gives policy insights, which vary depending on the income level of the considered countries[3].

Chapter 4 explores the hypothesis that the direct effect of government expenditure on the environment varies conditional on the level of economic development and institutional quality in a country. It identifies and estimates three distinct channels that comprise the total direct effect of government expenditure on air pollution, namely a marginal effect, an effect conditional on economic growth and an effect conditional on institutional quality. Since the adjustment rate of emissions to their equilibrium level is slow due to technological and institutional reasons, dynamics are explicitly taken into account by applying appropriate econometric methods. The respective policy implications are presented in the end of the Chapter.

Chapter 5 proposes the use of Vector Autoregressions by using sign restrictions to identify the policy shocks, in order to analyze the short- and mid-term interactions between fiscal policy and pollution. Furthermore, it constructs the impulse responses to linear combinations of fiscal shocks, corresponding to the scenarios of deficit-financed spending and deficit-financed tax-cuts. The exact pattern of the effects depends on the source of emissions, the

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[3] The work presented in Chapter 3 has been published in the international peer-reviewed journal *Ecological Economics* and is therefore cited throughout the rest of this dissertation as Halkos and Paizanos (2013).

scenario of fiscal policy implemented and the functional class of government expenditure being increased[4].

Finally, *Chapter 6* summarizes the research findings, as well as the conclusions and policy implications drawn from these findings.

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[4] The work presented in Chapter 5 has been accepted and is forthcoming for publication in the international peer-reviewed journal *Energy Policy*, in common with Professor George E. Halkos.

Chapter 1

Fiscal Policy and Economic Activity

1.1 Fiscal policy and long-term economic growth

Bergh and Henrekson (2011) identify three main analytical frameworks through which the determinants of growth including fiscal policy have been analysed in the literature, namely neoclassical growth models, endogenous growth theory and a third strand of literature that emphasizes the role of institutions[5]. In neoclassical growth theory, fiscal policy can only have a temporary effect on growth and in the long-term the economy grows at the exogenously determined rate of technological progress, which in the long run should be comparable in all countries (Solow, 1956; Swan, 1956; Cass, 1965; Koopmans, 1965). This issue is important since in case of comparable long term growth rates among countries, the long run effects of fiscal policy are less significant (Gwartney, et al. 1998).

However, many theoretical studies have shown that there are several mechanisms that justify significantly different growth rates among economies (Lucas, 1988; Romer, 1990), which is also confirmed by empirical evidence (Quah, 1996; Gwartney and Lawson, 1997). Endogenous growth theory specifies no diminishing returns in the production function and thus, any factor that affects the level of technology also affects the long-term growth rate of the economy (Romer, 1986; Barro, 1990; Rebelo, 1991). Psarianos (2002) identifies three

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[5] There are, of course, several other possible determinants of economic growth that have been discussed in the literature, including the role of geography (Diamond, 1997; Gallup et al., 1998; Sachs, 2001) and the importance of international trade (Sachs and Warner, 1995; Frankel and Romer, 1999) among others.

main distortions that may lead to a sub-optimal steady state rate of growth of output by the decentralized allocation of resources in this framework, as follows: (a) A weakening of the incentive to invest in R&D due to the probability of monopoly rents that reward successful innovators not being realized, (b) The inefficient allocation of capital goods in the production process due to the monopolistic pricing of those goods, and (c) The inability of the market to reward researchers for the reduction in the cost of future technological advancements that follows the expansion of current knowledge. Therefore, there is room for fiscal policy to induce the private economy to attain the socially optimal outcomes by corresponding subsidies to alleviate the aforementioned market failures, albeit at the cost of facing a *time-inconsistency problem*[6].

Finally, the significance of institutions on economic growth was initially highlighted by North (1987, 1991) and was empirically asserted by several studies (for example, Acemoglu et al., 2002; Dawson, 2003; Rodrik et al. 2004; Berggren and Jordahl, 2005; Glaeser et al. 2004).

1.1.1 How the government size affects economic growth

1.1.1.1. Factors that encourage long-run growth

The main analytical tool used to examine the effects of fiscal policy on economic growth is the endogenous growth theory. According to Lopez et al. (2010) and IMF (2015), endogenous growth theory identifies four main mechanisms through which government expenditure and tax reforms may increase long-run growth, as follows:

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[6] For details see Psarianos (2009).

Physical capital

Government spending being targeted at efficient public investments, like expenditure on infrastructure, may improve the productivity of the private sector and therefore, increase the rate of return on private investment both at the corporate and individual level. This increase in productivity leads to the increase of the long-term rate of growth (Nourzad and Vrieze, 1995; Sanchez-Robles, 1998). On the government revenues side, tax-cuts on capital income may increase savings and investments, and therefore enhance long-run growth (Rebelo, 1991; Devereux and Love, 1994).

Human capital

Economists have long pointed out the importance of human capital as one of the main determinants of long-term growth (Lucas, 1988; Mankiw et al., 1992; Barro, 2001). In particular, human capital accumulation increases growth directly as an input in production process, as implied by the neoclassical models, but also indirectly by promoting ideas and thus inducing technological progress (Jones, 2001). In the presence of positive externalities and market failures, in order to provide the optimal level of education and health, government expenditure (Guellec and van Pottelsberghe, 1999) and appropriate reformation of the tax-system (King and Rebelo, 1990; Pecorino, 1993) may support the accumulation of human capital. This may in turn increase the productivity of the private sector and therefore encourage economic growth as shown by several theoretical and empirical works.

Total factor productivity

Public investment has the potential to boost private sector factor productivity, as it has been shown by both neoclassical (Barro, 1990; Glomm and Ravikumar, 1994; Turnovsky and Fisher, 1995) and endogenous (Baier and Glomm, 2001) growth models. In the presence of

positive externalities from R&D and dissemination of ideas, there is an important role for governments which can alleviate market failures, increase total factor productivity and ultimately enhance long-run growth. In particular, government expenditure on infrastructure and services, like R&D, national defense and transportation system can directly enhance private sector productivity and support technological advancements while government provision of public goods such as education and health can improve the diffusion and use of new technologies. On the tax revenues side, appropriate tax reforms can provide incentives to encourage private R&D expenditure.

Labor supply

Several studies in the framework of endogenous growth theory examined the mechanisms through which fiscal policies may increase labor supply and enhance long-run growth (Deverux and Love, 1994; Turnovsky, 2000). Individual decisions on whether to participate in the labor market (extensive response) and how much to work (intensive response) are largely influenced by the tax-benefit system. Recent empirical works provide evidence that the influence of the tax system on these decisions is greater for specific groups, such as older workers and women and at the lower end of the income distribution (OECD, 2011).

1.1.1.2. Factors harmful for long-run growth

On the other hand, as the size of government grows, an increasing number of resources are progressively allocated by political rather than market mechanisms. Eventually, the enhancing effect of government size on long-term growth is expected to diminish and ultimately become negative. Gwartney et al. (1998) schematize these factors as follows:

Diminishing returns of government expenditure

As government grows compared to the private sector, the law of diminishing returns impoverishes the reinforcing effect of government expenditure on economic growth. At small levels of government size, government expenditure is targeted at fundamental functional categories such as the insurance of law and order, as well as the provision of national defense and protection of property rights, which encourage private sector efficiency and stimulate long-run growth[7]. Nevertheless, governments may further enhance economic growth by expanding their provision to several other functions. For instance, government expenditure on public goods like transportation infrastructure, education and health further encourage economic growth by alleviating market failures and increasing total factor productivity. However, if government expenditure continues to increase it is progressively targeted to gradually less productive and efficient activities, which could be more efficiently provided by the private sector. Therefore, such an improvident expansion of government is associated with negative returns and therefore hinders long-run growth.

Disincentive effects of higher taxation and government borrowing

As the level of government expenditure grows, higher tax-revenues and greater borrowing are required to finance it. A greater tax rate on the corporate level reduces the investment rate of return and therefore fewer risks and investment projects are undertaken by the private sector, eventually lowering private sector productivity (Browning, 1976). On the individuals' side, higher levels of labor income tax reduce the income of workers, distort their incentives to participate in the labor market and therefore reduce labor supply. Moreover, more borrowing by the government can crowd out private investment by increasing the interest rate and lead

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[7] In particular, spending on defence may stimulate economic output through a Keynesian increase in aggregate demand but may also hinder growth mainly through the crowding-out of investment or a reduction in public spending in other functional categories such as expenditure in infrastructure (Kollias et al., 2007; Kollias and Paleologou, 2010).

to higher tax-rates in the future. As a result, progressively more resources are allocated to the public sector and even in the case that there were no diminishing returns of government spending, these factors would have an alleviating effect on long-term growth.

Slowing of the wealth-creation process

Joseph Schumpeter (1942) described as ''creative destruction'' the process of punishment by competition of those who do not succeed in combining the available resources in an efficient way during production. In the private sector, driven by their efforts to maximize profits, decision-makers have great incentives to keep cost low, combine the production factors in the most efficient way and absorb improved new technologies rapidly. In this sense, the political system is significantly less dynamic than free markets, since adjustment to new opportunities and adoption of better technologies occurs at a much slower rate in the public sector. This is a significant inadequacy of governments, as this inflexibility is a key detrimental factor of long-run growth.

Figure 1.1 depicts the related hypothesis that the relationship between the growth rate and the size of government is an inversely U-shaped curve, known as the Armey curve (Armey, 1995). At very small levels of government size, depicted on the horizontal axis, as government expands from zero (complete anarchy), the economy growth-rate initially increases up to a threshold point B. However, as government size further expands, spending is targeted at less productive functions, which at some point begin to dominate the positive effects and consequently reduce the rate of economic growth, eventually rendering it negative at levels of government where expenditure is channeled to counterproductive activities. Moreover, it should be highlighted that in case of governments which do not undertake

activities solely based on their rate of return, the curve is downwards shifted, thereby further deterring the growth capabilities of the economy.

Figure 1.1. The size of government-growth curve
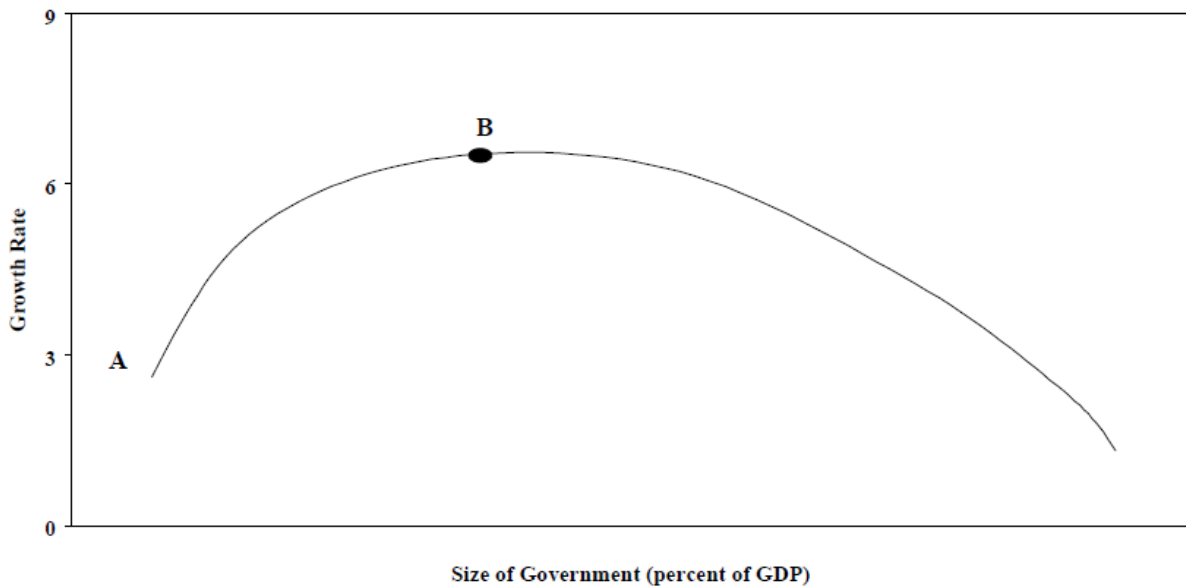
1.1.2 A brief literature review

The previous discussion of the mechanisms through which government expenditure and taxes affect economic growth suggests that this effect is ambiguous in the relevant literature. This section classifies the main empirical studies on the relationship between fiscal policies and long-term growth and briefly presents their methodology and results.

Government expenditure and economic growth

Early works concentrated on the effect of total government expenditure on economic growth. In this regard, several studies report a significantly negative impact of the share of government expenditure on growth rates, in line with the hypothesis that smaller

governments are associated with greater economic growth rates. Grier and Tullock (1989) analyzed a sample of 115 countries, using data averaged over 5-year periods and found a significantly negative effect of the government share of GDP on the growth of real GDP, however, most of the relation was based on the 24 OECD countries sub-sample in their research. In a couple of related studies, Landau (1983, 1986) examined cross-section data on 104 countries, controlling for education and energy consumption, and reported a negative impact of government consumption expenditure on the growth rate of per capita GDP. Marlow (1986), studied a sample of 19 developed countries over the period 1960-1980, controlling only for the level and growth of government expenditure and argued that a larger public sector harms long-term growth. A dataset of 23 OECD countries, as well as a more representative sample of 60 countries was examined by Gwartney et al. (1998) who provided evidence on the existence of a robust negative effect of government expenditure on economic growth, even after the effects of education, investment, institutional quality and macroeconomic stability were taken into account. Other important works that also report a robust negative effect of government size on economic growth include Barro (1991) and Bajo-Rubbio (2000).

On the other hand, a few studies have suggested a positive relationship between government size and long-term growth. Ram (1986), examining a sample of 115 countries for the period 1960-1980 reported that the effect of government expenditure on growth is significantly positive while he provided evidence that total factor productivity is greater in the public sector. However, it is likely that the results of this study are influenced by endogeneity, since greater growth rates are associated with an increase in government expenditure, although Rao (1989) failed to reject the hypothesis of exogeneity using Hausman tests (Engen and Skinner, 1992). In a more recent study, Colombier (2009) applied the M-estimator of Yohai et al.

(1991) and reported a positive effect of government expenditure on the growth rate of OECD countries. However, Bergh and Ohrn (2011) suggest that these estimates are driven by the unique dataset and specification used[8]. Finally, several other studies have suggested the existence of a positive relationship between government expenditure and economic growth (for example, Ghali, 1998 and Dalamagas, 2000).

Furthermore, a considerable number of studies have provided inconclusive evidence regarding the impact of government size on economic growth. An early work by Cameron (1982), based on cross-sectional data, found that the effect of share of government spending over GDP on economic growth was negative, although very weak. Levine and Renelt (1992) stressed the importance of following an appropriate specification, since they found that the estimated effects were not robust to the inclusion of different control variables. Dowrick (1993) incorporated technological growth in the Rao (1989) model and reported evidence of endogeneity of the government expenditure variable and therefore no evidence of a significant effect of government spending on economic growth. Other studies that report no evidence of a significant relationship between government spending and economic growth are Kormendi and Meguire (1985) and Sala-i-Martin (1997).

Taxation and economic growth

In general, the effect of taxes on economic growth is less ambiguous in the empirical literature, since it is reported to be significantly negative in the majority of studies. Koester and Kormendi (1989) examined cross sectional data and reported that, controlling for average tax rates, the marginal tax rate has a significant negative impact on economic growth. In a related study, King and Rebelo (1990), based their analysis on endogenous growth theory and

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[8] For details see Bergh and Henrekson (2011).

reported that an increase in the tax rate is associated with a reduction of long-term economic growth. Moreover, Deverux and Love (1994) suggested that an overall drop in tax rates significantly improves the growth rate, while Turnovsky (2000) reported that an increase in capital income tax is associated with a substantial reduction of economic growth. On the other hand, Lucas (1990) and Turnovsky (2004) did not find a significant effect of the tax rate on growth, a result that may be attributed to their assumptions of inelastic labor supply and existence of no human capital, respectively. Finally, Koester and Kormendi (1989) reported that marginal tax rates have a significant negative relationship with the level of per capita GDP only and not with economic growth.

Factors that influence the effect of government size on economic growth

Many studies have stressed the role of a number of factors that can influence the magnitude and significance of the effect of government size on economic growth. These determinants comprise the composition of government expenditure and taxation, the volatility of fiscal spending, the creation of fiscal deficits, the level of economic development, the initial size of government intervention and the quality of institutions.

The composition of government expenditure and taxation

The composition of government expenditure and taxation is an important factor of fiscal policy, since the different components of spending and type of taxes imposed may have very different implications on long-term growth. Barth and Bradley (1987), in an early study, examined 16 OECD countries during the period 1971-1983 and found a negative effect of government consumption spending on the growth rate, while the effect of government investment spending was positive, though insignificant. In a couple of related studies, Aschauer (1988, 1999) pointed out the importance of government capital accumulation and

reported a positive effect on productivity growth, while the associated effect of government consumption was weaker. The significant effect of government spending on education and health, public expenditure on infrastructure, as well as the role of R&D expenditure, has been well documented in the relevant literature (Lucas, 1988; Barro, 1990; Romer; 1990; Jones et al. 1993; Hansson and Henrekson, 1994; Agenor and Neanidis, 2006). Thus, the effect of government expenditure on long-term growth can be enhanced if it supports the accumulation of infrastructure that can be used as production factors in the private sector (Devarajan et al. 1996). Turning our attention to more recent studies, Bleaney et al. (2001) and Romero-Avila and Strauch (2008), reported that government consumption expenditure and spending on social welfare do not affect the rate of growth, whereas public investment has positive effects.

On the government revenues side, Easterly and Rebelo (1993a, 1993b) suggested that only income tax rates have a negative relationship with long-term growth, while other tax measures have no significant effect. Kneller et al. (1999) argued that the reinforcing effect of government investment expenditure is significant only when financed by non-distorting taxes and at relatively small size of government, while a rise in distorting taxes is associated with lower levels of long-term growth. Similar findings that direct, rather that indirect, taxation alleviates economic growth have been reported in more recent studies, such as these by Padovano and Galli (2002a, 2002b), Widmalm (2001), Lee and Gordon (2005) and Bergh and Ohrn (2011). Finally, Chen and Lu (2013) examined the effects of the rate of capital income and labour income tax rates and reported a negative relationship with economic growth for both types.

The volatility of fiscal spending

Fiscal volatility also constitutes a significant issue concerning the effect of fiscal policy on economic growth. According to Afonso and Furceri (2010), economic theory suggests that government spending volatility may have either a positive or negative effect on private investment and economic growth, based on how it affects business-cycle volatility. A positive effect on growth is associated with the capacity of fiscal policy to alleviate fluctuations of the business cycle and smooth economic fluctuations by the use of automatic stabilizers. On the other hand, if fiscal policy is characterized by the use of pro-cyclical measures, it may exacerbate the fluctuation of the business-cycle and thus reduce long-term growth (Fatas and Mihov, 2003; Lane 2003).

The role of fiscal deficits

Fiscal deficits may influence the level of savings in the economy and eventually, depending on the assumptions made, may have a significant or no impact on economic growth (Gray et al., 2007). In neoclassical growth theory, even if fiscal deficit reduces savings, it has no long-term impact on economic growth, despite causing a lower capital to labor ratio and ultimately increasing the interest rate and reducing the level of real wages. On the other hand, endogenous growth theory predicts a more persistent effect of the savings rate on long-term growth. Empirical evidence provides ambiguous results regarding the sign and significance of this effect. Fisher (1993) suggested that fiscal deficits have a negative relationship with economic growth by reducing both capital accumulation and private sector productivity growth. Adam and Bevan (2005) argued that the impact of fiscal deficit on growth rate may depend on the initial size of the deficit as well as the source that is used to finance it. In particular, deficits can: reinforce growth if financed by limited seigniorage; deter growth if financed by domestic debt; be growth enhancing if financed by external loans at market rates.

On the other hand, Taylor et al. (2011) suggested that there is a significant positive effect of a higher primary deficit on economic growth, even after controlling for the increase of the interest rate.

The level of economic development

As already mentioned, Wagner's law suggests that the size of government is typically smaller in developing countries. Bergh and Henrekson (2011) took this relationship one step further and argued that the effect of government size on economic growth is positive in poor countries. For example, Besley and Persson (2009) suggested that in developing countries there is a positive relationship between tax revenues and economic growth since at low levels of taxation only the most fundamental functions of government intervention, such as the protection of property rights, are implemented. In more developed countries, where tax revenues are higher, organized interest groups attempt to receive advantages for themselves and rent-seeking activities are larger, leading to market failures and eventually harming economic growth (Bergh and Henrekson, 2011; Buchanan, 1980; Olson, 1982).

However, empirical evidence on the relationship of government size and economic growth in developing countries is inconclusive. Miller and Russek (1997) reported negative effects of taxes on growth in OECD countries but positive effect for developing countries. On the other hand, Aslund and Jenish (2006) found that in developing countries there is a negative relationship between government expenditure and economic growth in recent years. Finally, many studies report an insignificant effect of government size on long-term growth in developing countries (Nelson and Singh, 1998; Campos and Coricelli, 2000; Beck and Laeven, 2005).

<u>The optimal size of government</u>

As already mentioned, the Armey curve developed by Armey (1995) exhibits that there is a non-linear relationship between government size and economic growth. In particular, this theory suggests that for small levels of government an increase in public expenditure may promote economic growth, however when the size of government exceeds a certain threshold the impact of a government spending expansion becomes negative. The foundation for this theory is that in countries where the size of government is large the share of public expenditures that is beneficial for private market productivity is typically smaller than in countries where the size of government is relatively small (Folster and Henrekson, 2001). Afonso and Furceri (2010) identify two early studies (Slemrod, 1995; Tanzi and Zee, 1997) that find a negative impact of government expenditure on economic growth when the size of government exceeds a certain threshold.

Focusing on the US economy, Grossman (1987) found that the level of government expenditures in 1983 exceeded by 87% the level that would maximize the private sector productivity and suggested that output could be significantly enhanced by reducing government expenditure and using the spare labour in the private sector. Moreover, Peden (1991) found that the optimal size of government expenditures in the US economy is about 17-20% of GNP, far less than the 35% observed in 1986 (Chobanov and Mladenova, 2009). In a related study, Chen and Lee (2005), examined economic growth in Taiwan and reported that all classifications of government size have a threshold effect and that a non-linear relationship of the Armey curve exists. Finally, Davies (2008), using panel data analysis, suggested that the optimal size of government with respect to economic performance is considerably smaller than the optimal size of government with respect to broader human development indicators, like the Human Development Index (HDI).

<u>The quality of institutions</u>

Another important factor that may influence the effect of government size on economic growth is the quality of the political system. For example, Guseh (1997) provided a model that distinguishes the impact of government size on long-term growth across political institutions and argued that the negative effect of the government size on economic growth is three times greater in autocratic regimes compared to the effects in democracies.

Economic theory suggests that government expenditures should increase up to the point where their marginal benefits equal the marginal cost of taxation required for financing them. Better political system institutions would affect both these determinants. Gray et al. (2007) presented a simple analytical framework on how institutional quality affects the relationship between government expenditure and economic growth, as portrayed in Figure 1.2. Point A presents the intersection of the marginal benefits and marginal cost of a government expansion and depicts the optimal size of government for a typical country, with average quality of institutions.

In countries with better institutions, the marginal benefit of government spending would increase due to better program design and improved management of resources. Moreover, on the taxation side, the marginal cost would decrease due to improved tax design and administration that would confine the distorting effects of raising tax revenues. Thus, in countries with better governance quality, the optimal size of government expenditure and taxes could increase to point A^* and eventually an expansion of government expenditure would not deter economic growth. On the other hand if the typical country opted to increase government size to the levels indicated by E^* and T^*, it would result to the creation of a dead-weight loss, captured by the area ABC. Empirical results in Gray et al. (2007) support this

negative relationship of government expenditure and economic growth in countries with weak institutions, but beyond a certain level of spending.

Figure 1.2. The influence of governance quality on the effect of government size on economic growth
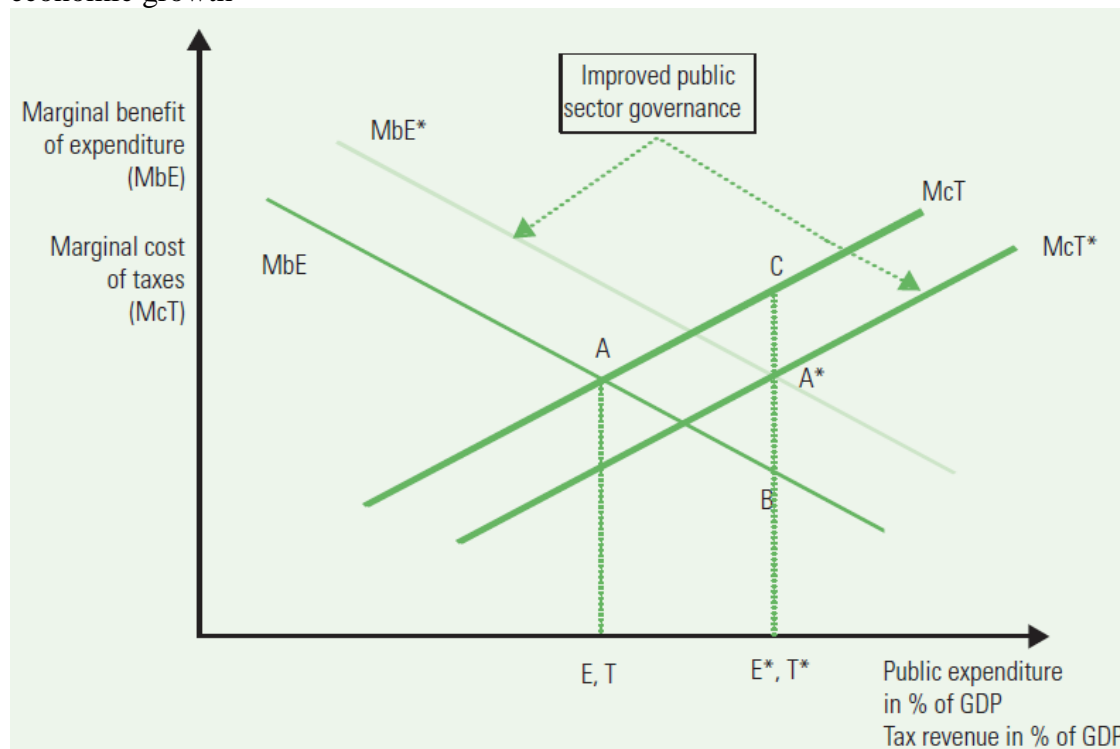
Methodological issues

Bergh and Henrekson (2011) have pointed out the main methodological issues in estimating the relationship between fiscal policy and economic growth[9]. The most important methodological concern in empirical studies that attempt to estimate the effect of government size on economic growth is to properly indicate causation from fiscal policy to growth (Bergh and Henrekson, 2011). As already mentioned, there is empirical evidence that supports Wagner's law of government size being positively associated with economic growth. On the other hand, in times of greater growth rates, unemployment falls and government expenditure

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[9] This section is based on the discussion in Bergh and Henrekson (2011).

is lower. Therefore, the estimated effect of government expenditure on economic growth is highly dependent on the set of countries taken into consideration in the analysis and the time period examined. Already in 1986, Saunders pointed out that cross-country evidence was not robust to the use of different measure of government size, alternate time periods and different groups of countries included in the analysis.

Related to the above, the estimation of a positive or negative effect of government expenditure on economic growth indicates correlation but does not necessarily imply causality from fiscal policy to growth. On the other hand, a negative coefficient on taxes actually provides strong evidence that high taxes deter economic growth, since reverse causality implies a positive correlation in this case (Bergh and Karlsson, 2010). The most commonly used method to overcome this shortcoming is employment of instrumental variables methods. Folster and Henrekson (2001) used two stage least squares (2SLS) method where the government expenditure and taxes were instrumented by their lagged levels, and also by fixed country effects, levels and differences of the population and initial GDP variables. This study confirmed the existence of a negative relationship between government size and economic growth. In a related study, Afonso and Furceri (2010) instrumented government expenditure and tax revenues by their lagged values, trade openness and country population and reported that the magnitude of the negative effect of government size on long-term growth decreases to some extent in EU the OECD countries. Finally, an alternative method is the use of the Generalized Method of Moments (GMM) that employs predetermined and exogenous variables as instruments in a systematic way. This method was applied by Romero-Avila and Strauch (2008) who found a significant negative of government consumption and social transfers on long-term growth, and a small, but significant, positive effect of government investments on growth.

The lack of good instruments for government size, however, means the issue has not yet been completely solved (Bergh and Henrekson, 2011). Bergh and Karlsson (2010) showed that certain tax credits and deductions are correlated with government size, but not with economic growth, thus they could be used appropriately as instruments. However, given that detailed data on deductions and tax credits are available only from 1996 onwards, it will take a number of years before a reasonably long time series can be constructed (Bergh and Henrekson, 2011).

1.2 Fiscal policy and short-run business cycles

Most macroeconomic models consent that an expansionary monetary policy is characterized by a decrease of the interest rate and is associated with a boost in growth and inflation while, at the same time, the majority of empirical evidence is consistent with this statement (Perotti, 2007). However, there is no such consensus as regards the effects of an expansionary fiscal policy. For instance, neoclassical models suggest that the real wage and private consumption will decline, while neo-Keyenesian models suggest an opposite effect. This section briefly reviews the predictions of the different theoretical models on the effects of an increase in government spending on goods and services and then reviews the growing body of literature that empirically examines these theories.

1.2.1. Theoretical models

1.2.1.1. The Classical model

In the standard classical model, markets are perfectly competitive and prices, real wages and interest rates are flexible. Therefore, the market mechanism guarantees the production of

goods at the level of full employment and the aggregate supply curve is vertical, i.e. inelastic to nominal values like the level of prices.

These assumptions have important implications on the effectiveness of fiscal policies that aim to stimulate demand (Demopoulos, 1998). Policy makers could implement policies that would shift aggregate demand, however these would have no effect on employment and output and thus, fiscal policy cannot be considered a stabilization tool. In particular, an increase in public spending, financed by a deficit or borrowing, will increase demand of funds and hence raise interest rates, which will eventually reduce private consumption and investment of the private sector. This crowding-out of the private sector will counterbalance any positive effects of the implemented policy and thus fiscal policy has no net effect on the economy's short-run performance.

1.2.1.2. The Keynesian model

Keynesian theory assumes short-run rigidity of prices while individuals experience money illusion, since there is no distinction between real and nominal values. As a result, there are unused production factors and there is a sizeable rate of unemployment. The aggregate supply curve is determined by the conditions of the non-competitive labor market and is fully elastic in the short-run at the level of the rigid price level, while it is vertical, i.e. inelastic to prices, in the long-run at the level of full employment.

In this model, the determinants of aggregate demand, including fiscal policy, can significantly affect output and employment. The total effect of an increase in government expenditure depends on the relevant magnitude of the multiplier and crowding-out effects (Mankiw, 2000). The multiplier effect is related to the additional shifts in aggregate demand

that result when expansionary fiscal policy increases income and thereby increases consumer spending. On the other hand, the crowding-effect is related to the offset in aggregate demand that results when expansionary fiscal policy raises the interest rate and thereby reduces investment spending. Concerning the effects of a tax-cut policy, these also depend on the relative size of the multiplier and crowding out effects. In particular, tax-cuts increase consumers' disposable income and therefore shift aggregate demand. Consequently, higher income leads to greater money demand, which eventually increases the interest rates and reduces private investment. Finally, it should be mentioned, that the Keynesian model predicts a greater enhancing effect of an increase in government expenditure on output and employment, compared to the effect of tax-cuts.

1.2.1.3. The Neoclassical model

In the neoclassical model, nominal wages and prices are flexible, whilst workers are not influenced by money illusion. In particular, workers predict the price level at each period and adapt their expectations at the real level of prices ($P = P^e$), claiming respective increases of their wages. Short-run discrepancies between the real and the expected levels of prices can affect the level of equilibrium output and therefore the aggregate supply curve has a positive slope in the short-run.

$Y = Y_F + a*(P - P^e)$, with $a > 0$
If $P^e < P$, then $Y > Y_F$ and if $P^e > P$, then $Y < Y_F$

All markets, including the labour market, are fully competitive and lead to full-employment equilibrium. Hence, the long-run aggregate supply curve is vertical, i.e. fully inelastic to the prices level. Moreover, real wages adapt instantaneously and the return to long-run

equilibrium occurs rapidly, therefore fiscal policy is not particularly important for the stabilization of the economy.

The neoclassical model, developed mainly in works by Lucas, Sargent and Wallace[10], has been used extensively for the analysis of fiscal policy. Furthermore, significant contributions and clarifications to the neoclassical model were provided by Aiyaggari et al. (1992) and by Baxter and King (1993). In this model an expansion of government expenditure should inevitably be accompanied by an equivalent rise in taxation to satisfy the intertemporal government budget constraint. Perotti (2007) identifies three main forms of fiscal expenditure expansion, namely a temporary expansion financed by lump-sum taxes, a permanent expansion financed by lump-sum taxes and a temporary increase of spending financed by distortionary taxes. In all cases, there is a negative wealth effect on individuals who reduce private consumption and increase labor supply in order to counterbalance the negative effect on their permanent income. The intertemporal substitution in labour supply is crucial for the magnitude of the fiscal multiplier. The increase of labour supply increases output and reduces the real wages. Considering that the capital/labour ratio remains the same, since it is determined uniquely by the rate of time preference, there is a boost in total investment due to the higher desirable level of capital of the economy. The aforementioned effects are relatively greater in magnitude in the case of government spending financed by distortionary taxes, followed by the case of a permanent expansion of expenditure based on lump-sum taxes, while the smaller changes occur in the case of a temporary increase in fiscal spending.

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[10] See, for example, Lucas (1981) and Lucas and Sargent (1981).

1.2.1.4. Neo-Keynesian models

In neo-Keynesian models the assumption of money illusion is not central, as is in standard Keynesian theory, albeit due to contracts of employment and other institutional factors of the economy there are price and wage rigidities (Erceg et al., 2000; Christiano et al. 2005) or price rigidities and wage flexibility (Goodfriend and King, 1997). In addition, workers do not have perfect foresight regarding future prices and economic activity fluctuations due to incomplete information. The aggregate supply curve in these models is more elastic than its counterpart in the neoclassical model and following the implementation of fiscal policy that shifts aggregate demand, the level of output may fluctuate more in the short-run.

In neo-Keynesian models a productivity shock is not a prerequisite of shifting out aggregate demand for labour and this can be achieved by other shocks including a fiscal policy expansion. According to the strength of the shift of labour demand, the real wage can increase and eventually cause a higher consumption, either through a substitution or credit constraint effect. In particular, Perotti (2007) classifies neo-Keynesian models into the following three categories, according to the mechanisms that government spending shocks increase real wages:

Countercyclical mark-ups

A positive demand shock leads output and marginal cost to increase and because prices cannot adjust immediately, the mark-up falls. For example, Rotemberg and Woodford (1992) suggest that a government spending expansion increases current demand compared to future demand and thus amplifies incentives to undercut collusive pricing between oligopolistic firms.

Nominal rigidities

In order to meet increased demand caused by a government spending shock, firms supply more output and therefore labour demand and output rises, while real wages increase despite the shift in labour supply (Linnemann and Schabert, 2003). However, it should be highlighted that the nature of rigidity matters since, in the case of wage rigidities, the real wage might decrease following a government spending shock.

Increasing returns

In Devereux et al. (1996) and Bilbiie et al. (2005) a government spending shock increases the equilibrium number of firms in the intermediate good sectors, which are characterized by increasing returns to specialization. Consequently, the productivity in this sectors increases and thus a higher real wage is achieved, despite the negative wealth effect on labour supply.

Following the rise in real wages, there are two mechanisms through which a rise in consumption may occur. Firstly, individuals with higher real wages tend to substitute leisure with consumption, therefore increasing private consumption (Devereux et al., 1996; Ravn et al. 2006). However, in models with nominal rigidities the increase in the real wage may not be enough to lead to an increase in consumption, which may be achieved by a second route through the introduction of credit constraints in the model (Gali et al., 2007).

1.2.2. Empirical literature review

Macroeconomic theory and particularly Keynesian models provide several practical insights to policy makers on how to implement fiscal policy to alleviate the adversary effects of business cycle fluctuations. A growing body of empirical works, based on time series econometrics methods relying on minimal assumptions and a priori theory, has tested the

validity of these theoretical insights. Nevertheless, the related literature does not provide unanimous evidence on the mechanisms through which fiscal policy may affect economic activity and the findings are highly dependent on the econometric approach employed. Following Caldara and Kamps (2008) we may categorize this strand of literature, based on the econometric approach used to identify fiscal policy shocks, as follows:

Recursive approach

This approach implies a causal ordering of the model variables and relies on Cholesky decomposition to identify fiscal policy shocks. Therefore, in this method, the ordering of the variables is crucial and should rely on viable and testable assumptions. Fatas and Mihov (2001) used this method and reported a government spending multiplier greater than one. Moreover, they found that this increase of output is associated with an increase in private consumption, while investment is not significantly affected. These findings are in line with the Keynesian model.

Structural VAR approach

Blanchard and Perotti (2002) proposed a two-step method to identify fiscal policy shocks. In the first step, institutional information regarding tax and transfer systems, as well as their timing, are used to isolate the automatic responses of government expenditure and taxes to the business cycle, therefore allowing estimation of the fiscal policy shocks in the second step. Their findings suggest that government spending reinforces output, private consumption and real wages, consistent with Keynesian theory. On the other hand, they also reported that both increases in government expenditure and taxes have a significant negative relationship

with private investment[11]. This finding reconciles with the neoclassical model but is not consistent with Keynesian models, which, although agnostic about the sign of these effects, predict opposite qualitative effects of spending and taxes on private investment. Related studies, with findings that are consistent with Keynesian theory, include Perotti (2007) and Fragetta and Melina (2010).

Sign restrictions approach

The sign restrictions approach was introduced by Faust (1998) in order to examine the effect of monetary policy. This method identifies policy shocks by imposing sign restriction on the impulse responses but does not impose any restrictions on the signs of the responses of the key variables of interest to fiscal policy shocks. Mountford and Uhlig (2009) applied this approach to examine the effects of fiscal policy on economic activity in the U.S. and found that a surprise deficit-financed tax cut is the best fiscal policy to stimulate the economy, while a deficit-financed government spending shock only weakly stimulates the economy. Moreover, they reported that government spending shocks crowd-out both residential and non-residential investment without causing interest rates to rise. These finding are not consistent with standard Keynesian theory, according to which government expenditure multipliers are greater than tax multipliers and crowding-out is caused by an increase in taxes[12].

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[11] For a similar finding regarding the effect of government expenditure on private investment see Alesina et al. (1999) and Alesina and Ardagna (2010).

[12] The finding that the tax multiplier is greater than the government expenditure multiplier is reported in a growing number of recent studies. For example, Ramey (2011) reported that the government expenditure multiplier in the U.S. economy is 1.4, while in a related study Romer and Romer (2009) found that a reduction of tax revenues by $1 increases GDP by $3. Contrary to that, according to the January 2009 Council of Economic Advisers of the U.S. government, an extra dollar of government spending raises GDP by $1.57, while a dollar of tax cuts raises GDP by only 99 cents (Mankiw, 2009).

Event-study approach

In order to identify macroeconomic policy shocks, Ramey and Shapiro (1998) looked for fiscal episodes which can be considered exogenous with respect to the state of the economy. The majority of the studies using this approach contemplate the effects of defence expenditure increases, since this category can be considered exogenous when related to spending associated with wars or unexpected military build-ups (Perotti, 2007; Ramey, 2011). The aforementioned studies report that an increase in defence expenditure stimulates output, while it reduces real wages and consumption.

Chapter 2

Environmental Macroeconomics

2.1. Economic growth and the environment

The physiocratic[13] and classical schools[14] of economic thought, already during the eighteenth and nineteenth centuries, pointed out the significance of land in the production process, and highlighted the existence of natural constraints on economic growth (Harris and Codur, 2004). Most notably, Thomas Malthus (1798, 1820) argued that humanity was trapped in a world where population growth would intensively consume natural resources and eventually cause, particularly for the lower class, misery and therefore prevent any permanent improvement of their state. Malthus suggested that two types of stabilizers may assist in holding population within sustainable limits: positive checks, which raise the death rate; and preventive checks, which lower the birth rate (Hollander, 1997). The positive checks include war, hunger and disease; the preventive checks birth control, abortion, encouragement of celibacy and postponement of marriage. Moreover, Malthus offered no gleam of hope, since he dismissed the effectiveness of several possible solutions to put an end on this vicious cycle, such as the argument that improvements in agricultural productivity could satisfy increasing nutritional needs. It is therefore not surprising that with such ominous predictions, Economics were characterized as the *dismal science* (Heilbroner, 1953).

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[13] Includes writers like A.R.J. Turgot, the Marquis de Condorcet and Francois Quesnay.
[14] Particularly in the writings of Adam Smith and David Ricardo.

Nevertheless, this inconvenient characterisation of Economics appears highly unfair, considering that macroeconomic theory was oriented, for more than a century, towards a hypothesis of continuous growth in GDP and not much attention was given to the relationship between economic growth and environmental degradation until early 1970s. It was indeed this neglection that led Brock (1973) to argue that growth theory is biased, since it does not explicitly take into account the environmental costs of economic growth. On a similar note, Daly (1990) pointed out the failure of an ''*environmental macroeconomics*'' to emerge, apart from the efforts to consider environmental factors in national accounting, which were already being developed during the 1990s. Microeconomic treatment of environmental policy considers the optimal allocation of a given scale of resource flow within the economy but neglects the scale and composition of economic activity relative to the ecosystem that supports it (Daly 1991; Heyes, 2000). An ecological approach to macroeconomics requires the appreciation of physical constraints to economic growth (Harris, 2009).

2.1.1. Theoretical framework

2.1.1.1. The circular flow model

A fundamental theoretical tool of macroeconomic theory is the circular flow model of an economic system. In its standard form, this model describes the exchange of services and goods, as well the supply and demand of factors of production between two types of economic actors, namely consumers (households) and producers (firms). However, the environment and the natural resources, which support the production process, are not considered in the standard version of this model.

Figure 2.1. The augmented circular flow model
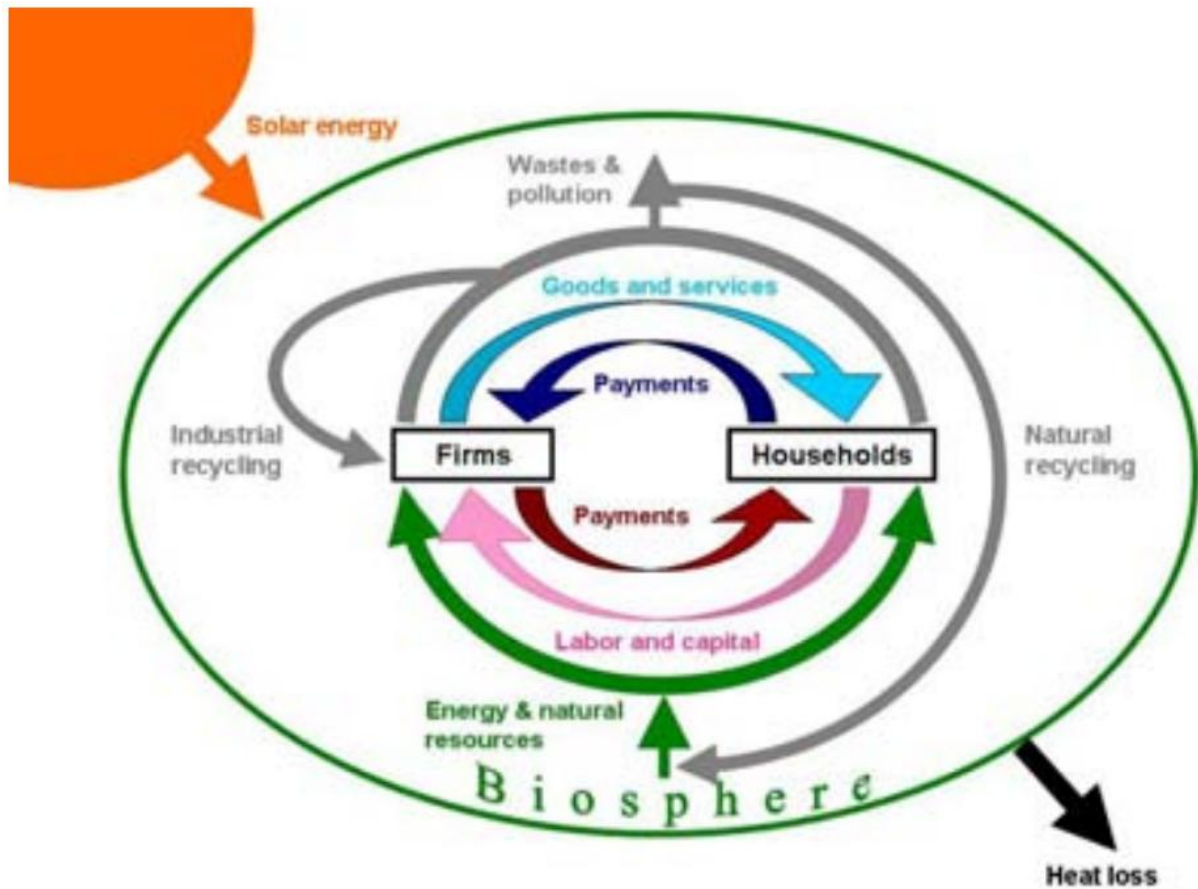
Source: Harris and Codur (2004-p.4).

According to contemporary economic theory, an economy has at least three factors that contribute to production and eventually to economic growth and welfare: human capital, physical capital and natural capital (Lopez et al., 2010). Natural capital in particular, comprises natural resources as well as environmental quality. Therefore, the standard circular flow model can be enhanced by the introduction of the biosphere as ''*a provider of natural resources and also as the receptor of various undesirable outputs of the production/consumption processes, i.e. of pollution and wastes*'' (Harris and Codur, 2004). Following Harris and Codur (2004), we may consider the entire economic activity to be embedded in the biosphere. Related to this, Kumbhakar and Tsionas (2015) examined the environmental production process (for example, during the production of electricity) and

emphasized the existence of inefficiencies in by-product technologies, which implies that more than the minimal amounts of the undesirable outputs are produced (SO_2 and NO_x emissions). Moreover, they identified the presence of technical inefficiencies which means that, given a level of inputs, less than the maximum possible level of desirable outputs is produced.

Thus, a more sophisticated circular flow model should be considered. Such a model should represent the procedures and mechanisms of economic activity and its interactions with the biosphere, taking into account that certain by-products of economic activity are subsequently recycled through biological and geophysical processes. These relationships are portrayed in Figure 2.1.

2.1.1.2. Environmental pollution in growth models

During recent decades, the increasing urgency of environmental problems, both in national and global levels, provoked a growing body of research that incorporate environmental pollution factors in growth models and explicitly explores the relationships between economic growth, capital accumulation and environmental degradation. The foundation of these models is the acknowledgement of a flow of waste material as a by-product of the production process, which deteriorates the environment and possibly the factor productivity. Moreover, in these models environmental quality is positively valued by individuals.

According to Xepapadeas (2005) and assuming that the flow of emissions is related mainly to output production, the neoclassical aggregate production function for the economy can be written as:

$$Y = F\left(K_p, AL, K_\alpha\right) \tag{1}$$

where K_p is the pollution generating capital, AL represent effective labour that allows for labour augmenting technical change and K_a is the abatement capital which helps reduce pollution levels. The flow of emissions can be represented as $Z = \phi(K_\alpha)Y$ where φ depicts emissions per unit of output and $\phi'(K) < 0$, assuming existence of emissions reducing technologies.

Alternatively, the effective flow of pollution, BZ, can be incorporated in the production function in order to capture productivity effects of the environment, for example by improving the health of the labour force, as proposed by Brock (1973):

$$Y = F\left(K, AL, BZ\right) \tag{2}$$

where $\dfrac{\partial F}{\partial Z} > 0$.

Regarding consumption, environmental quality may enter the utility function by assuming that individuals derive satisfaction from the consumption of goods as well as from the quality of the environment. Hence, the utility function for the ith individual is:

$$U\left(c_i, Z\right) \tag{3}$$

and the criterion function of the government to achieve social optimization, takes the form:

$$\int_0^\infty e^{-\rho t} N(t) U\left(\bar{c}(t), P(t)\right) dt, \tag{4}$$

where N(t) is the population, t represents time, $\bar{c}$ is per capita consumption and ρ depicts the future utilities discount rate.

The development of the models that explore the interrelationships between economic growth and the environment is closely linked to the evolution of growth theory. As already discussed in Chapter 1, the first wave of models constituting the neoclassical growth theory, considered technical change as exogenous and the role of government policy to be limited, with no effect on the exogenously determined long-run growth rate. On the other hand, endogenous growth theory incorporated technological progress as an endogenous factor, which allowed the determination of the growth rate endogenously in the model and eventually offered the theoretical framework for a more active and efficient role for government policy. Therefore, following the classification and analytical framework proposed by Xepapadeas (2005) the predictions and policy implications of three types of related theories are briefly presented below, namely models with fixed savings ratio and exogenous technical change, optimal growth models with exogenous technical change and finally, endogenous growth models.

- **Models with a fixed savings ratio**

These models consider that the savings ratio is fixed and no related optimization process is followed by individuals. In addition, the degradation of environmental quality does not reduce utility and is therefore not taken into account, a situation that may in some cases not deviate from reality, for instance in industrialised societies. Under these assumptions, at the steady-state environmental pollution grows at the fixed rate n + g, where n and g represent the exogenous rates of population and labour augmenting technology growth rates, respectively. Therefore, accumulation of pollution would only cease when there is no exogenous growth, i.e. when n = g = 0 and the economy also stops growing. The introduction of emissions reducing technologies in this model is one way to sufficiently prevent the

accumulation of pollution as the economy grows. In this case the level of steady-state pollution is reduced, albeit pollution in physical units still grows at an exogenous rate.

Apparently, an equilibrium steady-state level of pollution might not exist in the aforementioned basic model. This could be achieved if the flow of emissions is incorporated as an input in the production function, as in Eq. (2), and could be justified as a maximum level of emissions imposed by emission standards or by technological constraints. In this model the steady-state growth rates of the main variables in per capita terms are constant and determined exogenously, while the steady-state levels of these variables are determined by the specified level of emissions. Moreover, due to nonlinearities, certain levels of the specified environmental standard might result in the fast accumulation of pollution which may be difficult, or even impossible, to reverse. Xepapadeas (2005) points out that such an *environmental trap* may be likely in this case, since environmental standards are not set in an optimum way based on the disutility related to environmental pollution.

- **Optimal growth models**

In these models, environmental considerations are explicitly taken into account by introducing the utility function of the representative household. However, the steady state for the competitive economy has the same characteristics as the standard Ramsey–Cass–Koopmans model without environmental pollution, with only the growth rate of consumption being lowered. This result reflects the fact that producers do not take into account the disutility from pollution, environmental degradation will continue as long as the economy grows at an exogenous rate, and that there are diminishing returns in physical capital. On the other hand, as expected due to environmental externalities, the optimal levels of the main variables are reduced when the optimization problem of the social planner is taken into account. This result may be achieved by imposing environmental taxes or introducing

abatement activities that diverge resources from capital formation or consumption. The achieved steady state levels are reduced compared to the competitive equilibrium, due to the internalization of environmental externalities by the social planner. However, also in this case, the growth rates are not affected by environmental concerns, since these rates are determined exogenously.

- **Endogenous growth models**

Endogenous growth theory defines capital in the broad sense to include human capital and therefore constant returns are achieved. Moreover, if the occurrence of diminishing returns in the abatement sector is prevented, it is possible to have sustained growth without pollution accummulation. The fundamental factor that leads to growth is the accumulation of knowledge which is considered a public good while technological progress is endogenous, and driven by investment in R&D, in expectation of future monopolistic profits. Therefore, in the framework of endogenous growth models with an environmental dimension, growth rates can be affected by government policies that internalize the negative externalities linked with pollution and positive externalities associated with the knowledge accumulation and human capital.

These policies include public expenditure in education, R&D and health, environmental taxes, maintenance of public order, as well as regulations of international trade and environmental protection. Environmental policies can be distinguished between market-based instruments and regulatory instruments. Bithas (2011) emphasized the need to combine both types of instruments to ensure sustainability, since in order to satisfy the necessary and sufficient conditions for it, the intertemporal externalities should be internalized alongside the interspatial externalities. In particular, conventional environmental policy instruments can

ensure the environmental welfare of current generations and achieve allocative efficiency under existing economic and social conditions (Bithas, 2006). Nevertheless, command and control instruments, suitably designed to reflect absolute ecological targets which respect the environmental rights of future generations, could complement payment rules and provide the sufficient conditions for sustainability.

2.1.2. Empirical evidence

2.1.2.1. The Environmental Kuznets Curve

A thorough examination of the growth models sketched in the previous section suggests that, at least from a theoretical point of view, there are important interrelationships between economic growth and the environment while the exact magnitude and sign of this relationship depends on several factors. As Xepapadeas (2005) points out, growth theory provides indeterminate evidence regarding this relationship. First, if disutility from environmental degradation is not considered, environmental quality might degrade with economic growth. On the other hand, if externalities of pollution are taken into account, environmental concerns might limit growth if the productivity of capital in production and pollution abatement tends to zero as capital accumulates. Finally, sustained growth could be associated with stable pollution in the presence of non-diminishing returns in abatement processes or output production. Nevertheless, it is important to explore which of these mechanisms are confirmed by empirical evidence. Thus, a great deal of empirical work, sought to test the relationship between per capita income and the environment, was undertaken during the 1990s and still consists an active research field of Environmental Economics.

Much of the studies that explore the relationship between economic growth and environmental degradation test the hypothesis of the existence of the Environmental Kuznets Curve (EKC). This terminology is related to the work of Kuznets (1955) who hypothesized an inverted-U shape relationship between an indicator of income inequality and the level of economic growth. The EKC hypothesis posits that during the early stages of economic development environmental degradation increases, until a threshold level of income is reached and thereafter improvements in environmental quality are achieved. This relationship is depicted in Figure 2.2.

Figure 2.2. Stylized Environmental Kuznets Curve
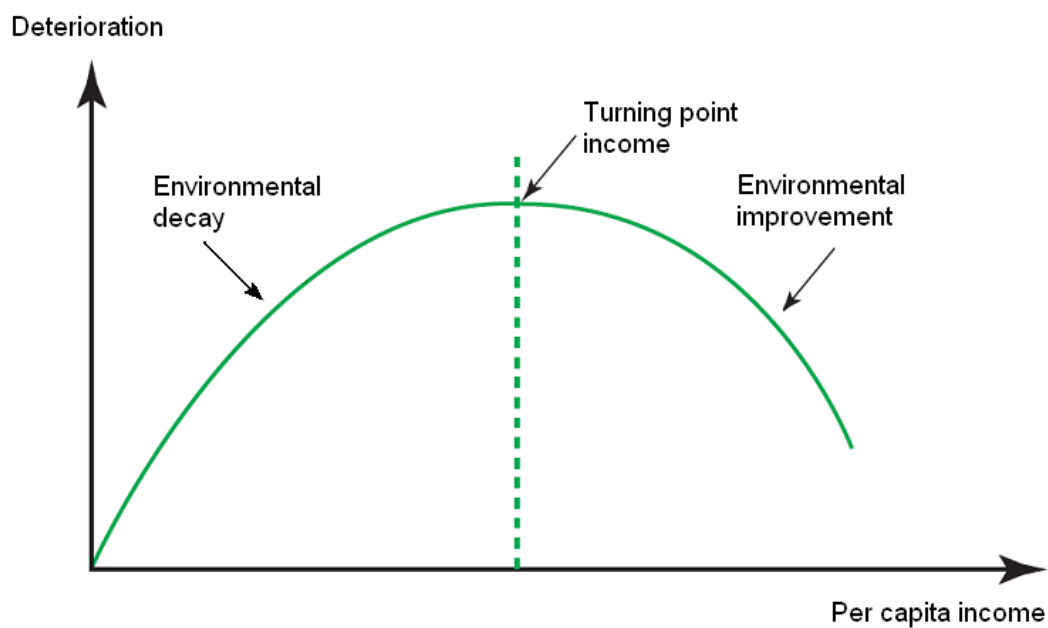
Source: Modified from Halkos (2013b).

2.1.2.2 Rationale for the existence of an EKC

According to the literature which identifies several factors that lead to the existence of the EKC, the main determinants of the growth-pollution relationship may be categorized as follows (Halkos, 2013b; Panayotou, 2003; Alstine and Neumayer, 2010; Stern, 2014):

- **Scale effect**

The expansion of production, ceteris paribus, i.e. with the mix of products produced, the mix of production inputs used, and the state of technology all held constant, increases environmental pressures and is associated with deterioration of environmental quality (Panayotou, 1993, 1997).

- **Composition effect**

During the course of economic development the output mix of the economy changes (Janicke et al., 1997; Copeland and Taylor, 2004). In particular, at the early stages of economic development as the rural sector contributes the larger percentage of GDP, environmental pollution is minimum. However, as the economy develops and the role of industries becomes more important, environmental pressures progressively increase. This pollution intensity is eventually relieved as the economy further grows and relies more on the service sector.

- **Technique effect**

The technique effect is associated with three distinct mechanisms that may reduce environmental pressures, depending on the elasticity of substitution in production (Lopez, 1994; Grossman and Krueger, 1995; de Bruyn and Opschoor, 1997; Han and Chatterjee, 1997). Firstly, it involves the modification of inputs mix employed in production, in such a way as to substitute pollution intensive factors with other which are environmentally

friendlier. Moreover, as an economy grows, its capabilities in supporting R&D expenditure increase, eventually leading to improvements in the state of technology. Thereafter, these improvements lead to the introduction and diffusion of cleaner technologies, which may substitute older ones that were more pollution intensive. Finally, new technologies enhance the productivity of physical capital and therefore limit the use of pollution intensive inputs per unit of output.

- **Demand for environmental quality**

As income increases, demand for environmental quality also rises, implying that environmental quality is a normal good, i.e. its income elasticity is positive (Beckerman, 1992). In developing countries, demand for environmental quality is rather small but, as the economy grows, environmental concerns rise and demand for enhanced environmental quality shifts out. This effect is also related with the Frisch coefficient of preferences which reflects how the value of goods declines with income, in particular how the marginal utility of income declines with income (Lopez, 1994).

- **International trade**

Many studies have shown that the existence of the EKC may reflect the changing scale, composition and technique patterns that are associated with liberalized trade and economic growth (Alstine and Neumayer, 2010; Grossman et al., 1993, 1995; Heil and Selden, 2001; Suri and Chapman, 1998). According to Halkos (2013a) the environmental effect of trade liberalization may be decomposed into three distinct effects. First of all, environmental degradation may increase through the scale effect due to the increased volume of international trade (scale effect). On the other hand, international trade is associated with implementation of stricter environmental regulations, which promote technological advances

that reduce pollution levels (technique effect). Finally, the composition effect may increase pollution in developing countries by encouraging the establishment of new industries which are more pollution intensive, particularly in view of the lower environmental standards of these countries (*displacement hypothesis*[15]). Furthermore, the *pollution haven hypothesis* may explain the establishment of more pollution intensive industries in developing countries, where there are less stringent environmental regulations and there is a comparative advantage in the production of pollution-intensive goods in relation to developed countries (Dinda, 2004; Cole, 2004).

- **Population growth**

Higher income causes a reduction in the population growth rate, consequently alleviating population pressures on environmental pollution, since in general a larger population is associated with more pollutant emissions (UNDP, 1999; Zhu and Peng, 2012).

2.1.2.3 Empirical evidence for the existence of an EKC

The empirical analysis of the EKC has focused on whether a given measure of environmental degradation shows an inverted-U-shaped relationship with income per capita[16]. Consequently, the 'turning point' can be calculated by the level of per capita income at which the EKC peaks. Grossman and Krueger (1993) were the first to conduct an EKC study. In particular, using the Global Environmental Monitoring System[17] (GEMS) dataset for 52 cities in 32 countries in the period 1977–88, they estimated EKCs for SO_2 and suspended particles. In each regression, they employed a cubic specification of the level of PPP adjusted per

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[15] For example, see Tobey (1990) and Rock (1996).

[16] It should be mentioned that several studies have extended this hypothesis and explored the existence of cubic specifications of the economic growth – environment relationship. For example, see Shafik and Bandyopadhyay (1992), Zarzoso and Morancho (2003), Binder and Neumayer (2005) and Halkos (2013a). Also see Bella et al. (2014) and Yang et al. (2015) for more recent and sophisticated approaches regarding the estimation of the relationship between CO_2 emissions and economic growth.

[17] This dataset is a panel of ambient measurements from a number of locations in cities around the world.

capita GDP and controlled for various site-related variables and a time trend. The turning points for SO_2 and dark matter were estimated between $4,000-5,000, while the concentration of suspended particles appeared to decline even at lower income levels. During the first decade after the aforementioned work, a growing body of literature focused on empirically testing the EKC hypothesis and confirmed turning points in the range of $3,000-23,000[18] (Selden and Song, 1994; Cole et al., 1997; Torras and Boyce, 1998; Kaufmann et al., 1997; List and Galett, 1999).

A recurring pattern in the literature, is that an EKC exists for pollutants with semi-local and medium-term impacts (Shafik, 1994; Arrow et al., 1995; Cole et al., 1997; Ansuategi et al., 1998; Halkos, 2003). On the other hand, for some aspects of the environment, no turning point is confirmed. These aspects include CO_2 emissions (Shafik, 1994; Holtz-Eakin and Selden, 1995), direct material flows (Seppala et al., 2001) and biodiversity loss (Asafu-Adjaye, 2003[19]). One plausible explanation of this finding is that an EKC holds for those measures of environmental pollution that have significant implications on human health and/or may not be easily externalized; these tend to improve already at low levels of income. On the other hand, those indicators that have the characteristics of global public goods and are relatively easier to externalize onto others tend to deteriorate with economic growth since they have historically not been subject to particular regulation (Alstine and Neumayer, 2010).

In a related common finding, the turning points for emissions of each pollutant are reported to be higher than that for its ambient concentrations, ceteris paribus (Selden and Song, 1994). According to Stern (2014), a plausible explanation for this finding is that in the initial stages of economic development urban and industrial development tends to concentrate more in a smaller number of cities, which also have rising population densities, while the opposite is

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[18] For a comprehensive review see Stern, 2014.
[19] For contrary evidence see Perrings and Halkos (2012).

happening during the later stages of economic growth. Therefore, it is not unlikely to observe declining pollution concentrations as income rises, even if total national emissions continue to increase (Stern *et al.*, 1996). However, it should be mentioned that to find a causal relationship between environmental damage and economic activity, ambient concentrations do not provide the most proper indicator of environmental impact (Halkos and Tsionas, 2001). Moreover, the use of emission indicators avoids dependence of the estimated results on geographic location characteristics and atmospheric conditions.

Despite the overwhelming presence of empirical studies on the existence of the EKC, there are a growing number of studies that have suggested that several other factors must be taken into account before drawing robust conclusions. Halkos and Tsionas (2001) argued that the EKC hypothesis may be a function of income and employed regime switching models on a cross-section of developing and developed countries, explicitly taking into account the presence of non-linearities. Their results suggested that there is an increasing relationship between two pollution indicators (CO2 and deforestation) and income.

Stern and Common (2001) pointed out that estimates of the EKC for sulphur emissions are very sensitive to the choice of sample used in the analysis. In particular, they found that SO_2 emissions per capita were a monotonic function of income per capita when they used a global sample and an inverted U-shape function of income in a sample of OECD countries only. Halkos (2003) highlighted the existence of dynamics in the examined relationships and proposed the use of dynamic econometric methods. In particular, using the same database as Stern and Common (2001), but employing a dynamic model formulation, he found much lower turning points, well within the sample levels of income, in the range of $2,805–$6,230 and confirmed existence of inverted U-shape curves. The differences in the extracted relationships between these studies, as well as the differences in the estimated turning points

may be, solely, attributed to the econometric models' functional form used and the adoption of static or dynamic analysis.

Related to the aforementioned issues, if the environmental indicator used in the analysis and GDP are non-stationary, i.e. they show a common trend over time, then spurious regression results may be reported. Tests for integrated variables designed for use with panel data find that sulphur and carbon emissions and GDP per capita are integrated variables (Stern, 2014). Therefore regression estimates by using time series or panel data are reliable only if the regression exhibits co-integration, i.e. there is a long-term relationship between the models variables. Otherwise, the model must be estimated by the use of alternative approaches such as first differences or the between estimator, which first averages the data over time (Stern, 2010). According to Alstine and Neumayer (2010), only a small number of studies have addressed this potential problem properly (for example, Galeotti, Manera, and Lanza, 2006; Perman and Stern, 2003; Wagner and Müller-Fürstenberger, 2005).

Finally, several other determinants of environmental quality have been incorporated in the EKC empirical specifications, in order to avoid potential omitted variable bias that could influence the relationship between economic growth and the environment. These additional determinants comprise variables such as measures of institutional quality and political freedom (Torras and Boyce, 1998), corruption (Welsch, 2004; Cole, 2007), openness to international trade (Suri and Chapman, 1998; Cole, 2004), structure of GDP (Panayotou, 1997) and population growth (Zhu and Peng, 2012).

2.1.2.4 Policy implications from the EKC literature

Acceptance of an EKC hypothesis implies that there is an inevitable level of environmental degradation that accompanies a country's early development stage but with a significant improvement at a later stage of this country's economic growth (Halkos, 2003). However, a fundamental issue that has to be addressed is whether the EKC relationship is quasi-automatic or policy induced (Alstine and Neumayer, 2010; Grossman et al., 1995). A part of the steepness of the inverted U-shaped relationship between economic growth and pollution could be attributed to policy distortions in the form of under-pricing of natural resources and subsidies to energy and agrochemicals, which are destructive both in terms of economic efficiency and environmental perspectives (Halkos 2013a). Governments can flatten out their EKC by confining policy distortions that lead to market failures, reinforcing the establishment of property rights over natural resources and in general, opt to internalize environmental externalities to the sources that generate them by enforcing stricter environmental regulations (Panayotou, 1993). Regulatory institutions, normative institutions, and the beliefs and values that are imposed on, or internalized by, social actors may also determine corporate decisions' and shape corporate social responsibility through the legal requirements that are imposed on business (Skouloudis and Evangelinos, 2012). Related to this, Jones et.al (2010, 2012) stressed the need to increase environmental education, the requirement to create social networks in order to promote information spillovers and the importance of increasing citizens' participation during the decision-making phase of environmental policy. These factors may further alleviate environmental degradation by increasing citizens' environmental awareness and willingness to pay for environmental quality improvements (Halkos and Matsiori, 2012, 2014). Figure 2.3 is a schematic illustration of these policy implications.

Considering developing countries, if the technique effect is emphasized through policy, then these countries may be able to ease their way through the EKC, as abatement already exist. Therefore, there is a need for technology transfer and abatement assistance to developing countries to achieve sustainability, since production methods in developed countries are relatively less pollution intensive. Finally, the finding that the EKC increases monotonically for pollutants with more global externalities highlights the need for the establishment of international environmental treaties and cooperation, which will aid the internalization of such externalities.

Figure 2.3. The EKC under different policy and institutional scenarios
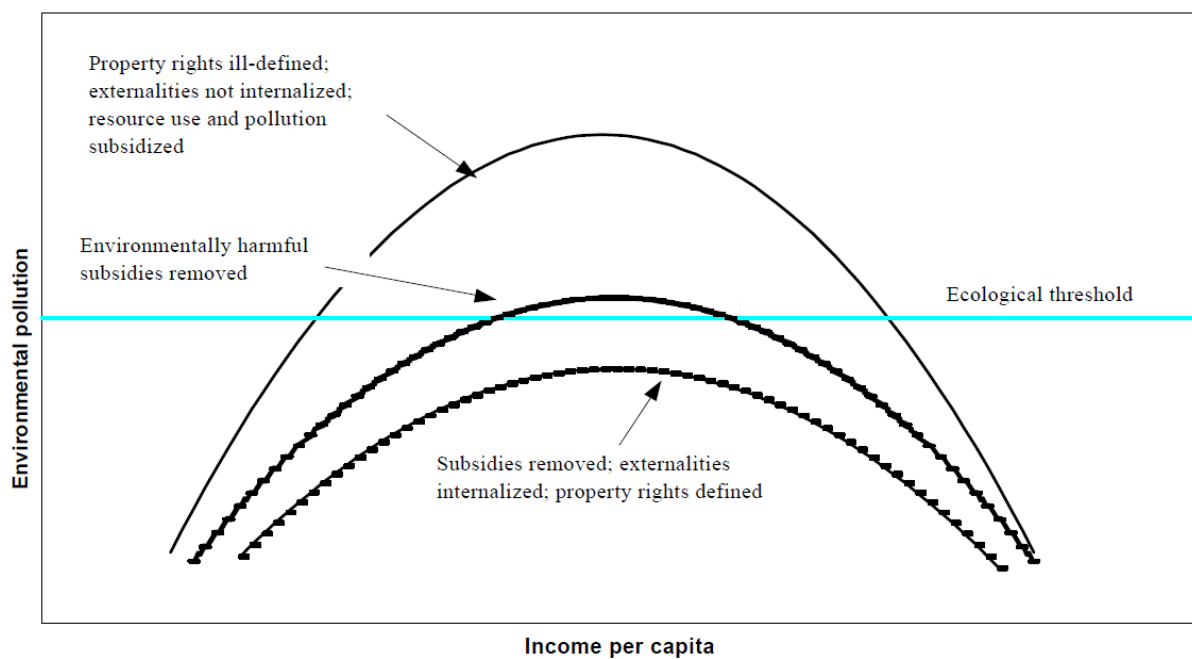
Source: Panayotou (1997-p6).

2.2. Fiscal policy and the environment

As already mentioned, economic theory identifies three main factors which are important for production and to promote economic growth sustainability, namely, physical capital, human capital and natural capital. Physical capital accumulation leads to economic growth and eventually enhances welfare. On the other hand, accumulation of human and natural capital not only contributes to growth by boosting total factor productivity and increasing investment returns, but these forms also consist direct components of welfare (Lopez et al. 2010).

Natural capital, which comprises natural resources and environmental quality, is considered a public good, since it is characterized by significant externalities. Inadequacy to internalize such externalities due to market failures, systematically leads to overexploitation of natural capital and degradation of environmental quality. Moreover, considering human capital, there are limited incentives for the private sector and often for the public sector to invest on that, since returns of investments on education, knowledge and health require several years to materialize. This inherent gap in the optimum accumulation of human and natural capital may ultimately imperil the sustainability of long-term growth. As discussed in the previous sections, when considering public goods and in the presence of externalities, there is a significant role for government policies and intervention.

2.2.1. The important role of fiscal policy on the environment

An important tool through which governments can alleviate the negative consequences of market failures and contribute to growth sustainability is the implementation of fiscal policy,

especially taking into account that government expenditures often account for more than 30 percent of GDP.

According to Lopez et al. (2010), there are three reasons that render fiscal policy crucial in this framework. First, fiscal policy may determine the allocation of resources to human capital, physical capital and natural capital in an optimum way by creating appropriate incentives through expenditure and tax policies. Second, implementation of fiscal policy can generate macroeconomic expansions and contractions and determine intergenerational transfers through debt, social security, taxation on the use of natural resources and pollution and finally, by expenditures on mitigation and adaptation strategies. Third, there is also the possibility that fiscal policy may harm environmental quality. For example, government may succumb to lobbies and interest groups and offer subsidies and tax exemptions and thus, encourage resource extraction, depletion, and generation of emissions that contribute to the deterioration of environmental quality. This highlights the requirement for high institutional quality and political freedom that can promote good governance and help avoid bad practices.

Furthermore, five more ways through which fiscal policy can affect environmental quality may be additionally identified. First, as the size of government increases as a percentage of GDP, progressively the structure of production in the economy changes in favour of the service sector, which is less pollution intensive compared to the industrial and rural sectors. Second, government spending on public order and safety reinforces the protection of property rights which may in turn alleviate environmental externalities such as the overexploitation of natural resources and assist the enforcement of environmental regulations. Third, public spending in education and health can increase public awareness regarding the adverse effects of environmental pollution and therefore increase demand for improved environmental

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quality. Moreover, a greater educational level may also contribute to the control of population growth rate that can reduce environmental pressures. Moreover, if the environment is considered a luxury public good, it is likely that it will only be demanded when the demand for other public goods has been satisfied, i.e. at large levels of government size (Frederik and Lundström, 2001). Finally, investment in infrastructure, such as the public transportation system, can reduce environmental degradation by encouraging more environmental cleaner methods of production and consumer behaviour.

In addition, it is important to mention that each one of the above ways through which fiscal policy may affect environmental degradation, may also interact with economic growth and therefore can influence environmental quality indirectly through this channel. These interrelationships are depicted in Figure 2.4.

Figure 2.4. Framework for sustainable growth
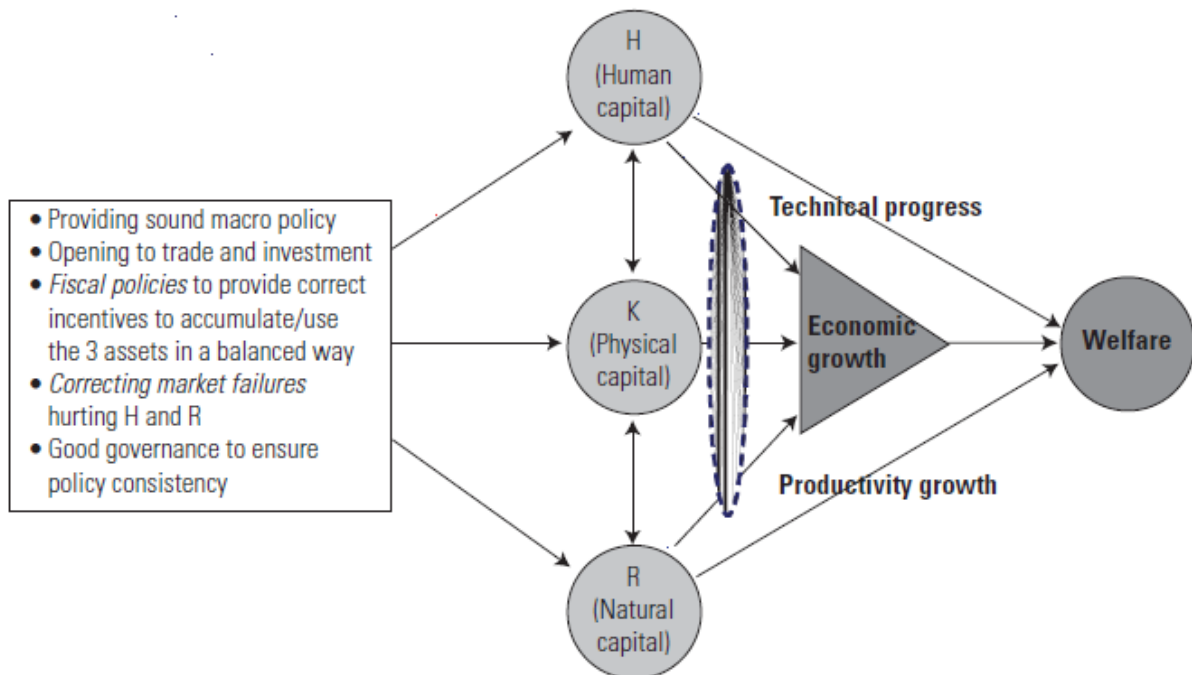
Source: Lopez et al. (2010-p8, originally from Thomas et al., 2000).

2.2.2. Decomposing the effect of government expenditure on pollution

Despite the potentially significant implications of fiscal spending on environmental pollution, it is surprising that this relationship was not considered in the literature and only recently theoretical and empirical studies have systematically started to explore it. A comprehensive review of the related theoretical works and empirical evidence in the literature is presented in the respective sections of Chapters 3-5 of this dissertation.

It is important however to mention at this point, that the mechanism through which government expenditure may affect environmental degradation is expected to differ, according to the generating source of the pollutants and in particular whether they are production or consumption generated. These differences are important since they can influence the magnitude and the significance of the estimated effect of government expenditure on different indicators of pollution. The theoretical underpinnings of this relationship are hereby sketched, based on the models proposed by Lopez et al. (2011) and Galinato and Islam (2014). Both these studies focused on the effect of the composition of government expenditure, i.e. of the share of public goods in total government expenditure, on the environment. In their research, public goods are defined broadly to include expenditures that complement rather than substitute for production in the private economy and comprise such functional categories of expenditure as spending on education, health, social security, transport, communication, public order and safety, housing and community amenities, environmental protection and finally, spending on religion and culture.

Effect on production-generated pollution

Lopez et al. (2011), using the terminology employed to decompose the effect of international trade on environmental quality, suggest four main mechanisms through which government expenditure can affect environmental pollution, as follows:

- **Scale effect**

Depending on the relationship between fiscal spending and economic growth, increased government spending may amplify or reduce environmental pressures.

- **Composition effect**

Government expenditure may favor human capital intensive instead of physical capital intensive activities which are more pollution-generating inputs, and therefore is likely to improve environmental quality by modifying the output mix of the economy.

- **Technique effect**

Government expenditure in education and health encourages the accumulation of human capital and is associated with greater labor efficiency. To the extent that human capital and physical capital are substitutes in production, it is likely that a greater provision of human capital would encourage more environmentally friendly production and therefore reduce the pollution per unit of output. Furthermore, government spending in R&D may further enhance knowledge diffusion and lead to the adoption of cleaner technologies.

- **Income effect**

Depending on the relationship between fiscal spending and economic growth, expenditures on public goods can also induce an income effect, according to which increased income

raises the demand for improved environmental quality and thus more environmental regulation, which consequently may reduce pollution.

The analysis of Lopez et al. (2011) suggests that the effect of government expenditure on environmental pollution, ceteris paribus, is strictly non-positive when a) there is a larger output elasticity of public goods in the non-polluting sector compared to the polluting sector and b) the marginal utility of consumption is elastic[20]. Moreover, if both the above mentioned assumptions hold, a shift in fiscal spending from private subsidies to public goods is expected to cause a reduction in production-generated pollution.

Effect on consumption-generated pollution

Galinato and Islam (2014) recognized that the mechanism that connects consumption-generated pollution and government expenditure must consider the ways that government spending affects consumers' budget, income and prices. In particular, they suggested that government expenditure might affect consumption-generated pollution through the following two channels:

- **Scale effect[21]**

Fiscal spending on sectors like health and education increases the current and future income of households and may in turn lead to an increase of consumption pollution.

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[20] The assumption that the elasticity of consumption is greater than 1 is supported by several studies. For example, see Evans (2005).

[21] It should be noted that Galinato and Islam (2014) define this effect as *income effect*; however we refrain using this definition here, in order to avoid confusion with the income effect on production-generated pollution which tends to reduce environmental pollution. For a similar approach see Islam and Lopez (2015).

- **Regulations effect[22]**

Government expenditure encourages the development of institutions and therefore the establishment and enforcement of environmental regulations which enhance environmental quality (Fullerton and Kim 2008). For example, such a regulation is the introduction of a pollution tax which changes the output price of a good.

Other relevant channels

Furthermore, the following two mechanisms are expected to be significant in both production- and consumption-generated pollution and interact with the effect of government expenditure on environmental quality:

- **Governance quality**

Galinato and Islam (2014) emphasize the importance of governance quality in this framework. In particular, they suggest that in democratic regimes, where it is more likely to adopt stricter environmental instruments compared to non-democratic administrations, the effect of environmental regulations has been found to dominate that of the scale effect and therefore lead to a reduction of consumption pollution. Likewise, it is expected that enhanced institutional quality may reinforce also the alleviating effect of government expenditure on production-related pollution.

- **Special interest groups**

Special interest groups that support a large government in order to gain private benefits can lead to environmental degradation, particularly if the dominant special interest groups are not promoters of environmental quality and influence the strictness of environmental regulation

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[22] This effect is also relevant in production-generated pollution, however its importance is expected to be greater in consumption-related pollution.

the government imposes (Mueller and Murrell 1986; Bernauer and Koubi, 2013; Galinato and Islam, 2014). In a related study, Bernauer and Koubi (2009) reported that labour union strength is negatively associated with air pollution, a finding that is consistent with this interpretation. The greater the strength of interest groups that tend to lose from stricter environmental policies, the higher the environmental degradation is likely to be (Bernauer and Koubi, 2009). This mechanism may influence the effect of government expenditure on pollution since the existence of such groups is associated with greater government size as pointed out by Mueller and Murrell (1986) and Sobel (2001).

Chapter 3

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

3.1. Introduction

Government expenditure has recently expanded in many countries to alleviate the adverse effects of the 2008-2009 economic crisis. A large fraction of GDP is spent by governments affecting a variety of economic variables and prosperity in particular. Recent studies suggest that government expenditure is an important determinant of environmental quality (Frederik and Lundstrom, 2001; Lopez et al., 2011; Bernauer and Koubi, 2013). The mechanisms through which prosperity, government expenditure and the environment interact with each other are investigated in theoretical papers by Heyes (2000), Lawn (2003) and Sim (2006). However, despite the important influence that public spending may have on the environment, this relationship has not been studied extensively in the literature.

The effect of government spending on the environment may be distinguished between direct and indirect effects. On the one hand, higher government expenditure is more likely to include redistributive transfers, which result to increased income equality and thus to higher demand for environmental quality. Moreover, if the environment is a luxury public good, it is likely that it will only be demanded when the demand for other public goods has been

satisfied, i.e. at large levels of government size (Frederik and Lundstrom, 2001). In a related study, Lopez et al. (2011) identify four mechanisms by which the level and composition of fiscal spending may affect pollution levels[23], 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. Further to the aforementioned mechanisms, a greater government size may also deteriorate environmental quality by basing its policy on the accommodation of the interests of certain groups that support the government but may not want to promote environmental quality. These groups are associated with greater government size (Mueller and Muller, 1986; Sobel, 2001) and influence the strictness of environmental regulation the government imposes (Bernauer and Koubi, 2013; Galinato and Islam, 2014).

On the other hand, government size has been found to reduce prosperity (Bajo-Rubio, 2000; Folster and Henrekson, 2001; Bergh and Karlsson, 2010), which may in turn lead to lower pollution at some levels and to higher pollution at others, depending on the shape of the Environmental Kuznets Curve (EKC), as shown by Grossman and Krueger (1995). Therefore, the total effect of government expenditure on the environment cannot be determined a priori.

Given this background and following a similar empirical strategy to that used by Welsch (2004) and Cole (2007)[24], the purpose of this research is to first investigate how government expenditure affects pollution at given income levels and other control variables, in particular to estimate a direct effect that mainly captures the composition effect and part of the

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[23] In particular, they examined the effect of the share of public goods in total government expenditure.
[24] In particular, they examined the effect of corruption on pollution, also distinguishing between direct and indirect effects.

technique effect as described in the Methodology section of this chapter; and then to examine the effect of government expenditure on the environment through the government expenditure impact on income (indirect effect) and to add the indirect effect to the direct effect to obtain the total effect.

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, 2010). In addition, the share of government expenditure dedicated to productivity increase in 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) found that government size correlates negatively with growth. At the same time, 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).

The estimated sign of the direct effect of government size on pollution is ambiguous in the empirical literature. Frederik and Lundstrom (2001) investigate the effect of political and economic freedom on the level of CO_2 emissions and find that the effect of government size on levels of pollution differs according to the initial size of government. They suggest that 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 (2013) an increase in 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.

Lopez et al. (2011) provided a theoretical basis for determining the effect of government expenditure on pollution. Specifically, they stressed the importance and estimated empirically the effect of fiscal spending composition on the environment. They argued that a reallocation of government spending composition towards social and public goods reduces pollution. Moreover, they found that increasing total government size, without changing its orientation, has a non-positive impact on environmental degradation. However, in a related study, Lopez and Palacios (2010, 2014) examined the role of government expenditure and environmental taxes on environmental quality in Europe and reported total government expenditure as a negative and significant determinant of air pollution, even after controlling for the composition of public expenditure.

The present study is the first that distinguishes between the direct and indirect effects of fiscal spending on the environment. For that reason, a two-equation model is jointly estimated, employing a sample of 77 countries covering the period 1980-2000 for two air pollutants (sulfur dioxide, SO_2 and carbon dioxide, CO_2). In estimating the proposed model the dynamic nature of the relationships examined is taken into account, by employing appropriate econometric methods for the estimation of dynamic panels, for the first time in this area of research. Furthermore, appropriate GMM estimation methods are used to mitigate potential reverse causality biases of the explanatory variables.

The remainder of this chapter is organized as follows: Section 3.2 presents the data used in the analysis and section 3.3 discusses the proposed econometric methods. The empirical results are reported in section 3.4 while the final section concludes the study.

3.2. Data

The sample used consists of 77 countries[25] with a full set of SO_2 and CO_2 emissions, share of government consumption over GDP, GDP/c and other explanatory variables information for the period 1980-2000. The analysis takes place up to the year 2000 because of limited availability of data on SO_2 after this period[26]. Consequently, for reasons of comparability the analysis for CO_2 is performed for the same time period. The database consists of 1,617 observations per variable[27].

The share of government spending variable used here is the general government consumption component of GDP, from the Penn World Table, and does not include public investment, interest payments, subsidies and other transfers. Ideally, it is preferable to have a measure of general government spending for all types of government expenditure; however there is paucity of related data for all the countries and time periods in the world sample used in this analysis. However, as pointed out by Angelopoulos et al. (2008) a large part of the spending included in the government consumptions share, has investment features such as health and education services, as well as spending on police and the judiciary system. Finally, it should be mentioned that public investment is included in the investment share in GDP, which is used as a control variable in the model.

To avoid dependence of results on geographic location characteristics and atmospheric conditions, emissions of the two pollutants were used rather than their concentrations. An

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[25]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

[26] SO_2 data are from the commonly used dataset provided by Stern (2005, 2006).

[27] Table A1 of the Appendix provides data sources and descriptions for all variables.

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 SO_2 moves away from the atmosphere within 10 days after its emission, its impact is mainly local or regional and thus, historically, sulfur dioxide has been subject to regulation. In contrast, CO_2 has not been regulated by governments, since its atmospheric life varies from 50 to 200 years and hence its impact is global.

The sources of pollution vary by pollutant. The main sources of SO_2 emissions are electricity generation and industrial processes. On the other hand, apart from energy transformation and industry, an important source of CO_2 emissions is transport. Apparently SO_2 pollution is characterized as production-generated, while CO_2 emissions are a mix between production and consumption–generated pollution. This distinction is important since the mechanism by which government expenditure size affects consumption pollution is likely to differ compared to production pollution. SO_2 emissions can be decreased by reducing consumption of fossil fuels (especially high-sulfur content coal), by using smoke-scrubbing equipment in power plants and by increasing energy efficiency. However, in consumption related pollutants the use and influence of environmental policies is more difficult, since the main tool to reduce them is the implementation of environmental taxes, which are often avoided as they are not politically popular.

3.3 Methodology

The proposed model consists of two equations jointly estimated, one being a conventional cubic formulation of the EKC augmented by the share of government expenditure over income and the second expressing income as a function of government expenditure and other factors. Specifically,

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

$$\ln(GDP/c)_{it} = \gamma_i + \delta_t + \alpha_1 \ln Govshare_{it} + a_2 \ln Z_{it} + u_{it} \qquad (2)$$

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

The income variable and its powers in Eq. (1) control for scale effects. To control for the income effect the household final consumption expenditure is used, while total investment is used as a proxy for capital stock. Institutional factors reflecting pollution regulation are taken into account by using a measure of democracy level, however this proxy is imperfect and thus, the government variable also captures some of the unobserved environmental regulations effect. In addition, the share of trade over GDP is used to examine whether involvement in international trade affects pollutants, while the population density captures part of the scale effect. Finally, μ_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. Thus, following the terminology used to classify the pollution effects in the trade literature, the coefficient on the government expenditure variable mainly captures the composition effect and part of the technique effect.

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

3.3.1 Econometric issues and estimation

In estimating Eqs. (1) and (2) the unobserved heterogeneity across countries must be taken into account. The standard approach is to use fixed (hereafter FE) and random effects (hereafter RE) model formulations with the choice depending on the assumption adopted about the correlation between the cross-section specific error-component and the explanatory variables. When such correlation is present, then RE estimators are not consistent and efficient and the use of FE is more appropriate. For instance, in the pollutants equations these country-specific characteristics may include differences in climate, geography and fossil fuels endowments, all of them potentially correlated with emissions (Leitao, 2010). Additionally, it is very likely that country unobserved characteristics are correlated with income and the other explanatory variables, implying that FE estimation is preferred. This assumption is supported by the use of Hausman test, in which the RE model was rejected in favor of the FE model, for both Eqs. (1) and (2).

Since the balanced panel data used in this research consists of large N and T dimensions, non-stationarity is important. Of particular concern is the dynamic misspecification of the pollutants equations as pointed-out by Halkos (2003). If a static model is used, then all adjustments to any shock occur within the same time period with the shock, however this could be justified only in equilibrium or if the adjustment mechanism is rapid. According to Perman and Stern (1999) this is extremely unlikely and instead it is expected that the return to long-run equilibrium emission levels is a rather slow process.

To estimate a non-stationary dynamic panel the dynamic fixed effects (DFE) estimator developed by Pesaran and Smith (1995) and Pesaran et al. (1997, 2004) is employed. In DFE estimation the intercepts differ across countries but the long-run coefficients and the adjustment process are assumed to be equal. However, if equality of the slope coefficients

does not hold in practice, this technique yields inconsistent estimators. This assumption is tested using a Hausman test.

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

$$\ln(P/c)_{it} = \mu_i + \sum_{j=1}^{p} \lambda_{ij} \ln(P/c)_{i,t-j} + \sum_{j=0}^{q} \beta_{ij}' K_{i,t-j} + \varepsilon_{it} \tag{3}$$

where number of countries $i = 1, 2, \ldots, N$; number of periods $t = 1, 2, \ldots, T$, for sufficiently large T; K_{it} a $k \times 1$ vector of explanatory variables including government expenditure and income variables; and μ_i a country-specific effect, is set-up.

If the variables in Eq. (3) are integrated of order one, i.e they are I(1), and co-integrated, then the error term is an I(0) process for all i. A principle feature of co-integrated 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. The error correction equation is formed as:

$$\Delta \ln(P/c)_{it} = \phi_i [\ln(P/c)_{i,t-1} - \zeta_i' K_{it}] + \sum_{j=1}^{p-1} \lambda_{ij}^* \Delta \ln(P/c)_{i,t-1} + \sum_{j=0}^{q-1} \beta_{ij}'^* \Delta K_{i,t-j} + \mu_i + \varepsilon_{it} \tag{4}$$

where $\phi_i = -(1 - \sum_{j=1}^{p} \lambda_{ij}), \zeta_i = \sum_{j=0}^{q} \beta_{ij} / (1 - \sum_k \lambda_{ik}), \lambda_{ij}^* = -\sum_{m=j+1}^{p} \lambda_{im} \ \ j = 1, 2, \ldots, p-1$

and $\beta_{ij}^* = -\sum_{m=j+1}^{q} \beta_{im} \ \ j = 1, 2, \ldots, q-1$.

Nonlinearity in the parameters requires that the models are estimated using maximum likelihood.

Another econometric concern for Eqs. (1) and (2) is the bias occurring from the potential endogeneity between government spending with pollution and income, respectively.

Government spending often increases with pollution because governments implement ecological taxes and thus increase government revenues. Moreover, the exact relationship between government spending and income is an active research area but there is empirical and anecdotal evidence that governments alter the amount and composition of fiscal spending to deal with the effects of business cycles (Lane, 2003).

To address this reverse causality problem the Arellano-Bond (1998) Generalized Method of Moments (GMM) is used. GMM accounts for the inertia which is likely to exist in the determination of the dependent variables and mitigates potential reverse causality biases of the explanatory variables by using predetermined and exogenous variables as instruments in a systematic way. For both equations the assumption is made that the lagged dependent variables, as well as government expenditure and income are endogenous, while all the other explanatory variables are treated as strictly exogenous.

Moreover, an additional exogenous instrumental variable for Eq. (1) was used, namely the lagged weighted average of government expenditure in other countries, weighting by the inverse of the distance between the two countries. Since the emissions rather than concentrations of pollutants are used, the lagged weighted average government spending in other countries is not expected to affect directly emission levels in a given country, but only through its effect on that county's government expenditure and income.

In Eq. (2) the democracy level was also employed as an exogenous instrument[28]. There are many empirical studies suggesting a relationship between public expenditure and the level of democracy in a country. Boix (2003) suggested that the size 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

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[28] Exclusion of the additional instrumental variables, in both equations, did not alter the results in any significant way.

increasing spending on infrastructure and internal security. Martin and Plümper (2003) found a U-shaped relationship between the level of political participation and spending behavior of opportunistic governments. On the other hand, 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).

For both equations the validity of instruments is tested with the Hansen test[29], which failed to reject the null hypothesis that the instrumental variables are uncorrelated with the residuals. In addition, the Difference Hansen test for the exogenous Instrument Variable subset is also reported and does not reject the null that the subset is valid.

3.3.2 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:

$$\frac{d(P/c)}{dGovshare} = \frac{\partial(P/c)}{\partial Govshare} + \frac{\partial(P/c)}{\partial(GDP/c)}\frac{\partial(GDP/c)}{\partial Govshare} \qquad (5)$$

where the first expression is the direct effect and the latter is the indirect effect via the government expenditure impact on prosperity. It should be noted that while the direct effect remains constant throughout the whole income range, the indirect and hence the total effect depend on the level of per capita income, because of the inclusion of quadratic and cubic income terms in Eq. (1).

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[29] We report the Hansen test instead of the Sargan statistic since the latter is not robust and shows tendency to over-reject when heteroskedasticity and/or autocorellation are present in the model (Arellano and Bond, 1991).

3.4. Results

Table 1 presents the coefficient estimates of per capita income, by applying different estimation methods[30]. To account for autocorrelation and heteroskedasticity, all standard errors reported are robust and in particular for the FE estimation the Huber-White-Sandwich estimates of the variance-covariance matrix are reported. The estimated effect of the government expenditure share on GDP is negative and statistically significant at the 1% level, regardless of the method used.

The FE estimates are presented in the second column. The estimated coefficient of government expenditure is equal to -0.210, while the DFE estimate of government size effect on income is -0.872, suggesting that consideration of dynamics increases the estimated impact of government share on per capita income, even without accounting for endogeneity.

In the fourth column, applying the Arellano-Bond two-step[31] GMM estimator, dynamics are still taken into account, however the government share is treated as endogenous in this case. First-differences and orthogonal-deviations GMM were used to control for fixed country effects. The significance of the lagged dependent variable (p-value=0.000) suggested that dynamic specifications should be preferred. It should be noted that the assumption of uncorrelated u_{it} is important here, so tests for first- and second-order serial correlation related to the residuals from the estimated equation are reported in the fourth column. 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 that the

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[30] The variation of the number of observations across different methods is due to appropriate use of lagged variables and availability of data for all variables used.
[31] Since there is evidence of heteroskedasticity we apply the more appropriate two-step Arellano-Bond procedure.

assumption of serially uncorrelated errors is inappropriate at least for 1% and 5% significance levels.

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

Model	OLS	FE	DFE	GMM A-B
	(1)	(2)	(3)	(4)
Log government share	-0.198[***]	-0.210[***]	-0.872[***]	-1.809[***]
	(0.042)	(0.069)	(0.328)	
Log investment	0.688[***]	0.142[***]	0.430[*]	0.876[**]
	(0.039)	(0.038)	(0.227)	
Log school	0.830[***]	0.130	0.290	0.108
	(0.109)	(0.099)	(0.475)	
Population growth	-0.239[***]	-0.014[**]	-0.255[***]	-0.222[***]
	(0.036)	(0.006)	(0.077)	
Trade-openness	0.002[***]	0.003[***]	0.006[*]	0.022[***]
	(0.000)	(0.001)	(0.0035)	
Constant	3.383[***]	7.855[***]		
	(0.557)	(0.489)		
R^2	0.493	0.201		
F test	0.000	0.000		
Wald test				0.000
Hausman FE v. RE		0.000		
Hausman PMG v. DFE			1.000	
Hansen test				0.202
Hansen IV subset				0.743
A-B test of AR(1)				0.000
A-B test of AR(2)				0.092
Nobs/Countries/IVs	1,596	1,596/76	1,520/76	1,406/74/61

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

Long-run estimates, calculated by dividing each estimated short-run coefficient by one minus the coefficient of the lagged dependent variable are reported. To obtain robust standard errors, the Windmeijer's finite-sample correction for the two-step covariance matrix is used. 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 1.809%.

The signs and significance of the coefficients associated with the other control variables were all plausible and consistent with the literature, apart from the human capital proxy which although had the expected sign, is significant only in the OLS estimates. The impact of capital stock, represented by the share of investment in GDP, is positive and significant across all estimation methods. Population growth had a consistent negative and significant effect, while the trade-openness coefficient is also significant with an expected positive sign.

The Arellano-Bond estimates are considered as benchmarks here, therefore subsequent analysis and the estimation of the EKC equation is based on fitted values of real per capita income from the GMM estimation.

Before turning to the estimation of per capita pollution the time series properties of the main variables of the model should be examined. 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. Since the panel data set examined consists of both $N \to \infty$ and $T \to \infty$ dimensions, the tests of stationarity performed are based on the Fisher-type Phillips-Peron unit root test. This test allows heterogeneity of the autoregressive parameter and although in its general form does not control for cross-sectional dependence, it is more powerful than Levin et al. (2002) in that case[32]. Table 2 presents the results of the Phillips-Perron unit root tests on the variables of interest. There is evidence against stationarity in levels and in all cases the variables are I(1).

Furthermore, application of the DFE method requires that the variables in the model are co-integrated, implying that there is a long-run relationship among them. Table 3 presents the Pedroni and the Kao (Engle based) co-integration tests for the two pollutants equations. The

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[32] To mitigate the impact of cross-sectional dependence the mean of the series across panels is computed and then subtracted from the series (columns 2 and 4 in Table 2).

null hypothesis of no co-integration at the conventional statistical significance level of 0.05 is rejected in four of the seven cases for the SO_2 equation and in five cases for CO_2. 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 not-reject the null hypothesis (Pedroni, 2004), suggesting that evidence of co-integration is even stronger than that depicted in Table 3.

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
	(1)	(2)	(3)	(4)
$LogSO_2/c$	0.063	0.763	0.367	0.526
$\Delta(Log\ SO_2/c)$	0.000	0.000	0.000	0.000
$LogCO_2/c$	0.383	0.093	0.000	0.000
$\Delta(LogCO_2/c)$	0.000	0.000	0.000	0.000
LogGovernment share	0.821	0.511	0.464	0.527
Δ(LogGovernment share)	0.000	0.000	0.000	0.000
LogGDP/c	1.000	0.980	1.000	1.000
Δ(LogGDP/c)	0.000	0.000	0.000	0.000
LogTrade-openness	0.924	0.022	0.345	0.137
Δ(Log Trade-openness)	0.000	0.000	0.000	0.000
LogInvestment	0.986	0.063	0.466	0.797
Δ(Log Investment)	0.000	0.000	0.000	0.000
Loghousehold consumption	1.000	0.760	0.801	0.655
Δ(Log household consumption)	0.000	0.000	0.000	0.000
Democracy level	0.156	0.999	0.109	0.990
Δ(Democracy level)	0.000	0.000	0.000	0.000
Population Density	0.347	1.000	1.000	1.000
Δ(Population Density)	0.000	0.000	0.000	0.605

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.

Table 3: Pedroni residual cointegration test for the pollution equations

	SO_2/c		CO_2/c	
	Statistic	Probability	Statistic	Probability
Panel v-statistic	-5.110	1.000	4.228	0.000
Panel rho-statistic	8.904	1.000	9.360	1.000
Panel PP-statistic	-48.42	0.000	-17.72	0.000
Panel ADF-statistic	-9.604	0.000	-8.128	0.000
Group rho-statistic	12.82	1.000	13.31	1.000
Group PP-statistic	-54.63	0.000	-18.52	0.000
Group ADG-statistic	-8.973	0.000	-7.237	0.000
Kao-test (Engle-based)	-42.26	0.000	-39.25	0.000

Table 4a provides estimates of per capita pollution emissions utilizing the estimates from GMM in Eq. (2). In the model, as mentioned, according to the Hausman test FE were preferred to RE. Hence, for each pollutant FE and DFE estimates are reported. Based on FE estimates (columns 1 and 3) the government share of GDP has a negative and significant direct effect on SO2/c and an insignificant negative relationship with CO2/c.

Table 4a: Estimates of pollution emissions/c

	SO_2/c		CO_2/c	
	FE	DFE	FE	DFE
Log(government share)	-0.292**	-0.910***	-0.096	-0.256*
	(0.134)	(0.305)	(0.101)	(0.143)
LogGDPc	-50.49***	-36.51**	-18.23***	-13.17**
	(12.56)	(17.74)	(5.370)	(6.502)
$(LogGDPc)^2$	6.642***	5.136**	2.402***	1.792**
	(1.541)	(2.160)	(0.638)	(0.777)
$(LogGDPc)^3$	-0.283***	-0.231***	-0.099***	-0.075**
	(0.063)	(0.088)	(0.025)	(0.031)
Log(trade-openess)	-0.157***	-0.075	-0.104	-0.071
	(0.057)	(0.143)	(0.065)	(0.058)
Log(investment)	-0.064	0.175	0.100**	0.139**
	(0.060)	(0.127)	(0.048)	(0.056)
Log(household consumption)	-0.468	-1.313	-0.377	-0.479
	(0.340)	(0.823)	(0.264)	(0.348)
Democracy level	-0.007	0.001	0.001	0.005
	(0.005)	(0.010)	(0.004)	(0.005)
Population density	1.245	8.567**	6.285***	7.283***
	(2.069)	(3.521)	(1.265)	(1.453)
Constant	123.60***		44.22***	
	(33.59)		(14.41)	
Error correction term		-0.154***		-0.272***
		(0.033)		(0.035)
Turning Points	672/9,321	369/7,406	437/24,101	314/26,370
R^2	0.317		0.495	
F test	0.000		0.000	
Hausman FEv.RE	0.001		0.000	
Hausman MGv.PMG		1.000		0.851
Hausman PMGv.DFE		0.998		1.000
Nobs/Countries	1,480/74	1,406/74	1,480/74	1,406/74

Note: Robust standard errors in parentheses. 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. Comparing the MG and PMG estimators with the use of a Hausman test, the PMG estimator, the efficient estimator under the null hypothesis, is preferred and thus assuming long-run coefficients to be equal across panels is more appropriate in this panel. Furthermore, another application of the Hausman test suggested that the simultaneous equation bias between the error term and the lagged dependent variable is minimal in this panel and hence the use of the DFE model is most appropriate in this case. DFE estimates indicated that the government share of income possesses a negative relationship with SO_2/c and CO_2/c, which is significant at 1% and 10% levels, respectively.

Table 4b: Estimates of pollution emissions/c using GMM

	SO_2/c		CO_2/c	
	First-Differences	Orthogonal-Deviations	First-Differences	Orthogonal-Deviations
Log government share	-0.903[**]	-1.107[***]	0.193	0.005
LogGDPc	-114.27[**]	-127.83[**]	-50.13[***]	-44.97[**]
$(LogGDPc)^2$	14.86[***]	16.38[**]	6.266[***]	5.646[**]
$(LogGDPc)^3$	-0.627[***]	-0.686[**]	-0.253[***]	-0.229[**]
Log(trade-openess)	-0.074	-0.111	-0.082	-0.099
Log(investment)	0.067	0.111	0.087[**]	0.156[***]
Log(household consumption)	-0.760[***]	-0.556	-0.026	-0.301
Democracy level	-0.004	-0.005	0.001	0.002
Population density	4.545	0.693	4.935[*]	5.518[***]
Turning Points	742/9,799	944/8,691	898/16,481	880/15,678
Wald test	0.000	0.000	0.000	0.000
Hansen test	0.270	0.181	0.174	0.207
Hansen IV subset	0.173	0.042	0.086	0.080
A-B test of AR(1)	0.001	0.000	0.009	0.005
A-B test of AR(2)	0.331	0.325	0.357	0.328
Nobs/Countries/IVs	1,425/75/60	1,425/75/60	1,425/75/60	1,425/75/60

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

Finally, Table 4b reports GMM First-Difference and Orthogonal-Deviations estimates of the EKC equation. The estimated effect of government expenditure on the environment is similar in magnitude to the DFE estimates for both pollutants but is statistically significant only in the case of SO_2. Since GMM estimates take into account dynamics and mitigate reverse causality biases, in what follows first-differences GMM results are used as benchmark.

Both pollutants have a significant cubic relationship with per capita income in all estimates. Interestingly, taking into account endogeneity in the A-B GMM estimates produces turning points for CO_2 well within the sample. The household income effect is negative, although insignificant in all cases except for SO_2 in first-differences GMM. The share of investment is found to increase pollution, but the effect is significant only for CO_2. On the other hand, the coefficient of trade-openness is always negative, but mostly insignificant. Finally, the effect of population density is robustly positive, while the democracy is insignificant in all specifications.

Table 5 presents the direct, indirect and total effects of government expenditure on pollution based on the estimates in Tables 4a-4b. 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.

A negative direct effect of government share of income on pollution is estimated by all models, as already indicated in Tables 4a and 4b. Concentrating on GMM results, an increase of government expenditure by 1%, ceteris paribus, results in a 0.903% reduction of SO_2/c. However, the direct effect on CO_2 is insignificant. The indirect effects were statistically significant and negative at the median income level, leading to a negative total effect for both pollutants. The negative sign of the indirect effect occurs from the positive

relationship between income and pollution at the median income level. Explicitly, at the sample median level of income an increase in the government share of GDP leads to a reduction in income and as a result to a reduction in emissions. Additionally, the estimated indirect effects are notably larger than the direct effects.

Table 5: Impact of government spending on pollutants (elasticities)

Effects	SO$_2$/c			CO$_2$/c		
	FE	DFE	GMM (F-D)	FE	DFE	GMM (F-D)
Direct	-0.292**	-0.910***	-0.903**	-0.096	-0.256*	0.193
	(0.134)	(0.305)	(0.390)	(0.101)	(0.143)	(0.186)
Indirect	-2.063**	-1.462	-4.628**	-2.094**	-1.899*	-2.843**
	(1.027)	(1.356)	(2.048)	(0.984)	(1.012)	(1.211)
Total	-2.355	-2.372	-5.532	-2.094	-2.155	-2.843
Change of sign point	10,003	9,268	10,809	24,210	30,201	16,438

Note: Indirect and total effects are calculated at sample median level of per capita income ($4,669). Robust standard errors in parentheses. Standard errors of the indirect effect are estimated using the Delta method for estimating the variance of a non-linear function.
*Significant at 10%.
**Significant at 5%
***Significant at 1%.

Figures 1 and 2 present the direct, indirect and total effects of government share of income on emission levels against per capita income. For CO_2 the direct effect is insignificant and therefore not taken into account. The indirect effect increases with per capita income, since

$\dfrac{\partial (GDP/c)}{\partial (Govshare)} = $ -1.809 and $\dfrac{\partial (P/c)}{\partial (GDP/c)}$ falls from 1.27 to $-$ 7.17 for SO$_2$/c and from 0.22 to -

1.39 for CO_2/c throughout the sample income range. These patterns largely depend on the relationship between pollution and income levels described by the EKC.

Figure 1: The effect of government share on SO_2/c
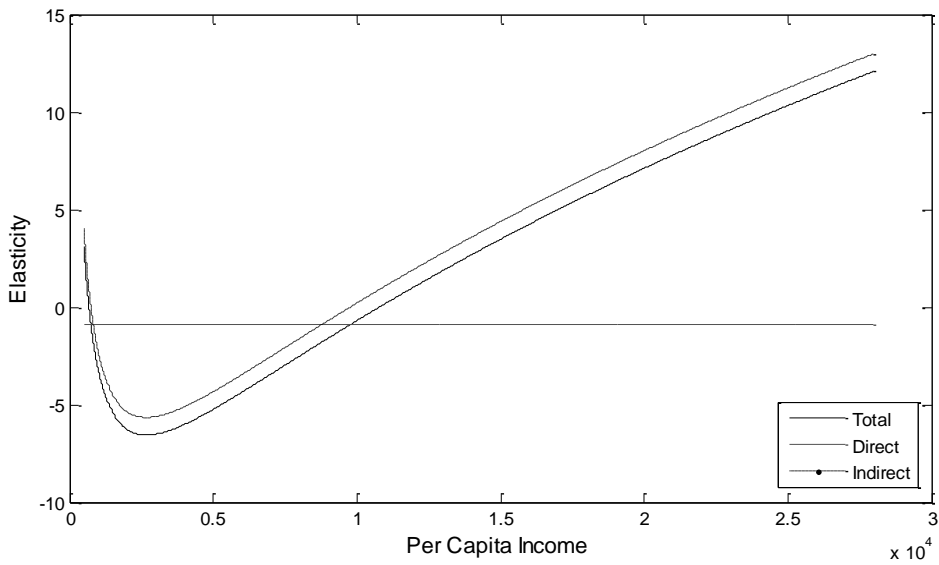
Figure 2: The effect of government share on CO_2/c
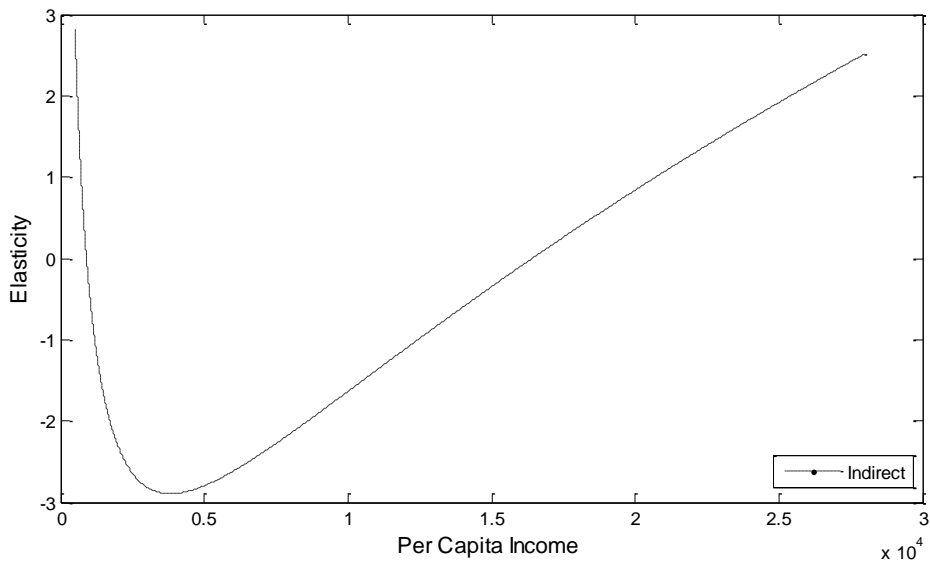
The total effect of government share on SO_2/c is negative for low levels of per capita income and then turns positive, while the total effect on CO_2/c is also negative but becomes positive for very high income levels[33]. Table 5 also reports the estimated income level at which the

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[33] Notably, for both pollutants, in very low levels of income (below the 5% percentile) the total effect is positive.

total effect changes from negative to positive. Particularly, GMM estimates indicated that this level is \$10,809 for SO_2/c and \$16,438 for CO_2/c, i.e. the total effect of government share of income on CO_2/c is negative through most of the sample income range. From the figures it becomes clear that the pattern of total effect is determined by the shape of the indirect effect.

The results of Table 5 suggest that the direct effect of government spending on pollution is insignificant and considerably smaller for CO_2, in absolute values. This finding comes as no surprise if the impact of the pollutants on human health and the technological capabilities of reducing their levels in the atmosphere are taken into account. In particular, SO_2 emissions externalities are local and immediate, while CO_2 emissions externalities are global and occur mostly in the future. Local environmental degradation, as in the case of SO_2, increases demand for technological improvements to diminish the impact on environmental quality.

The difference in magnitude and significance between the estimated direct effects of government expenditure on SO_2 and CO_2 could also be explained by how the different types of pollutants respond to certain policies. In particular, as already mentioned, the regulation of production-generated pollutants like SO_2 is expected to be more straightforward and this is reflected in the estimated effects.

3.4.1 Sensitivity analysis

If government expenditure composition is omitted from the model then this could bias the impact of government expenditure on pollution. A sensitivity analysis for the EKC equation is performed by including a government expenditure composition variable, constructed as described in Lopez et al. (2011). For SO_2 the estimated coefficient of this variable is

insignificant, while the magnitude and significance of the government expenditure remained unchanged[34]. Interestingly, the composition of government spending matters in the case of CO_2, where its sign is negative and significant at the 5% level, while the sign of the government expenditure remained unchanged compared to the main results[35].

Table 6: Robustness checks for omitted variables bias

Relative correlation restriction (Λ)	Bounds on Government share effect by pollutant $[\theta_L(\Lambda), \theta_H(\Lambda)]$	
	SO_2/c	CO_2/c
{0.00}	-0.360[**]	-0.150
	(-0.650, -0.070)	(-0.365, 0.065)
[0.00, 1.00]	[-0.476, -0.360]	[-0.150, 0.212]
	(-1.066, -0.092)	(-0.331, 0.561)
[0.00, 2.00]	[-0.763, -0.360]	[-0.150, 1.023]
	(-2.527, -0.095)	(-0.334, 2.822)
[0.00, 2.50]	$(-\infty, 0)$	$(-\infty, \infty)$
	$(-\infty, 0)$	$(-\infty, \infty)$
[0.00, 13.00]	$(-\infty, 0)$	$(-\infty, \infty)$
	$(-\infty, 0)$	$(-\infty, \infty)$
[0.00, 15.00]	$(-\infty, \infty)$	$(-\infty, \infty)$
	$(-\infty, \infty)$	$(-\infty, \infty)$
λ^*	2.25	2.25
$\lambda(0)$	13.20	0.47

Note: Bounds on effect of government share of GDP on pollution emissions/c, given relative correlation restrictions. Intervals in square brackets are the bounds themselves, while intervals in round brackets are Imbens-Manski 95% cluster-robust asymptotic confidence intervals.
*Significant at 10%.
**Significant at 5%
***Significant at 1%.

Furthermore, the existence of potential biases from omitted time-variant variables was tested. Apart from the composition of government expenditure, of particular interest is the unobserved environmental regulations effect. Table 6 reports the results from estimating the

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[34] Galinato and Islam (2014) also report an insignificant effect of the share of public goods in government expenditure on consumption pollution, and find that this effect operates only conditional on the level of democracy in a country. For details see Chapter 4 of this dissertation.

[35] The sample was smaller in this analysis due to limited availability (or even absence) of data for government spending composition for some countries, and this may affect the results, for example by introducing selection bias. We have also performed a sensitivity test including government spending composition in the income equation as suggested by Lopez and Galinato (2007). Its coefficient was insignificant at all significance levels, while that of government expenditure was not altered in magnitude and significance.

effect of government expenditure under a series of relative correlation restrictions, using the method proposed by Krauth (2011). To account for country fixed-effects, each variable was expressed in terms of deviation from the corresponding country-level average. The results suggest that the estimated effect for SO_2/c is robust, while the same does not hold for CO_2/c, as expected. In order for the effect on SO_2/c to cease being strictly negative, the correlation between government expenditure and unobservables would need to be 13.20 times larger than the correlation with the observables, which seems highly unlikely. However, for CO_2/c a relative correlation of only 47% or greater implies that the point estimate of the effect includes zero and thus is not strictly negative.

It was decided not to include interactive terms like government expenditure-income in the EKC equation, since the primary aim of this study is to examine whether government expenditure intermediates between income and pollution. If such a mechanism exists, it should show up in the model; and if the model can show this while making only the smallest deviation from the previous literature, so much the better[36]. However, a robustness check of the significance of the variables (government spending x GDP/c) and its square was performed. The interactive terms were found to be insignificant when all powers of income were included in the equation, but were significant when just the level of GDP/c was used, thus confirming the existence of an indirect effect.

The income equation with the inclusion of government spending squared was also estimated, to test whether there are decreasing returns to the government spending and income relationship, which could potentially affect the estimates of the indirect and total effects. However, there was no evidence of a quadratic relationship between income and government expenditure.

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[36] For similar approaches see Barrett and Graddy (2000) and Welsch (2004).

Finally, dominance tests for extreme observations were performed. Concentrating on DFE and GMM estimates, Table 7 presents the total effect of government share on both pollutants, as well as the turning points of these effects, when extreme observations are dropped from the analysis. 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 of Tables 7 and 5, it can be seen that the total effects magnitude and the estimate of the point at which the effect turns positive, are robust across the different datasets, indicating that the results are not determined by a small number of observations.

Table 7: Robustness checks of the estimates on the total effect of government share on the pollutants

	SO_2/c		CO_2/c	
	DFE	GMM(F-D)	DFE	GMM(F-D)
Bottom 1% of government share dropped	-2.743	-5.645	-2.307	-3.481
	(8,959)	(10,701)	(24,682)	(16,230)
Top 1% of government share dropped	-2.250	-6.643	-2.288	-3.182
	(8,090)	(10,913)	(24,670)	(14,544)
Bottom and top 1% of government share dropped	-2.480	-6.926	-3.057	-4.414
	(7,780)	(10,570)	(29,351)	(16,188)
Bottom 1% of pollutant dropped	-2.344	-5.413	-2.202	-2.423
	(9,433)	(10,469)	(32,001)	(16,570)
Top 1% of pollutant dropped	-2.282	-4.517	-2.293	-2.821
	(9,491)	(10,400)	(32,432)	(15,360)
Bottom and top 1% of pollutant dropped	-2.171	-4.445	-1.942	-2.520
	(9,520)	(11,093)	(24,826)	(16,026)

Note: Indirect effects are calculated at the sample median level of per capita income ($4,669). Effects presented are based on DFE and GMM(F-D) estimations of the EKC equation. Change of sign points in parentheses.

3.5. Conclusions

This study, using a sample of 77 countries for the period 1980-2000 and a two equations model, examined the effect of government size on pollution taking into account the dynamic

nature of this relationship. The findings confirm the theoretical and empirical developments on the existence of a correlation between income and pollution as well as between government size and economic performance. The reported results are not affected by biases which may occur by omitted variables and the existence of extreme observations.

A significant implication of the research in this chapter is that, in order to capture the total effect of government expenditure on the environment, the analysis should be conducted in a joint framework with two other bodies of literature, namely the literature linking fiscal policy with economic activity and the literature on the growth-pollution relationship.

The results suggest that the estimated direct effect of government expenditure is negative and significant for SO_2, but insignificant for CO_2. Estimation of a non-positive direct effect of government size on SO_2 is in line with the findings by Lopez et al. (2011) and Lopez and Palacios (2010, 2014). On the other hand, the indirect effect, which is considered for the first time here, varies depending on income levels. The total effect is largely determined by the more dominant indirect effect. In particular, for SO_2 the total effect is negative, although decreasing in absolute value, for low levels of income and then becomes positive in more developed countries. In contrast, for CO_2 the total effect is also negative for low incomes and turns positive only for very high income levels. These results may be attributed to the different characteristics of the pollutants that may determine the effect of government expenditure on them, such as the duration of their atmospheric lives, geographical and time scale of their effects on human health and on whether they are mainly production- or consumption-generated.

Policy implications, occurring from the analysis, differ according to the level of income in a country. The findings suggest that reducing government size enhances economic performance. However, cutting government expenditure should be undertaken with

particular care in some levels of GDP. For SO_2 and CO_2 pollution, results suggest that reducing the government size in countries with an income level less than $10,809 and $16,438 respectively, leads to deterioration of environmental quality. Therefore, cutting government expenditure in these countries should be accompanied by appropriate environmental regulation along with the establishment of international environmental treaties.

On the other hand, in countries with higher income levels, cutting government expenditures leads to improvements in both income 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. In that context and combining these findings with the results from Lopez et al. (2011), cutting out public spending items that increase market failure would be the most beneficial.

Appendix

Table A1: Data description and sources

Variable	Description	Source
SO_2/c	Sulfur dioxide emissions per capita, 1000 tons of sulfur	Stern(2005, 2006)
CO_2/c	Carbon dioxide emissions per capita, tons of carbon	Boden, Marland, Andres (2011)
Government share	Government consumption share of PPP converted Real GDP/c	Heston et al. (2009)
GDPc	GDP per capita (Constant US$ 1990)	Maddison(2010)
Investment	Investment share of PPP converted Real GDP/c	Heston et al. (2009)
Household consumption	Household consumption as a share of PPP converted Real GDP/c	Heston et al. (2009)
Trade-openess	Share of imports and exports in PPP converted Real GDP	Heston et al. (2009)
Population growth	Annual population growth rate	Maddison(2010)
School	Primary school enrollment (% gross)	World Bank(2011)
World government share	Weighted average of government share of Real GDP/c in other countries	Authors' calculations
Democracy	Degree of democracy, scaled -10 to 10	Polity IV(2010)

Chapter 4

The magnitude of the direct effect of government expenditure on the environment

4.1. Introduction

A growing body of literature has shown the economic implications of government expenditure to be significant and broad. Government spending has been shown to enhance long-run economic growth, by increasing the level of human capital and R&D expenditure, as well as by improving public infrastructure (Lucas, 1988; Romer, 1990; Barro, 1990). On the other hand, there is evidence that a greater size of government may be less efficient and therefore not necessarily associated with better provision of public goods and higher economic growth (Afonso and Furceri 2010; Bergh and Karlsson, 2010). Furthermore, a number of recent theoretical and empirical studies have shown that government expenditure is also a significant determinant of environmental degradation generated from both the production and consumption sectors (Lopez et al., 2011; Halkos and Paizanos, 2013[37]; Galinato and Islam, 2014; Lopez and Palacios, 2014; Islam and Lopez, 2015).

At the same time, many studies posit a link between several other factors and environmental pollution. In particular, it is documented that air pollution is influenced by various other determinants apart from fiscal policy, including economic growth, political institutions,

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[37] Presented in Chapter 3 of this dissertation.

population, trade and investment (Grossman and Krueger, 1995; Halkos, 2013a; Bernauer and Koubi, 2009; Zhu and Peng, 2012; Cole and Elliott, 2003). Moreover, some of these characteristics may interact with government expenditure and influence its effect on environmental quality. In this regard, it is highly unlikely that the effect of government spending on pollution is independent from country specific characteristics such as the level of economic development and the quality of institutions in a country. It is therefore surprising that the majority of the studies analyzing the effect of government expenditure on environmental quality report a unified estimate of this effect based on a world sample of countries.

Given the aforementioned background, the aim of this chapter is to provide a rigorous investigation of the relationship between government expenditure and air pollution. For this purpose, this study identifies three distinct channels that may determine the direct effect of government spending on pollution. The first channel operates through the level of income and is related to how the effect of government expenditure depends on the percentage of population that relies on public goods, the composition of the production sector of the economy, the demand for improved environmental quality, the composition of consumption goods and the composition of government spending. The second channel refers to the hypothesis that the effect of government expenditure on environmental degradation depends on the quality of the established political institutions in the economy. Finally, there is the marginal effect of government spending on the environment that is independent from any country specific characteristics. Failure to explicitly examine the first and second channels may lead to omitted variable bias, by not accounting for the effect of government expenditure on reducing emissions conditional on the level of economic development and on institutional quality (Galinato and Islam, 2014).

The contribution of this study is to quantify the direct effect of government expenditure on air pollution, by explicitly taking into account how this effect may differ according to the level of economic growth and the quality of political institutions in a country. There is only one previous study that has attempted a similar undertaking. In particular, Galinato and Islam (2014) examined the way the effect of government expenditure on pollution is influenced by the level of democracy, but they concentrated only on consumption-generated pollution and did not take into account the possible dependence of this effect on the level of economic growth. In a related study, Halkos and Paizanos (2013) examined how the effect of government expenditure on air quality depends on the level of income However, they did so by estimating the indirect effect according to which government expenditure may reduce economic growth and subsequently affect pollution. In contrast, this study concentrates on the estimation of the total direct effect of government expenditure on air pollution utilizing for the first time in this context, a large representative sample of 94 countries covering the period 1970-2008 for four air pollutants, namely sulphur dioxide (SO_2), nitrous oxide (N_2O), carbon dioxide (CO_2) and nitrogen oxide (NO_x). Furthermore, in examining these relationships, it is important to take into account their dynamic nature, since it is highly unlikely that the effect of government spending on the environment occurs instantaneously (Lopez et. al., 2011). Therefore, this research employs appropriate dynamic formulation and methods. Finally, this work also serves as a robustness check to the results reported in Halkos and Paizanos (2013) by using a different dataset for emissions data, a larger sample of countries and an extended period of time.

The remainder of the chapter is organized as follows; Section 4.2 examines the previous literature on the relationship between government expenditure and the environment, whilst Section 4.3 presents the data and introduces the suggested econometric methods used in the

analysis. Section 4.4 reports the empirical results and Section 4.5 provides the conclusions and policy implications of the analysis.

4.2. Literature Review

The mechanisms through which government expenditure and environment interact with each other were initially examined in theoretical papers by Heyes (2000), Lawn (2003) and Sim (2006). More recently, Lopez et al. (2011) identify four mechanisms through which the composition and size of government spending may affect production-generated pollution, namely the scale (greater environmental pressures associated with higher economic growth), composition (emphasis on human capital intensive activities instead of physical capital intensive activities which are more detrimental to the environment), technique (linked with improved labor efficiency) and income (due to higher income level that increases demand for enhanced environmental quality) effects. On the other hand, the mechanisms through which government expenditure affects consumption-generated pollution differ and are identified by a scale effect[38] which tends to increase pollution by enhancing the purchase power of consumers, and by a regulation effect through which pollution is reduced, due to the enforcement of stricter environmental regulations (Galinato and Islam, 2014).

The empirical literature offers indeterminate qualitative evidence regarding the effect of government size on pollution. Several studies have suggested that government expenditure is associated with greater energy intensity and worse environmental quality (Yuxiang and Chen, 2010; Frederik and Lundstrom, 2001; Bernauer and Koubi, 2013). In a related study, Halkos and Paizanos (2013) took into account both the direct and indirect effects of government expenditure on environmental quality and reported that the direct effect reduces

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[38] For details see Chapter 2 of this dissertation.

air pollution whereas the indirect effect, which operates through the impact of government spending on income, deteriorates environmental quality in developed countries.

On the other hand, Lopez et al. (2011) highlighted the importance of fiscal spending composition and suggested that a reprioritization of government expenditure towards public goods improves environmental quality. Furthermore, they reported that increasing total government expenditure without altering its composition, has a non-deteriorating impact on environmental quality. Lopez and Palacios (2014) investigated the effect of government spending and environmental taxes on air pollution in the EU and provide evidence that total government expenditure reduces emissions of SO_2 and O_3, a result that is maintained even after controlling for the composition of public expenditure. Finally, Islam and Lopez (2015) concentrated on the U.S. economy and found that a reallocation of spending from private goods to public goods by state and local governments reduces air pollution concentrations, whereas the composition of federal spending has no significant effect.

The level of income is an important determinant of environmental quality that may also interact with government expenditure and influence its effect on pollution. The environmental Kuznets curve (hereafter EKC) hypothesis posits that in the early stages of economic development environmental degradation will increase until a certain level of income is reached and then improvement of environmental quality is achieved (Gross and Krugman, 1995). EKC studies identify several factors as the most important in determining the inverted-U shape of the curve. Halkos (2003) summarizes these factors to improvements in environmental quality occurring from advances in production technology; the exportation of 'dirty industry' to less developed countries; the role of preferences and regulation on the emissions profile of polluters; the better institutional set up in the form of credible property rights; regulations and good governance which may create public awareness against

environmental degradation; and the technological link between consumption of a desired good and the abatement of its undesirable by-products in the form of pollution.

The effect of government expenditure on air pollution is expected to be greater in developed countries, since the income effect that follows an increase in government expenditure is more likely to exceed the scale effect and therefore contributes to a greater reduction of emissions, especially for production-generated pollutants (Islam and Lopez, 2015). Related to this, if the environment is considered a normal, or even a luxury public good, it is likely that it will only be demanded when the demand for other public goods has already been satisfied, which is more likely to occur in developed countries with greater government sectors (Frederik and Lundström, 2001; Martinez-Mongay, 2002). Moreover, government expenditure in high income countries is more likely to be directed to education and R&D spending categories and therefore reinforce the magnitude of the technique and composition effects. On the other hand, the effect of government spending on pollution may be exaggerated in developing countries, due to larger market failures and the relatively higher portion of the population that depends on government expenditure for public goods such as education and health (Lopez et al. 2010).

Another significant determinant of environmental quality, which may also influence the effect of government spending, is the quality of governance. In non-democratic regimes, small elites are affected disproportionately by stricter environmental policies, since they rely on polluting industrial activities to increase their personal wealth and therefore have incentives to oppose the establishment of environmental regulations (Bernauer and Koubi, 2009; Bernauer and Koubi, 2013; Lake and Baum, 2001; Niskanen, 1997; Farzin and Bond, 2006). Related to that, corruption may interact with political stability and further deteriorate environmental quality by reducing the stringency of environmental regulations (Fredriksson and Svensson, 2003; Fredriksson et al., 2003; Welsch, 2004; Cole, 2007; Halkos and

Tzeremes, 2013). On the other hand, in democracies the median voter faces a relatively lower burden from environmental policies and therefore the implementation of stricter environmental policies is more likely in such regimes.

Overall, a better quality of political institutions is expected to reinforce the magnitude of the effect of government expenditure on pollution. Higher levels of government expenditure aid the establishment and enforcement of environmental regulations, which in turn may lead to the development of institutions that improve environmental quality (Fullerton and Kim, 2008). Galinato and Islam (2014), provided evidence that following an increase of government expenditure on public goods, the efficiency of environmental regulations on reducing consumption-generated pollution is significantly enhanced in democratic regimes, leading to an alleviating effect on environmental degradation.

4.3. Data used and proposed econometric methods

4.3.1 Data

The sample used consists of 94 countries[39] with data on SO_2, N_2O, CO_2, NO_x, GDP per capita, the share of government consumption and other relevant explanatory variables

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[39] The countries considered in the analysis are the following:
EU&NA: Austria, Belgium, Bulgaria, Canada, Denmark, Finland, France, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Romania, Spain, Sweden, United Kingdom, United States.
Non EU&NA: Angola, Argentina, Bahrain, Benin, Bolivia, Brazil, Burkina Faso, Burundi, Cambodia, Cameroon, Chile, China, Colombia, Costa Rica, Djibouti, Dominican Republic, Ecuador, El Salvador, Gabon, Gambia The, Ghana, Guatemala, Guinea, Honduras, India, Indonesia, Iran, Iraq, Israel, Japan, Jordan, Kenya, Korea Republic of, Laos, Lebanon, Liberia, Madagascar, Malawi, Malaysia, Mali, Mauritania, Mauritius, Mexico, Mongolia, Morocco, Nepal, New Zealand, Niger, Nigeria, Norway, Pakistan, Panama, Peru, Philippines, Rwanda, Saudi Arabia, Senegal, Sierra Leone, Singapore, South Africa, Sri Lanka, Sudan, Swaziland, Switzerland, Syria, Tanzania, Thailand, Togo, Trinidad & Tobago, Tunisia, Turkey, Uganda, Uruguay, Vietnam, Zambia, Zimbabwe.

information for the period 1970–2008[40]. The data for all pollutants emissions are from the Emissions Database for Global Atmospheric Research (EDGAR) v4.2. Data on emissions of the four pollutants were used instead of their concentrations, to avoid dependence of results on geographical and atmospheric condition characteristics. National income data are from Maddison (2010) while the data for the government share of GDP[41], investment and population were collected from the Feenstra et al. (2015). Finally, the source for the trade data was the World Bank Indicators (2014), while that of the degree of democracy was the Polity IV Project (2014). The database includes 3,525 observations per variable.

It is important to mention that the atmospheric life characteristics and the geographical range of the impact of each of the four pollutants vary substantially. The atmospheric life is the period of time required for two-thirds of an emission to be removed from the atmosphere and its magnitude largely determines the geographical range of the impact of each pollutant on human health. SO_2 emissions move away from the atmosphere within 10 days after their generation, while NO_x emissions remove within a few hours to a couple of weeks. As a result, the impact of these two pollutants is mainly local or regional and immediate. The health impacts of SO_2 involve respiratory problems and aggravation of existing heart disease, while NO_x emissions damage lung tissues, reduce lung function and worsen existing heart disease. Therefore, these pollutants have historically been subject to considerable regulation, since the political cost of stricter regulations on them may be much lower than the cost of enforcing stricter regulations on other pollutants (Cole, 2007). On the other hand, the atmospheric lives of CO_2 and N_2O may reach 200 and 114 years, respectively. Their impact is global, they can cause health damage far from their original sources and affect

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[40] We have not included government spending composition in this model, due to paucity of related data for such a long time period and extended sample of countries. For a robustness check of the estimates to the inclusion of this variable, in this framework, see Chapter 3 of this dissertation.
[41] This variable is the government consumption share of GDP. For details see Chapter 3.

mostly the future generations. Therefore these pollutants have not been systematically regulated by governments.

Table 1: Background information on the pollutants

	SO_2	N_2O	CO_2	NO_X
% from transport	9.48%	3.28%	15.81%	43.86%
% from industry	18.80%	14.46%	16.63%	12.15%
% from energy transform	46.84%	3.52%	38.55%	30.31%
% from agriculture	0.31%	50.73%	0.35%	2.94%
Atmospheric life:	1-10 days	114 years	50-200 years	a few hours - weeks
Resultant impact:				
- local	Yes	No	No	Yes
- global	No	Yes	Yes	No

Moreover, the generating sources of emissions vary by pollutant. This distinction is important, since the mechanisms by which government expenditure affects consumption-generated pollution are likely to differ compared to production-generated pollution (McAusland, 2008). The main sources of SO_2 emissions are electricity generation and industrial processes, while a notable proportion of N_2O stems from agriculture. On the other hand, apart from energy transformation and industry, an important source of CO_2 and NO_x emissions is transportation, which is mainly passenger oriented. Apparently, SO_2 and N_2O pollution may be characterized as production-generated, NO_x emissions may be regarded as consumption-generated pollution and CO_2 emissions as a mix between these two categories. SO_2 emissions can be decreased by reducing the consumption of fossil fuels (especially high-sulphur content coal), by using smoke-scrubbing equipment in power plants and by increasing energy efficiency. N_2O pollution can be decreased by reducing nitrogen-based fertilizers, by adopting related technological upgrades and by fuel switching in fossil fuel combustion during industrial processes. However, for consumption-related pollutants, the implementation of environmental policies is expected to be more difficult and less efficient, since the main tool to reduce these pollutants is the imposition of environmental taxes,

which are often avoided, as they are not politically popular (Conefrey et al. 2013; Gemechu et al. 2014). Table 1 presents background information on the four pollutants.

4.3.2 Econometric approach

To establish the specification between air pollution, government share and the other control variables, the Box-Cox test was performed to test linearity against logarithmic functional forms. In addition, two or three powers of the income variable are used based on the results of the Akaike and Bayesian information criteria, while employing greater powers of this variable leads to multicollinearity. Thus, depending on the pollutant examined, a quadratic or cubic specification of the model is estimated. Specifically, findings of the tests suggested the estimation of the following model, which represents a conventional formulation of the EKC augmented by the lagged government expenditure and its interactions with income and democracy, as well as by the inclusion of a number of relevant control variables:

$$
\ln(P/c)_{it} = \beta_1 \ln Govshare_{it-1} + \beta_2 (\ln Govshare_{it-1} \times \ln GDP/c) + \beta_3 (\ln Govshare_{it-1} \times polity) +
$$
$$
+ \beta_4 \ln(GDP/c)_{it} + \beta_5 (\ln(GDP/c))_{it}^2 \quad + \beta_6 (\ln(GDP/c))_{it}^3 + \beta_7 X_{it} + \mu_i + \zeta_t + \varepsilon_{it} \tag{1}
$$

where subscripts i and t represent country and time respectively, while all variables, except for polity, are expressed in natural logarithms.

The income variable and its powers control for the scale and income effects of government expenditure on pollution. Total investment is used as a proxy for capital stock. Political stability is controlled by the inclusion of the level of democracy, while the effects of international trade (Cole, 2004) and total population (Selden and Song, 1994; Panayotou, 1997), which capture part of the scale effect, are also taken into account. The term μ_i

represents country effects which can be random or fixed, ζ_t is a time effect common to all countries and ε_{it} is a disturbance term with the usual desirable properties. Therefore, for production-generated emissions and following the terminology used to classify the pollution effects in the trade literature, the coefficients on the government expenditure variable and its interactions capture the composition and part of the technique effect as well as some of the unobserved environmental regulations effect,. On the other hand, regarding consumption-related pollution the coefficients of government expenditure capture mainly the environmental regulations effect.

The interaction terms of government share with income and of government share with democracy capture the extent to which the level of economic development and institutional quality influence the effect of government expenditure on pollution. At the margin, the total direct effect of government spending on pollution can be calculated by examining the partial derivative:

$$\frac{\partial \ln(P/c)}{\partial(\ln Govshare_{it-1})} = \beta_1 + \beta_2(\ln GDP/c) + \beta_3 polity \tag{2}$$

The coefficients of interest in Eq. (1) are β_1, β_2 and β_3. If greater income level and improved institutional quality enhance the effectiveness of government share on pollution, β_2 and β_3 are expected to be significantly negative. On the other hand, since a larger government in a low income country with limited level of institutional quality may have harmful consequences for the environment, for example by a relatively greater impact of special-interest groups that support a large government size to promote their private benefits (Mueller and Murrel, 1986; Bernauer and Koubi, 2013), the marginal effect of government expenditure on emissions, captured by β_1, may be positive.

In estimating Eq. (1), unobserved heterogeneity across countries should be explicitly addressed. Based on the particular concerns regarding the correlation between the cross-section error-components and the independent variables, unobserved heterogeneity can be taken into account by use of random or fixed effects, hereafter RE and FE, respectively. Country-specific characteristics that are associated with air pollution include climate variation, geography and natural resources endowments (Leitao, 2010). Furthermore, country unobserved characteristics may be correlated with the explanatory variables of the model. In the presence of such correlations, the use of FE is more appropriate since the RE approach leads to inconsistent and inefficient estimations in that case. This assumption is tested by the use of Hausman test, which provides evidence that the FE formulation is preferable to RE for the estimation of Eq. (1) in all pollutants specifications.

The panel dataset used in this research consists of large N and T dimensions, therefore, non-stationarity and the potential dynamic misspecification of the pollutants equations should be taken into account (Halkos, 2003). In particular, static models assume that adjustments to any shock occur instantaneously, though this could only be justified in equilibrium or if the adjustment mechanism is rapid, which is very unlikely considering that the return to long-run equilibrium emission levels can be relative slow for several reasons (Perman and Stern, 1999). For example, technological advances that usually accompany economic development may take several years to be fully implemented and utilized by industries. In addition, due to psychological reasons and as a result of the force of habit (inertia), industries and consumers may not alter their production methods and consumption behaviour immediately after a technological advance or a distributional effect, occurring from a change in public spending. Moreover, imperfect knowledge may further delay the adjustment process. Finally, established institutional characteristics (firms/industries) of the industrial market as well as

the type of fuels used and wind velocities, may also contribute to the existence of lags in the examined relationships.

4.3.2.1 Partial adjustment model

Including more than one lags of the government expenditure and income variables in Eq. (1), in order to capture dynamics, may result in multicollinearity. Thus, this study uses a partial adjustment model that constitutes an autoregressive model transformation of estimating distributed lag models. This approach assumes that there is an equilibrium (i.e. optimal or long-run) emissions level at which the economy achieves the desired level of welfare, under the given state of technology and other characteristics of the economy. Hence, the optimal level of pollution is a linear function of the explanatory variables of the model and can be expressed as follows:

$$\ln(P/c)^*_{it} = \beta_0 + \beta_1 Z_{it} + u_t \tag{3}$$

where Z_{it} includes all the explanatory variables of the model.

Since the optimal level of pollution is not directly observable, following Nerlove (1958) the following partial adjustment process is postulated:

$$\ln(P/c)_{it} - \ln(P/c)_{it-1} = \delta[\ln(P/c)^*_{it} - \ln(P/c)_{it-1}] \tag{4}$$

where δ is a coefficient of adjustment, such that $0 \leq \delta \leq 1$ and where $\ln(P/c)_{it} - \ln(P/c)_{it-1}$ is the actual change and $\ln(P/c)^*_{it} - \ln(P/c)_{it-1}$ is the desired change in emissions levels.

Eq. (4) postulates that the actual change in emissions in any given time period is some fraction δ of the desired change for that period. If δ = 1, it means that the actual level of emissions is equal to the optimum level implying that actual pollution adjusts to its optimum level instantaneously. On the other hand, if δ = 0, it means that nothing changes since the actual level of pollution observed is the same as that in the previous time period. Typically, δ is expected to lie between these extremes, since adjustment to the optimum level of pollution is likely to be incomplete, as already mentioned, due to rigidity, technology, inertia and contractual obligations. The adjustment mechanism can be alternatively written as:

$$\ln(P/c)_{it} = \delta \ln(P/c)_{it}^{*} + (1-\delta)\ln(P/c)_{it-1} \tag{5}$$

showing that the observed pollution level at time t is a weighted average of its optimum level at that time and the actual pollution level in the previous time period. Substitution of Eq. (5) into Eq. (4) gives

$$\ln(P/c)_{it} = \delta\beta_0 + \delta\beta_1 Z_{it} + (1-\delta)\ln(P/c)_{it-1} + \delta u_{it} \tag{6}$$

Eq. (6) is the short-run pollution specification thus, the coefficients of the government spending variable and its interactions with income and democracy, obtained from the estimation of this equation, can be interpreted as the short-run elasticity of government spending on pollution. The respective long-run elasticity can be obtained by dividing the short-run coefficients by the term δ.

Finally, for each subsequent year after a government expenditure increase, the partial effects on the environment can be estimated by using the Koyck transformation. In particular, assuming that the subsequent effects of government expenditure are all of the same sign as their short-run counterparts and that they decline geometrically each year, the partial effects are calculated by:

$$\beta_{\kappa t} = \beta_{i0}(1-\delta)^t \qquad\qquad\qquad\qquad\qquad\qquad\qquad (7)$$

4.3.2.2 Estimation of non-stationary dynamic panel

Furthermore, the model is also estimated with the use of more appropriate non-stationary heterogeneous panels methods. The asymptotics of large N and large T dynamic panels are different from the asymptotics of panels with large N and small T (Blackburne and Frank, 2007). Small T panel estimation usually relies on fixed- or random-effects estimators, or a combination of fixed-effects estimators and instrumental-variable estimators, such as the Arellano and Bond (1991) generalized method-of-moments estimator. These estimation methods require pooling individual groups and allowing only the intercepts to differ across the groups but in the case when both N and T are large, the assumption of homogeneity of slope parameters is often inappropriate and possible heterogeneity should be explicitly taken into account. Moreover, in large N and T dynamic panels, non-stationarity is an important concern that is not directly addressed by conventional methods.

Therefore, this study uses the dynamic fixed effects (DFE) estimator to estimate a non-stationary dynamic panel (Pesaran and Smith, 1995; Pesaran et al., 1997, 2004). DFE estimation assumes that the intercepts differ across countries but the long-run coefficients and the adjustment process are assumed to be equal. However, if equality of the slope coefficients does not hold in practice, DFE yields inconsistent estimators and other methods like the Mean Group (MG) or Pooled Mean Group (PMG) estimators should be used. These assumptions are tested by using the Hausman test.

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

$$\ln(P/c)_{it} = \mu_i + \sum_{j=1}^{p} \lambda_{ij} \ln(P/c)_{i,t-j} + \sum_{j=0}^{q} \beta'_{ij} K_{i,t-j} + \varepsilon_{it} \tag{8}$$

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

If the variables in Eq. (8) are integrated of order one, i.e. they are I(1), and co-integrated, then the error term is an I(0) process for all i. A feature of co-integrated 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. The error correction equation is formed as:

$$\Delta \ln(P/c)_{it} = \phi_i [\ln(P/c)_{i,t-1} - \zeta'_i K_{it}] + \sum_{j=1}^{p-1} \lambda^*_{ij} \Delta \ln(P/c)_{i,t-1} + \sum_{j=0}^{q-1} \beta'^*_{ij} \Delta K_{i,t-j} + \mu_i + \varepsilon_{it} \tag{9}$$

where $\phi_i = -(1 - \sum_{j=1}^{p} \lambda_{ij}), \zeta_i = \sum_{j=0}^{q} \beta_{ij} / (1 - \sum_{k} \lambda_{ik}), \lambda^*_{ij} = -\sum_{m=j+1}^{p} \lambda_{im} \quad j = 1, 2, ..., p-1$

and $\beta^*_{ij} = -\sum_{m=j+1}^{q} \beta_{im} \quad j = 1, 2, ..., q-1$.

Nonlinearity in the parameters requires that the models are estimated using maximum likelihood.

Finally, another econometric concern during estimation of Eq. (1) is the bias occurring from the potential endogeneity between government spending and pollution, since government spending often increases with pollution, for example because governments impose ecological taxes and thus increase tax revenues. Moreover, as already mentioned, the impact of government expenditure may not occur instantaneously. To address this issues, the lagged

share of government expenditure is used, which is also expected to mitigate bias attributed to reverse causality.

4.4. Results and discussion

The analysis begins with the examination of panel unit root tests for the variables considered in the model formulation. Testing for unit roots in panel data requires consideration of both the T and N dimensions. Since the panel data set in this case consists of both $N \rightarrow \infty$ and $T \rightarrow \infty$ dimensions, the tests of stationarity performed are based on the Fisher-type Dickey-Fuller unit root test, which is more appropriate in this case[42]. This test allows heterogeneity of the autoregressive parameter and is more powerful than Levin et al. (2002) in the presence of cross-sectional dependence in the model, although in its general form it does not control for cross-sectional dependence[43]. Table 2a presents the results of the Fisher-type Dickey-Fuller unit root tests on the variables of interest. There is evidence against stationarity in levels, since in all cases the variables are I(1).

Furthermore, in order to use the DFE method, the variables in the model should be co-integrated, implying that there is a long-run relationship among them. Table 2b presents the Pedroni, the Kao (Engle based) and the Fisher combined Johansen co-integration tests for the four pollutants equations. The Pedroni Residual Co-integration test rejects the null hypothesis of no-cointegration, at the 0.01 statistical significance level, in four of the seven cases for all pollutants equations. 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 are

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[42] For details see Halkos (2011).

[43] 4. We also compute the mean of the series across panels and subtract this mean from the series (columns 2 and 4 in Table 2a) to mitigate the impact of potential cross-sectional dependence, which is not explicitly taken into account by Fisher-type tests.

characterized by low power (Pedroni, 2004), suggesting that evidence of co-integration is stronger than that revealed by the results. Moreover, both the Kao and Fisher-Johansen tests indicate the existence of a long-term relationship between the variables in all specifications.

Table 2a: 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
	(1)	(2)	(3)	(4)
Log Government share lagged	0.826	0.998	0.931	0.836
Δ(Log Government share lagged)	0.000	0.000	0.000	0.000
Log SO_2/c	0.989	0.989	0.274	0.819
Δ(Log SO_2/c)	0.000	0.000	0.000	0.000
Log N2O/c	0.780	0.155	0.000	0.025
Δ(Log N2O/c)	0.000	0.000	0.000	0.000
Log CO_2/c	0.494	0.933	0.136	0.633
Δ(Log CO_2/c)	0.000	0.000	0.000	0.000
Log NO_x/c	0.377	0.483	0.752	0.586
Δ(Log NO_x/c)	0.000	0.000	0.000	0.000
Log GDP/c	1.000	0.769	0.923	0.945
Δ(Log GDP/c)	0.000	0.000	0.000	0.000
Log Polity	0.822	0.775	0.006	0.000
Δ(Log Polity)	0.000	0.000	0.000	0.000

Note: Fisher-type Dickey-Fuller 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.

Table 2b: Panel co-integration tests for the pollution equations

	SO_2/c	N_2O/c	CO_2/c	NO_x/c
Panel v-statistic	1.000	1.000	1.000	1.000
Panel rho-statistic	1.000	1.000	1.000	1.000
Panel PP-statistic	0.000	0.000	0.000	0.000
Panel ADF-statistic	0.000	0.000	0.000	0.000
Group rho-statistic	1.000	1.000	1.000	1.000
Group PP-statistic	0.000	0.000	0.000	0.000
Group ADF-statistic	0.000	0.000	0.021	0.000
Kao test (Engle based)	0.000	0.000	0.000	0.000
Fisher - combined Johansen	0.000	0.000	0.000	0.000

Note: P-values reported. Individual intercept and trend included in all cases apart from the Kao test. The first two sets of statistics refer to the Pedroni Residual co-integration test, with automatic length selection based on SIC. The Fisher stat reported is the max-trace test of at least 1 co-integration equation.

The results of the Partial Adjustment Model, for the four pollutants specifications, are reported in Table 3. According to the Hausman test, the FE formulation is preferred to RE thus, for each pollutant the FE estimates are presented. Moreover, to account for

autocorrelation and heteroskedasticity, all standard errors reported are robust, based on the Huber–White-Sandwich estimates of the variance–covariance matrix.

Table 3: Estimates of production generated per capita emissions using the Partial Adjustment Model

	SO_2/c		N_2O/c		CO_2/c		NO_x/c	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log Government share lagged*GDPc, lagged		-0.037***		-0.019		-0.002		-0.043***
		(0.011)		(0.014)		(0.017)		(0.015)
Log Government share lagged*polity, lagged		-0.003**		-0.004**		-0.001		-0.005***
		(0.0015)		(0.001)		(0.001)		(0.002)
Log Government share lagged	0.030**	0.311***	0.027*	0.167	0.003	0.019	0.069***	0.396***
	(0.012)	(0.088)	(0.013)	(0.107)	(0.012)	(0.133)	(0.018)	(0.122)
Log GDPc	-4.348***	-4.905***	0.359**	0.355**	0.612***	0.619***	-5.627***	-6.246***
	(1.300)	(1.286)	(0.156)	(0.166)	(0.187)	(0.182)	(1.648)	(1.651)
Log GDPc^2	0.586***	0.650***	-0.019**	-0.022**	-0.031***	-0.032***	0.729***	0.798***
	(0.164)	(0.163)	(0.009)	(0.009)	(0.011)	(0.011)	(0.207)	(0.206)
Log GDPc^3	-0.026***	-0.028***					-0.030***	-0.033***
	(0.007)	(0.007)					(0.008)	(0.008)
Polity	-0.003**	-0.008**	-0.001	-0.008***	0.0002	-0.002	-0.001	-0.009***
	0.001	(0.003)	(0.001)	(0.001)	(0.0008)	(0.003)	(0.001)	(0.003)
Log Investment	0.027**	0.025**	0.026**	0.025**	0.031***	0.031***	0.023	0.021
	(0.010)	(0.010)	(0.011)	(0.011)	(0.009)	(0.009)	(0.017)	(0.017)
Log Trade openness	-0.005	-0.003	-0.012**	-0.011*	0.010	0.011	-0.018*	-0.016
	(0.009)	(0.009)	(0.006)	(0.006)	(0.007)	(0.007)	(0.010)	(0.131)
Log Population	0.006	0.014	-0.028	-0.026	0.008	0.008	0.004	0.012
	(0.018)	(0.018)	(0.022)	(0.023)	(0.021)	(0.022)	(0.027)	(0.026)
Constant	8.865***	10.435***	-3.610***	-3.522***	-2.858***	-2.867***	11.02***	12.80***
	(3.304)	(3.248)	(1.007)	(1.065)	(0.899)	(0.866)	(4.13)	(4.110)
Lagged dependent variable	0.863***	0.856***	0.811***	0.807***	0.857***	0.856***	0.740***	0.731***
	(0.023)	(3.248)	(0.050)	(0.052)	(0.017)	(0.017)	(0.049)	(0.048)
Total long-run gov.share elasticity	0.219**	-0.634***	0.141*	-0.322	0.022	-0.127	0.265***	-0.327**
Turning Points	796/4,230	679/7,785	12,675	3,191	19,360	15,865	567/19,149	804/12,457
R^2	0.813	0.814	0.671	0.673	0.828	0.828	0.614	0.617
F test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hausman FE v. RE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nobs/Countries	3,525/94	3,525/94	3,468/94	3,468/94	3,525/94	3,525/94	3,525/94	3,525/94

Note: Robust standard errors in parentheses. All tests' values reported are probabilities. Total long-run government expenditure elasticity is calculated at the sample median level of income and polity for EU & NA countries in 2008.
*Significant at 10%.
**Significant at 5%
***Significant at 1%.

Odd numbered columns present the estimated equations without the inclusion of the interaction variables of government expenditure with income and the democracy level. In this case, the coefficient of the lagged government share captures the short-run marginal effect on emissions. The effect is significantly positive for all pollutants, except in the case of CO_2. This result is in line with the hypothesis that a larger government in developing countries with a low level of institutional quality deteriorates environmental quality by promoting private benefits of special-interest groups. This finding may be attributed to the relative strength of the special interest groups channel in the sample of countries and time period used, as well as the source of emissions data employed in this analysis. In particular,

one major difference between emission data from the EDGAR database and data from other sources is that the former does not take into account better abatement activities, like for example in the SO_2 data provided by Stern (2005, 2006) which depict a significant slowing trend in the SO_2 emission estimates in the examined period (Stern, 2006; Grether et al., 2010). Thus, the use of the EDGAR dataset of emissions is expected to lessen the magnitude of the alleviating effect of the technique and composition effects of government expenditure on pollution.

As already mentioned, exclusion of the interaction variables may lead to omitted variable bias, since this approach does not account for the alleviating effect of government expenditure on air pollution conditional on the level of economic development and on institutional quality. Thus, the even numbered columns in Table 3 report the estimates for each pollutant equation with the inclusion of the interactive terms. These specifications are considered as benchmark in what follows. Moving on to the examination of the results for SO_2, one observation is that the marginal impact of government share remains positive, however this impact decreases for higher levels of income and democracy. This result is in line with theoretical predictions that higher development level and better institutional quality amplify the alleviating effect of government expenditure on environmental degradation. Concerning N_2O emissions, the marginal impact of government expenditure is positive but insignificant, while only the level of democracy significantly improves the effect of government spending on this pollutant.

Regarding consumption-generated pollution, government expenditure has no significant effect on CO_2 emissions through any of the considered channels. On the other hand, the marginal impact on NO_x emissions is positive and significant, but this effect is alleviated for higher levels of income and democracy. The total long-run direct effect of government expenditure on air pollution, calculated at the sample median level of income and polity for

EU and North America (hereafter EU & NA) countries in 2008, is significantly negative on SO_2 and NO_x emissions, while there is no evidence of a significant total effect, either positive or negative, on N_2O and CO_2 emissions. In particular, the results suggest that a 1% increase of government expenditure leads to a long-run reduction of SO_2 emissions by 0.634% and to a reduction of NO_x emissions by 0.327%.

It is interesting to note that the estimated coefficients of the lagged pollutant variables are significant in all cases at the 1% level, suggesting that taking into account dynamics is necessary. Moreover, the rates with which emissions adjust to their equilibrium values, in the sense of the assimilative capacity of the environment, are similar among the four pollutants and considered relatively slow. In particular, the lag coefficients in the estimated equations show that the rate of adjustment of emissions to their equilibrium levels range from a rate of around 14.4% per annum (1–0.856) for SO_2 and CO_2, to a rate of 26.9% (1-0.731) per year for NO_x. These results imply that 14.4 and 26.9 per cent of the discrepancy between the desired and the actual levels of SO_2 and NO_x emissions, respectively, are eliminated in a year. In other words, the adjustment of emissions is effected within four to seven periods, depending on the examined pollutant. Figure 1 depicts the partial total direct effects of government expenditure on SO_2 and NO_x emissions for a 10 year period after the initial shock. For both pollutants the partial effects are negative but they are greater in magnitude and more persistent in the case of SO_2.

With respect to the EKC, the results show that there is a significant inverted N-shaped cubic relationship between per capita income and SO_2 and NO_x emissions, while this relationship is quadratic for N_2O and CO_2. Another observation is the significantly negative direct effect of democracy on all pollutants except for CO_2, certifying the hypothesis that democracy reduces pollution by enhancing the stringency and enforcement capability of environmental regulations. Finally, 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 pollution equations, except in the case of NO_x. Population growth has a consistent positive, albeit insignificant, effect on air pollution, while trade-openness significantly reduces N_2O emissions and is negative but insignificant on the other cases.

Figure 1: The partial effects of government expenditure on SO_2 and NO_x emissions.
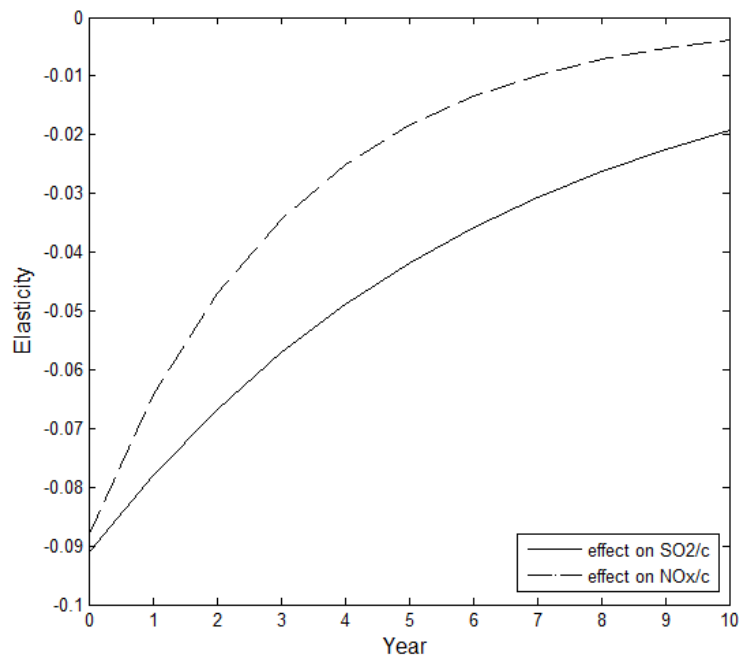
Estimates based on the partial adjustment model. The effects are calculated at the sample median level of income ($24,101) and polity (10) for the EU&NA countries, in 2008.

Table 4 presents the estimates of per capita emissions using the DFE method, which explicitly takes into account dynamics. Comparing the MG and PMG estimators with the use of a Hausman test, the PMG estimator, the efficient estimator under the null hypothesis, is preferred and thus, assuming long-run coefficients to be equal across panels, is more appropriate in this panel. Additionally, another application of the Hausman test suggests that the simultaneous equation bias between the error term and the lagged dependent variable is minimal in the model and indicates that the DFE model is the most appropriate method in

this case. The reported standard errors are robust to intra-group correlations. Finally, all coefficients from the DFE model are properly signed and similar to the Partial Adjustment Model estimates.

Table 4: Estimates of per capita emissions using Dynamic Fixed Effects

	SO_2/c	N_2O/c	CO_2/c	NO_x/c
Log Government share * GDPc, lagged	-0.260***	-0.086	0.023	-0.158***
	(0.080)	(0.084)	(0.104)	(0.056)
Log Government share * polity, lagged	-0.021*	-0.021**	-0.011	-0.017**
	(0.012)	(0.009)	(0.011)	(0.008)
Log Government share lagged	2.194***	0.764	-0.130	1.426***
	(0.626)	(0.638)	(0.787)	(0.472)
Log GDPc	-32.20***	1.691**	-17.97*	-21.46***
	(7.203)	(0.713)	(10.13)	(4.901)
Log GDPc^2	4.269***	-0.103**	2.497**	2.753***
	(0.887)	(0.041)	(1.255)	(0.603)
Log GDPc^3	-0.187***		-0.109**	-0.115***
	(0.036)		(0.051)	(0.024)
Polity	-0.053**	-0.041**	-0.021	-0.032**
	(0.025)	(0.016)	(0.018)	(0.014)
Log Investment	0.187**	0.146**	0.160**	-0.089
	(0.083)	(0.068)	(0.071)	(0.072)
Log Trade openness	-0.049	-0.068**	0.078	-0.074*
	(0.071)	(0.034)	(0.064)	(0.043)
Log Population	-0.001	-0.205**	0.050	-0.049
	(0.139)	(0.098)	(0.156)	(0.111)
Convergence coefficient	-0.141***	-0.188***	-0.138***	-0.261***
	(0.024)	(0.052)	(0.022)	(0.051)
Turning Points	982/4,105	3,673	330/12,965	871/9,799
Hausman MG v. PMG	0.812	0.653	0.926	0.791
Hausman MG v. DFE	0,998	1.000	1.000	1.000
Nobs/Countries	3,431/94	3,374/94	3,431/94	3,431/94

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

To improve our impression of the total direct effect, the effect on pollution of a 1% increase in the size of government at different levels of income and democracy is calculated, based on the DFE estimates. The results are illustrated in figures 2 and 3.

Figure 2: Elasticity of emissions conditional on the level of income.
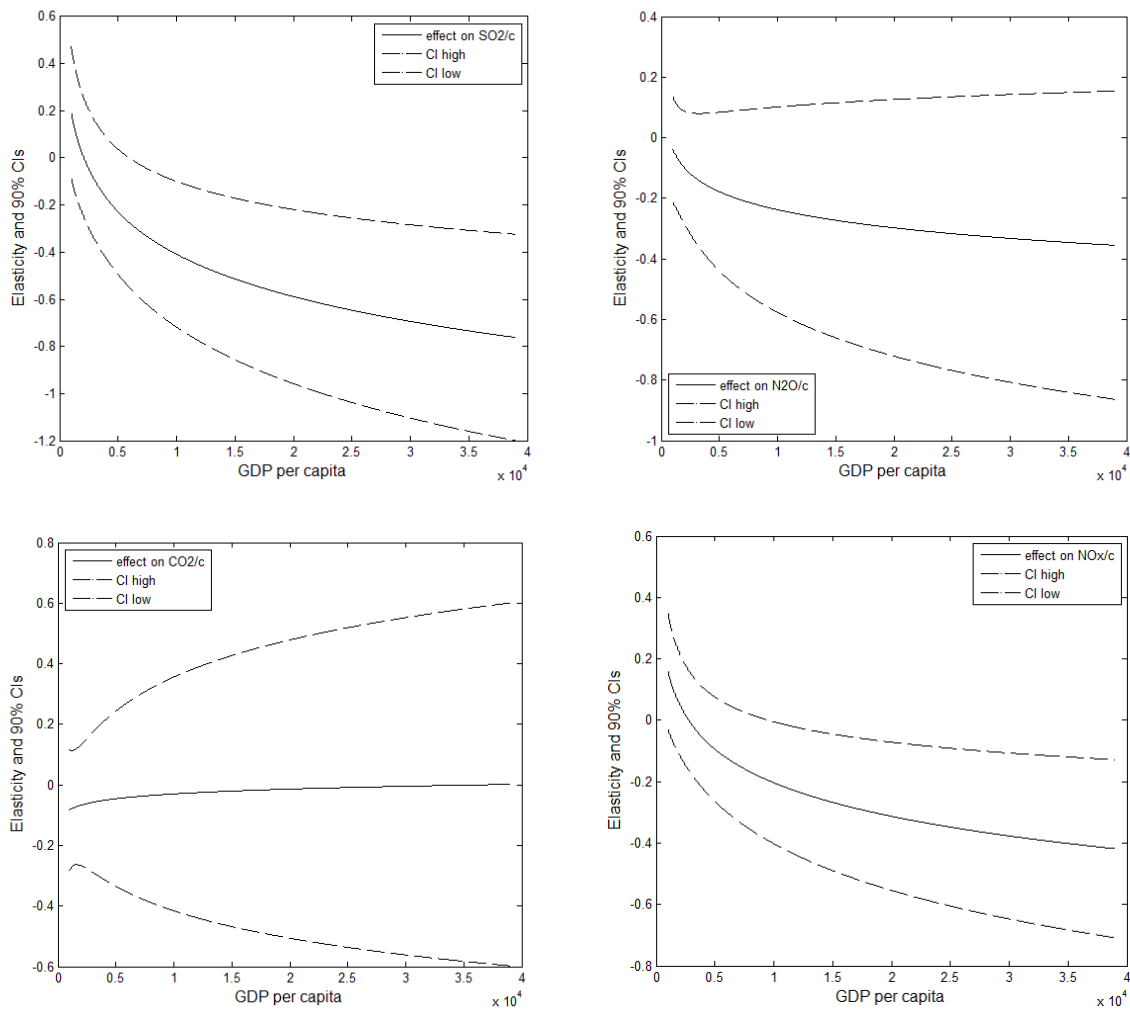
Estimates based on the DFE estimation method. The effects are calculated at the sample median level of polity (10) for the EU&NA countries, in 2008.

Figure 3: Elasticity of emissions conditional on democracy level.
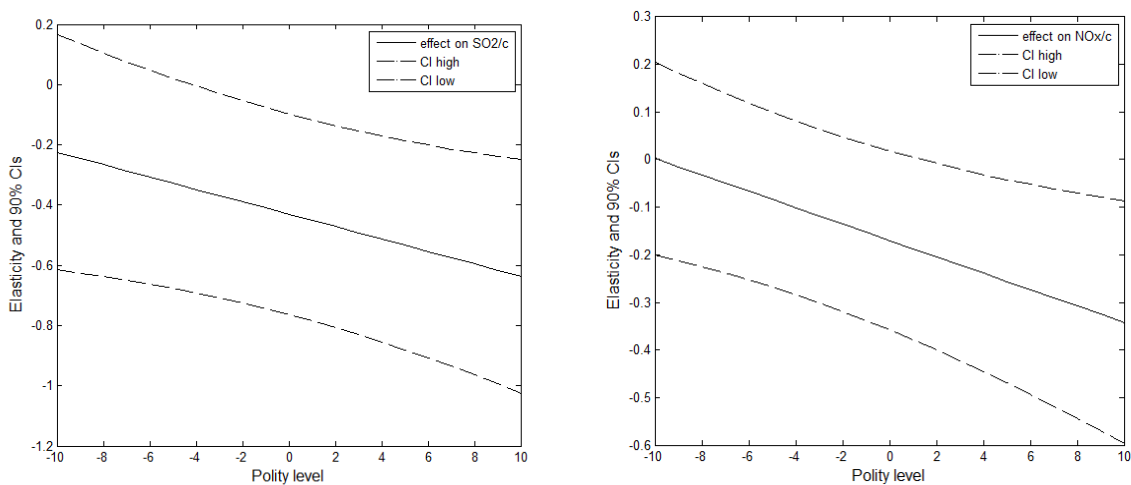
Estimates based on the DFE estimation method. The effects are calculated at the sample median level of GDP ($ 24,101) for the EU&NA countries, in 2008.

For countries with very low level of income the effect of government expenditure on SO_2 is positive but insignificant, even when calculated at the maximum level of institutional quality. In particular, for the lowest income of the sample, a 1% increase in the size of government increases SO_2 emissions by 0.2%. The effect becomes significantly negative, at the 10% level, for income levels above $ 5,500, as indicated by the dashed lines for the confidence intervals. At the maximum level of income, SO_2 emissions decrease by 0.73%. Therefore, SO_2 emissions decrease by 465% when income rises from its lowest level to its maximum of $ 40,000. This result suggests that in developed countries the alleviating effect of government expenditure on SO_2 pollution is significantly enhanced. As in the partial adjustment model, the effect of government expenditure on N_2O and CO_2 emissions is insignificant at all levels of income and democratic quality. Concerning NO_x emissions, for countries with very low level of income the effect of government expenditure is positive and insignificant, even for the maximum level of institutional quality. In particular, for the lowest income of the sample, a 1% increase in the size of government increases NO_x emissions by 0.17%. This effect becomes significantly negative, at the 10% level, for income levels above $ 7,500, as shown by the dashed lines for the confidence intervals. At the maximum level of income, NO_x emissions decrease by 0.42%. Therefore, NO_x emissions decrease by 347% when income increases from its lowest level to its maximum of $ 40,000.

Focusing on the effect of government expenditure on pollution conditional on the democracy level, the results suggest that there is no significant effect on N_2O and CO_2 pollution. Regarding the effect on SO_2 emissions, calculated at the median level of income of EU & NA countries in 2008, a 1% increase of government spending decreases emissions by 0.23% and 0.62%, at the minimum and maximum level of democracy respectively. Therefore, SO_2 emissions reduce by 170% when democracy increases from -10 to its maximum value of 10. As shown by the confidence intervals, indicated by the dashed lines, this effect is significant

at 10% for levels of democracy above -4. Regarding NO_x emissions, when the polity level is

-10, a 1% increase of government expenditure slightly decreases pollution by 0.01%, while

at the maximum level of democracy NO_x emissions decrease by 0.34%. Finally, these effects

are significant at the 10% level only for levels of democracy above 2.

Table 5: The effect of government spending on per capita pollution emissions

Effect	SO_2/c		N_2O/c		CO_2/c		NO_x/c	
	EU&NA	Non-EU&NA	EU&NA	Non-EU&NA	EU&NA	Non-EU&NA	EU&NA	Non-EU&NA
Through GDP/c	-2.625[***]	-2.092[***]	-0.871	-0.694	0.234	0.186	-1.596[***]	-1.272[***]
Through democracy	-0.206[*]	-0.123[*]	-0.206[**]	-0.124[**]	-0.114	-0.068	-0.172[**]	-0.103[**]
Marginal	2.194[***]	2.194[***]	0.764	0.764	-0.130	-0.130	1.426[***]	1.426[***]
Total	-0.637[***]	-0.021	-0.313	-0.054	-0.01	-0.012	-0.342[**]	0.051

Note: Estimates based on the DFE estimation method. The effects through GDP and through democracy are calculated at the sample median level of per capita income ($24,101 and $3,103 respectively) and polity level (10 and 6 respectively) for the EU&NA and Non-EU&NA groups, in 2008.

Table 5 summarizes the estimates for the total direct of government spending and its

components on air pollution, splitting the sample between EU & NA countries and the rest

of the world. Corruption in EU & NA countries may be mostly due to tax evasion, whereas

firms in low income countries try to avoid regulations, including environmental regulations

(Biswas et al. 2012). Moreover, the quality of the environment in developing countries may

be harmed due to the lack of appropriate institutional capabilities to impose and achieve a

targeted level (Rothman, 1998). At the same time higher levels of income and education

may enable developed countries to enforce stricter environmental regulations and give

higher priority to regulating environmental damage after other basic needs have been

satisfied (Halkos, 2013a). Thus, the alleviating effect of the government expenditure on air

pollution in developed and developing countries is expected to differ in magnitude and

significance. The estimates indicate that a 1% increase of government size significantly

reduces SO_2 emissions in EU & NA countries by 0.637% and by 0.021% in the rest of the

world, however the latter effect is insignificant. The larger contributor to this alleviating

effect of government expenditure on environmental degradation in EU & NA countries is the

level of income. On the contrary, in developing countries the effect through income is significant but not large enough, in absolute values, to overcome the positive marginal effect. The same pattern is observed for NO_x emissions, where a 1% increase of government spending leads to a 0.342% reduction of emissions in developed countries. On the other hand, government spending is not associated with changes in N_2O and CO_2 related pollution, although the alleviating effect on emissions through democracy is statistically significant in both country groups in the case of N_2O.

Finally, in order to test the robustness of the estimated results, Table 6 presents the dominance tests for extreme observations. In particular, focusing on the DFE estimates, the total direct effect of government share on both pollutants when extreme observations are dropped from the analysis is presented. The model is also estimated without the top and bottom 1% of government share expenditure data and then a similar approach was followed with the emissions variables. Comparing the results with those of Tables 5 and 6, it can be seen that the magnitude of the total direct effect is 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 of the total direct effect of government share on the pollutants

	SO_2/c	N_2O/c	CO_2/c	NO_x
Bottom 1% of government share dropped	-0.669***	-0.354	-0.014	-0.351**
Top 1% of government share dropped	-0.669***	-0.280	-0.011	-0.289**
Bottom and top 1% of gov. share dropped	-0.634***	-0.312	-0.014	-0.315**
Bottom 1% of pollutant dropped	-0.540***	-0.308	-0.122	-0.328**
Top 1% of pollutant dropped	-0.616***	-0.122	-0.021	-0.306**
Bottom and top 1% of pollutant dropped	-0.520***	-0.127	-0.115	-0.291**

Note: The effect is calculated at the sample median level of per capita income of EU & NA countries in 2008 ($24,101). Robust standard errors calculated using the Delta method for estimating the variance of functions. The effects presented are based on the DFE estimations of the pollution equation.
**Significant at 5%
***Significant at 1%.

Overall, the results suggest that the direct effect of government expenditure on air pollution is significant and considerably greater on SO_2 and NO_x in absolute values, rather than on N_2O and CO_2. A plausible explanation for this finding is related to the different impact of the pollutants on human health and the varying technological capabilities of reducing emissions levels in the atmosphere. In particular, SO_2 and NO_x emissions externalities are local and immediate, while N_2O and CO_2 emissions externalities are global and occur mostly in the future. Moreover, local environmental degradation, as in the case of SO_2 and NO_x, increases demand for technological improvements to diminish their negative impact on human health (Halkos and Paizanos, 2013). The difference in magnitude between the estimated direct effect of government spending on SO_2 and NO_x may also be attributed to the different ways that production- and consumption-generated pollutants respond to policies. As already mentioned, the regulation of production-generated pollutants is more straightforward, while consumption-generated pollution is expected to be relatively more difficult to be controlled through changes in fiscal policy (Galinato and Islam, 2014).

4.5. Conclusions and policy implications

During recent years there has been an emphasis on the implementation of expansionary macroeconomic policies as a tool to lessen the adverse effects of economic crisis. In particular, public expenditure increased sharply in many countries during these years, affecting economic performance and other indicators of welfare. In this regard, although the enhancement of environmental quality is not the major goal of fiscal policy, not least due to lack of public support (Greenberg, 2005), it is nevertheless important to consider the possible effects of such policies on the efficiency of environmental regulations and their potential impact on pollution levels. In light of this background, the research in this chapter

subjected the relationship between government expenditure and pollution to a detailed empirical examination by explicitly analysing the channels underpinning this linkage. In particular, the hypotheses that economic growth and greater institutional quality reinforce the alleviating effect of government spending on air pollution were tested. Data covering a large panel of countries for the period 1970-2008 were utilized to estimate the determinants of SO_2, N_2O, CO_2 and NO_x emissions, by employing appropriate dynamic model formulations. The findings are robust across the two different dynamic estimation methods used and are not affected by biases which may occur by the existence of extreme observations.

The results presented in this chapter demonstrate that there is a significantly negative direct effect of government expenditure on SO_2 and NO_x emissions, while this effect is insignificant on N_2O and CO_2 related pollution. Moreover, the results reveal that the alleviating direct effect of government spending on air pollution is significantly reinforced in developed countries that also constitute democratic jurisdictions, due to the greater demand for enhanced environmental quality, larger fraction of public spending targeted at education and R&D, the use of environmentally cleaner technologies and the increased efficiency of environmental regulations. Furthermore, the total direct effect of government spending on air pollution is also largely determined by the different characteristics of the pollutants. In particular, the estimated effects are greater in significance and in magnitude on pollutants that are characterized by shorter atmospheric life time, local geographical range and therefore more immediate impact on human health. Furthermore, there is evidence that production-generated pollution is easier to be controlled by the implementation of fiscal policy, compared to consumption-generated pollution. Overall, these results are in line with those reported in Halkos and Paizanos (2013) who also found a negative direct effect of government expenditure on SO_2 emissions which is a production-generated pollutant with

local externalities, while they report that there is no significant direct effect on CO_2 emissions which is a mix between production- and consumption-related pollutant and is characterized by global externalities.

Turning to policy implications, the results of this study provide reassurance to macroeconomic policy makers that the direct effect of a fiscal spending expansion is not detrimental to environmental quality and in fact may lead to significant improvements in air quality, particularly in developed and democratic countries. Therefore, fiscal spending may be used to complement the efforts to improve environmental quality rendering them easier and more cost efficient. The effect of government spending on environmental quality in developing countries and autocratic regimes can be reinforced by mitigating policy distortions such as the protection of industry and energy subsidies and by enforcing property rights over natural resources that may promote the internalization of environmental costs to the sources that generate pollution (Panayotou, 1993). Moreover, the need for technology and knowledge transfers to developing countries is crucial to advance the abatement methods used and promote environmental cleaner production methods. Concerning the mitigation of pollutants with more global impact like N_2O and CO_2, the adoption of international environmental treaties that will internalize such externalities is required (Lekakis, 2000; Morales and Guerrero, 2006; Halkos, 2013a). Finally, it should be mentioned that there are several other factors that may also affect environmental quality, which ought to be considered in designing fiscal policies, like the composition of government spending and the cumulative effect of each policy on economic growth (Lopez et al., 2011; Halkos and Paizanos, 2013).

Chapter 5

The short-run effects of fiscal policy on CO_2 emissions: Evidence from the U.S.A.

5.1. Introduction

A large part of Gross Domestic Product (GDP) in many countries worldwide is being spent through government consumption and investment. Moreover, in response to the world economic crisis that initiated in 2008, several governments followed expansionary macroeconomic policies to support and expedite the recovery of their economies, subsequently influencing many macroeconomic variables and welfare in general. Related to that, an increasing number of studies have suggested that fiscal spending is also a significant determinant of environmental pollution (Lopez et al., 2011; Halkos and Paizanos, 2013[44]; Galinato and Islam, 2014; Lopez and Palacios, 2014; Islam and Lopez, 2015). Therefore, even though the enhancement of environmental quality is not the major objective of fiscal policies, it is nevertheless important to consider the potential impact of such policies on the efficiency of environmental regulations and on pollution levels.

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[44] Included in this dissertation as Chapter 3.

Taking the above mentioned background into account, the purpose of the present study is to examine the relationship between environmental quality and macroeconomic variables by focusing on whether fiscal policy affects CO_2 emissions. To accomplish this task, this study employs a sample of quarterly data of the U.S. economy, for the period 1973-2013. The environmental variable used is CO_2 emissions, for which there is a full quarterly data set available during the examined period. This research distinguishes between production- and consumption-generated sources of this pollutant and estimates a model that encompasses macroeconomic and other relevant variables using Vector Autoregression methods, which explicitly take dynamics in the analyzed relationships into account. In this regard, there is an extensive strand of literature that investigates several other air pollution determinants, apart from fiscal policy. In particular, it is documented that CO_2 emissions from fossil fuel combustion are influenced by a number of short- and long-term factors including population growth (Zhu and Peng, 2012), economic growth (Grossman and Krueger, 1995; Sobrino and Monzon, 2014), energy prices (Hang and Tu, 2007), trade (Cole and Elliott, 2003) and consumer behaviour (Baiocchi et al. 2010).

The contribution of this study is the explicit examination of the effect of fiscal policy on environmental quality in the framework of a macroeconomic model. In particular it examines for the first time how different realistic policy implementation scenarios, that aim to stimulate the economy, may also impact environmental quality. In addition, there is no other study which examines the impact of government revenue on the environment at the aggregate macroeconomic level.

The remainder of the chapter is organized as follows: The next section provides a review of the relevant literature, presents the data and introduces the suggested econometric methods

employed in the analysis. The empirical results are reported and discussed in section 5.3, while the last section presents the conclusions and policy implications of the study.

5.2. Methods

5.2.1 Theoretical and empirical background

Calbick and Gunton (2014) suggest that policy factors account for much of the variation in emissions among developed countries and they identify behavioural choices based on existing technologies as the most significant determinants of greenhouse gas emissions. Regarding government spending, economies with a large fiscal sector are associated with larger redistributive payments, which enhance equality of income and as a result lead to greater demand for enhanced environmental quality. In a related study, Frederik and Lundstrom (2001) report that if the quality of the environment is considered to be a luxury public good, it may only be demanded after more necessary public needs have been already addressed, which is more likely to occur in countries with a greater size of government spending.

It is important to mention that the mechanisms through which fiscal spending affects environmental pollution may differ according to the source of pollution, i.e. whether pollution is production- or consumption-generated (McAusland, 2008). For production-generated pollution, Lopez et al. (2011) recognize four different mechanisms through which the level of government expenditure may affect environmental quality. First of all, higher income levels, which are usually associated with increased government expenditure, enhance the demand for improved environmental quality (income effect). Furthermore, increased fiscal spending fosters human capital intensive activities which are less

detrimental to the environment compared to activities that are physical capital intensive (composition effect). Another channel that also tends to reduce environmental pollution is improved labor efficiency associated with higher levels of government spending on the health and education sectors (technique effect). Finally, depending on the relationship between fiscal spending and economic growth, increased government spending may lead to greater pollution in some levels of GDP (scale effect).

Considering consumption-generated pollution, fiscal spending on sectors like health and education increases consumers' current and future income and may in turn lead to deterioration of environmental quality, constituting the scale effect[45]. On the other hand, higher levels of government expenditure aid the establishment, enforcement and efficiency of environmental regulations, which may in turn lead to the development of institutions that enhance environmental quality (Fullerton and Kim, 2008), representing the environmental regulation channel. As a consequence, the total effect on consumption pollution depends on the relative magnitude of the scale and environmental regulation effects. In particular, in democratic regimes, where it is more likely to adopt stricter environmental rules compared to non-democratic administrations, the effect of environmental regulations has been found to dominate the scale effect and therefore a reduction in pollution levels is observed (Galinato and Islam, 2014). In addition, according to Lopez et al. (2010), government expenditure may facilitate pollution abatement by altering the composition of consumption goods towards less pollution intensive goods. For example, increased public spending may promote investment in public transportation and thus increase the use of such means of transportation that are considered to impose less environmental pressures, compared to the use of private forms of transportation (Zinmerman, 2005; Islam and Lopez, 2015).

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[45] For details see Chapter 2 of this dissertation.

The existent empirical literature offers indeterminate evidence on the estimated effect of fiscal spending on pollution. Regarding production-generated pollution, Bernauer and Koubi (2013) reported that a rise in fiscal spending increases air pollution, while the quality of governance does not significantly affect this relationship. In a related study, Yuxiang and Chen (2010) using provincial panel data provided evidence of a positive relationship between government expenditure and energy intensity in China. In addition, they demonstrated that this effect on energy intensity is greater in periods of economic crisis rather than in the years following economic recovery.

On the other hand, Frederik and Lundstrom (2001) reported that higher levels of economic freedom are associated with smaller pollution levels when the initial government size is small, but pollution worsens when the initial size of government is already large. Lopez et al. (2011) concentrated on the significance of the composition of public spending on the environment and stressed the importance of the percentage of public goods in total expenditure and found that an increase in the share of public goods reduces emission levels. Furthermore, they reported that increasing total government expenditure, with its composition remaining unchanged, also reduces environmental pollution, albeit this result is insignificant in some of the specifications they examined. In another relevant study, Lopez and Palacios (2014) analyzed the importance of fiscal spending and environmental taxes on pollution levels in European countries and reported that increasing the level of government expenditure improves environmental quality. Regarding consumption based pollution, Gallinato and Islam (2014) and Islam and Lopez (2015) reported that a larger share of social and public goods in total government expenditure enhances environmental quality, particularly in countries with democratic regimes.

Finally, it should be mentioned that although the focus of literature has been on the effects of government expenditure, it is nevertheless possible that the size of government revenues as well as the implementation of monetary policy also have an important role in the determination of environmental quality. Moreover, there are also indications of reverse causality from environmental pollution to macroeconomic policy (Rosenow et al., 2014).

5.2.2 Data description and summary statistics

The sample used to estimate the model consists of quarterly data for 12 macroeconomic and environmental variables for the U.S. economy, for the period 1973-2013. There are 164 observations per variable. This study employs the same set of variables as in Mountford and Uhlig (2009), essentially augmenting the model by the addition of CO_2 emissions variables[46]. In particular, the macroeconomic policy variables used are Total Government Expenditure (RBPEXP), Total Government Revenue (RBPREV) and Interest Rate (FFRT) accompanied by macroeconomic variables such as per capita Gross Domestic Product (GDPC), Private Consumption, Real Wages, Adjusted Reserves, Private Non-Residential Investment (as a proxy for capital stock), Energy Price Index[47] and GDP deflator[48]. It is important to note that, following Blanchard and Perotti (2002) and Mountford and Uhlig (2009), the government expenditure variable used in this study includes government consumption and investment, but excludes transfer payments.

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[46] It is worth mentioning that Mountford and Uhlig examined the period 1955–2000.

[47] The Energy Price Index variable we use is calculated as the weighted average price of coal, natural gas and oil and is preferred to the Producer Price Index, since it is more relevant for the purposes of this study.

[48] The use of both a Price Index and GDP deflator is common in the literature that examines the effect of monetary policy (Uhlig, 2005). This aids in the identification of the monetary policy shock but also mitigates the 'price puzzle' where the GDP deflator moves above zero first, before declining after a contractionary monetary policy shock (Aiyagari et al., 1992).

The macroeconomic variables employed in the analysis are derived from the Federal Reserve Board of St. Louis and the U.S. Bureau of Economic Analysis. All the components of national income are transformed in real terms by dividing their nominal values by the GDP deflator. The data for energy prices and CO_2 emissions are from the U.S. Environmental Protection Agency. Furthermore, CO_2 emissions may be distinguished in two categories according to their main source. In particular, emissions related to the industrial process are characterized as production-generated (CO_2IC), while those associated to residential and transport uses are characterized as consumption-generated (CO_2RTC).

The main human activity that emits CO_2 is the combustion of fossil fuels (coal, natural gas, and oil) for energy and transportation, accounting for 38% and 32% of total U.S. CO_2 emissions in 2012[49], respectively. Moreover, certain industrial (14%) and residential processes (9%) also emit CO_2. It is therefore important to study both consumption- and production-generated pollution since, as already mentioned, the mechanisms through which fiscal spending affects environmental quality are different and the respective estimated effects may also differ in each case. Production-generated CO_2 emissions can be decreased by using natural gas instead of coal to run machinery, by producing industrial goods from recycled or renewable materials and by improving energy efficiency. On the other hand, many strategies for reducing consumption related pollution are cross-cutting and apply to houses, businesses, industry, and transportation. Accordingly, the use and influence of environmental policies in consumption related pollutants is expected to be relatively more difficult and possibly require more time to achieve desirable improvements.

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[49] Emission estimates are derived from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012*.

The descriptive statistics of the CO_2 emissions and macroeconomic policy variables of the model are presented in Table 1. It is interesting to note that the mean value of CO_2RTC is higher than that of CO_2IC, depicting the fact that residential and transport activities are a relatively greater source of CO_2 emissions in the U.S. On the other hand, CO_2IC emissions variation is larger, as shown by the respective coefficients of variation. Regarding the macroeconomic policy variables, the average value of aggregate government spending is greater than that of government revenue, implying that the U.S. government mostly followed a deficit-financed fiscal policy during the examined period.

Table 1: Descriptive statistics of the CO_2 emissions and fiscal policy variables, 1973:1 – 2013:4

	CO_2IC	CO_2RTC	Total Expenditure	Government Revenues	Public Goods	Environmental Protection
Mean	0.001637	0.002555	5545.18	4571.35	1641.41	283.45
Median	0.001632	0.002531	5261.56	4256.18	1508.04	271.07
Maximum	0.002410	0.003119	10303.26	7230.34	3118.76	516.16
Minimum	0.001075	0.002115	1426.66	2424.63	415.80	77.76
Std. Dev.	0.000289	0.000198	2751.43	1111.59	838.95	115.11
Coef. of Var.	0.177	0.077	0.496	0.243	0.511	0.406
Observations	164	164	164	164	164	164

Note: Emissions data are in million metric tons of CO_2 per 1000 people. All macroeconomic variables are in dollars per capita terms.

5.2.3 Econometric approach

This study, following Mountford and Uhlig (2009), identifies the fiscal policy shocks by using sign restrictions while controlling for monetary and business cycle shocks. The computations are performed using a Bayesian approach. In order to describe the relationship between the structural VAR one-step ahead prediction errors and the structural macroeconomic shocks, the sign identification procedure starts with a reduced form VAR as:

$$Z_t = B_1 Z_{t-1} + B_2 Z_{t-2} + ... + B_p Z_{t-p} + \varepsilon_t$$

where Z_t is an *(m × 1)* vector, containing each of the *m* macroeconomic and CO_2 emissions variables included in the VAR model; B_i are coefficient matrices of size *(m x m)* containing the parameters to be estimated; and ε_t is the one-step ahead prediction error with variance-covariance matrix $E[\varepsilon_t \varepsilon_t^{'}] = \Omega$. The VAR system has two lags[50]. This choice is based on the performance of the following criteria[51]: Akaike Information Criterion (AIC) which suggests 3 lags, the Schwarz Information Criterion (SIC) which suggests 1 lag and the Hanann-Quinn Criterion (HQ) which suggests 1 lag. Based on these results 1 lag should be employed in the model, since the SIC and HQ criteria are more efficient when the number of observations is greater than 120, as is the case here (Khim-Liew, 2004). However, the Wald test for lag exclusion estimation on an estimated VECM[52] with a standard, for quarterly data, 4 lag length suggested that the 3rd lag coefficients are jointly insignificant. Furthermore, it is important in this framework that the residuals of the estimated model - at the selected lag length - are not autocorrelated. Related to this, Hendry and Juselius (2001) argue that the lag length ought to be set in such a way that the VAR residuals are free of autocorrelation, even if this implies longer lags than suggested by the information criteria. Performance of the Portmanteau Autocorrelation and the Residual Serial Correlation LM tests showed that when the model is estimated with 1 lag the residuals are significantly autocorrelated, while this is not the case when 2 lags are included in the model.

Moreover, no constant term or a time trend[53] are included in the model and the logarithm for all variables is used, except for the interest rate where the level was used. Since measures of aggregate output and consumption are included in the model and following the terminology

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[50] The number of lags we use differs from that employed in Mountford and Uhlig (2009), who are using six lags instead.

[51] For details see Halkos (2006, 2011).

[52] Since, as we will see in the next section the variables in the system are non-stationary, but co-integrated.

[53] The decision to exclude both the constant and time trend follows Uhlig (2005) and Mountford and Uhlig (2009). This improves the robustness of the results because of the interdependencies in the specification of the constant term and the roots in the autoregressive coefficients. For details see Uhlig (1994).

used to classify the effects on pollution, the coefficients of the government expenditure variable mainly capture the composition effect and part of the technique effect concerning production-generated emissions and the unobserved environmental regulation effect regarding consumption related pollution[54].

Table 2: Identification by sign restrictions

	Gov. revenue	Gov. spending	GDP, non-res.inv, cons, CO_2	Interest rate	Adjusted reserves	Prices
Non-fiscal shocks						
Business cycle	+		+			
Monetary Policy				-	+	+
Basic fiscal policy shocks						
Government revenue	-					
Government spending		+				

Table 2 summarizes the identification strategy used in the study. A business cycle shock is characterized by simultaneously moving output, government revenue, non-residential investment, consumption and CO_2 emissions in the same direction for four quarters following the shock. A monetary policy shock reduces interest rates and increases reserves and energy prices for four quarters after the shock. In addition, the monetary policy shock is set to be orthogonal to the business cycle shock. The basic fiscal policy shocks are then identified by requiring that they are orthogonal to both monetary policy and business cycle shocks. In particular, the government spending shock is defined as a shock where government spending rises for a year after the shock, while the government revenue shock is characterized by a decrease of government revenue for one year. However, it is important to note that in order to avoid any bias in the estimated results, there are no sign restrictions imposed on the reaction of the environmental and macroeconomic variables of interest to fiscal policy shocks.

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[54] As we consider only the U.S. economy, the inclusion of a governance quality proxy variable is not necessary in the model, particularly taking into account that there was little variation of regulations and stability in the U.S. during the examined period. This is reflected by many relevant indicators like those of the Polity IV Project. Consequently, any remaining regulatory effect being captured by the coefficients of government expenditure on emissions is expected to be related to time variant environmental regulations.

The main purpose of characterizing the business cycle and monetary shocks is to isolate the effects of these shocks on the fiscal variables. Rather than simultaneously identifying all shocks, subject to the orthogonality restrictions, the business cycle shock is identified first followed by the monetary policy shock, thus attributing as much variables movement as possible to these shocks. Moreover, the requirement that the monetary policy and business cycle shocks are orthogonal to a fiscal policy shock ensures the separation of the automatic responses of fiscal variables to these shocks. This identification strategy, combined with the measure of government expenditure used[55], serves the separation of changes in the variables of interest that are the result of actual fiscal policy shocks, rather than capturing their variation in response to the business cycle shocks. Therefore, this approach allows us to identify the genuine effects of fiscal policy on emission levels. For example, the method used avoids capturing the adjustments of fiscal policy to fluctuations in the economy that are associated with different production levels and hence CO_2 emissions from the production sector, since this would imply that fiscal stimulus does not cause the reduction in emissions but is a result of the decrease. Similarly, considering that energy prices constitute a major determinant of energy consumption and CO_2 emissions, this approach ensures that the identified fiscal policy shocks in the model are not related to rises in energy prices associated with downturns in the economy.

Furthermore, there is a difficulty in defining a fiscal policy shock since there are many different ways that fiscal policy can be implemented. To address this issue, this research considers fiscal policy shocks that range between a government spending and a government revenue shock and include any linear combination of them like a balanced budget policy. To enhance the identifying power of the model, the responses of the fiscal variables are restricted

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[55]As already mentioned, the government expenditure variable used excludes transfer payments that would automatically vary counter-cyclically.

for four quarters after the initial shock, ruling out short-term changes in government expenditure that do not constitute part of a specific fiscal policy implementation.

In particular, this study examines the implementation of realistic fiscal policies such as a deficit-financed expenditure and deficit-financed tax-cut shocks. A deficit-financed spending policy combines the basic fiscal shocks in such a way that fiscal expenditure rises by 1% and tax revenues remain constant for one year. By denoting $r_{j,a}(k)$ as the response at horizon k of variable j to the impulse vector a, then the above policy requires that:

$$0.01 = \sum_{j=0}^{k}(r_{GS,BGS}(k-j)BGS_j + r_{GS,BGR}(k-j)BGR_j) \quad \text{for } k = 0,...K$$

$$0 = \sum_{j=0}^{k}(r_{GR,BGS}(k-j)BGS_j + r_{GR,BGR}(k-j)BGR_j) \quad \text{for } k = 0,...K$$

where K = 4, GS and GR represent government expenditure and government revenue respectively, and BGS and BGR are correspondingly the scale of standard basic government spending and revenue shocks in period j. On the other hand, a deficit-financed tax-cut is designed as a sequence of basic fiscal shocks such that tax revenues are reduced by 1% and government expenditure is kept constant for one year after the initial shock. In this regard, it should be clear that other scenarios of interest may be analysed in a similar way as well[56].

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[56] The impulse responses to a balanced budget expenditure policy that requires both tax returns and government spending to rise in such a way that the increase in returns and spending is equalized for each quarter for a one year period were also considered. The results resembled those of the deficit spending scenario.

5.3. Results and discussion

5.3.1 Base model

Before estimating the model, the time series properties of the variables used in the analysis are tested. To accomplish this, the Augmented Dickey-Fuller (ADF), the Phillips-Perron (PP) and the DF-GLS unit root tests were conducted. The respective results for the variables of the model are presented in Table 3.

For each test two processes are reported, namely one with only the intercept being considered and another with both an intercept and a trend. The application of the Phillips-Perron test complements the ADF test and its main advantage is that it takes into account higher order serial correlation while also being more appropriate in the presence of a structural change. Finally, the DF-GLS test is additionally performed, since its power against the alternative of a deterministic trend is higher than that of the ADF (Elliott et al., 1996). The choice of the optimum number of lags used is based on an application of the Schwarz (SC) criterion. In general, there is no evidence of stationarity in levels and all the time series used are integrated of order one, at the 10% significance level.

The Johansen Co-integration test (Johansen and Juselius, 1990) is also used to determine the number of co-integrating relations. Since the trace and the maximum eigenvalue statistics may yield conflicting results, both of them are reported in this study. Table 4 reports the Johansen Co-integration test results. The first column shows the number of co-integrating relations under the null hypothesis, while the first block reports the trace statistics and the second block reports the maximum eigenvalue statistics. To determine the number of co-integrating relations, conditional on the assumptions made about the trend, one can proceed sequentially until failing to reject. At the 0.05 significance level, the trace statistic indicates

the existence of five co-integrating equations, while the maximum eigenvalue statistic

suggests that there are three co-integrating equations.

Table 3: Unit root ADF, Phillips-Perron and DF-GLS tests – Quarterly data 1973:1 – 2013:4

Variables	Deterministic	ADF		Phillips-Perron		DF-GLS	
		Level	Difference	Level	Difference	Level	Difference
CO_2IC	Intercept	-1.09(0)	-11.95(0)***	-1.15(4)	-11.95(5)***	0.96(0)	-2.34(6)
	Trend and intercept	-2.39(0)	-11.92(0)***	-2.48(1)	-11.92(0)***	-2.23(0)	-10.73(0)***
CO_2RTC	Intercept	-1.87(3)	-7.42(2)***	-2.60(4)	-17.50(4)***	-1.31(3)	-0.87(6)
	Trend and intercept	-1.81(3)	-7.43(2)***	-2.58(4)	-17.50(4)***	-1.89(3)	-1.97(6)
RBPEXP	Intercept	-1.20(4)	-3.70(3)***	-0.87(8)	-11.27(8)***	-0.01(5)	-1.92(4)
	Trend and intercept	-2.31(5)	-3.76(3)***	-1.56(8)	-11.27(8)***	-2.40(5)	-2.38(4)
RBPREV	Intercept	-1.87(1)	-11.45(0)***	-2.17(7)	-11.74(7)***	-1.63(1)	-11.27(0)***
	Trend and intercept	-3.19(4)	-11.42(0)***	-2.57(7)	-11.71(7)***	-3.15(4)	-4.30(3)***
FFRT	Intercept	-1.81(1)	-10.38(0)***	-1.66(5)	-10.38(0)***	-1.75(1)	-1.72(4)
	Trend and intercept	-3.93(5)	-10.35(0)***	-3.32(5)	-10.35(0)***	-3.36(5)	-2.92(4)
RGDPC	Intercept	-0.80(1)	-8.66(0)***	-0.90(6)	-8.89(5)***	-2.25(1)	-7.58(0)***
	Trend and intercept	-1.61(1)	-8.66(0)***	-1.59(6)	-8.85(4)***	-1.74(1)	-8.48(0)***
RCON	Intercept	-1.20(1)	-6.41(1)***	-1.06(7)	-9.64(6)***	-2.05(2)	-5.62(1)***
	Trend and intercept	-1.13(2)	-9.29(0)***	-1.05(7)	-9.58(6)***	-1.45(2)	-6.02(1)***
RNRESINV	Intercept	-1.38(2)	-6.39(1)***	-1.25(7)	-9.73(6)***	-1.98(2)	-5.65(1)***
	Trend and intercept	-0.97(2)	-9.39(0)***	-0.85(7)	-9.69(5)***	-1.31(2)	-6.01(1)***
GDPDEF	Intercept	-3.48(2)***	-2.29(1)	-7.85(9)***	-2.39(7)	-0.43(2)	-1.49(1)
	Trend and intercept	-3.38(2)	-3.23(1)	-3.93(9)	-4.33(8)***	-0.84(2)	-3.25(1)
WAGES	Intercept	-0.34(0)	-14.63(0)***	-0.31(3)	-14.57(3)***	1.95(0)	-1.45(6)
	Trend and intercept	-2.37(0)	-14.59(0)***	-2.41(5)	-14.53(3)***	-1.85(0)	-7.17(1)***
ARES	Intercept	0.89(1)	-9.63(0)***	1.15(4)	-9.58(3)***	1.94(1)	-9.63(0)***
	Trend and intercept	-0.88(1)	-9.80(0)***	-0.66(4)	-9.79(2)***	-1.08(1)	-9.82(0)
PPICF	Intercept	-1.37(2)	-10.36(1)***	-1.61(3)	-9.66(6)***	-1.40(2)	-5.22(2)***
	Trend and intercept	-1.40(2)	-10.39(1)***	-1.60(4)	-9.69(7)***	-1.40(2)	-5.97(2)***

Note: Numbers in parentheses are lag levels determined by the Schwarz Bayesian Criterion for the DF tests and the Newey-West bandwidth selection for the Phillips-Perrons test.

***Indicates significance at the 1% level.

Table 4: Johansen Cointegration test

Hypothesized No. of CE(s)	Trace test		Max Eigenvalue	
	Trace Statistic	Probability	Max-Eigen Statistic	Probability
H_0: r = 0	503.611	0.000	133.977	0.000
H_0: r ≤ 1	369.634	0.000	83.209	0.002
H_0: r ≤ 2	286.424	0.000	67.037	0.028
H_0: r ≤ 3	219.388	0.002	56.737	0.073
H_0: r ≤ 4	162.650	0.033	43.690	0.290
H_0: r ≤ 5	118.960	0.119	30.732	0.737

Overall, the results show that the variables in the system are non-stationary but co-integrated, therefore, the estimation of the VAR in levels provides consistent estimates (Sims et al., 1990; Lütkepohl and Reimers, 1992). Moreover, in the Bayesian VAR methodology the parameters of the VAR are estimated in levels (Sims and Uhlig, 1991; Uhlig, 2005; Mountford and Uhlig, 2009). Hence, this study uses the variables in (log) levels to estimate the VAR model. Finally, the methodology used is robust to the presence of non-stationarity and though it does not impose any co-integrating long-run relationships between the variables, it does not preclude their existence either.

The impulse response functions and forecast error variance decomposition analysis are important to evaluating the estimated results, since they portray the way each variable responds to an innovation in other variables and how long these effects last. Before focusing on the effect of fiscal policy on CO_2 emissions, the impulse responses of the main macroeconomic variables of the model are considered and briefly compared to the recent literature on macroeconomic policy shocks using VAR models. For reasons of comparability, all impulse responses have been constructed in such a way as to reflect expansionary macroeconomic policies and hence, pertain to an increase of government expenditure and reductions of government revenue and of the interest rate.

5.3.1.1 The effects on macroeconomic variables

The impulse responses of the macroeconomic variables to the business cycle and expansionary policy shocks are portrayed in Figures 1-4. In response to the business cycle shock, output, consumption and private investment rise in the first four quarters by construction and this increase persists until the end of the second year after the shock. Energy prices also increase, however this effect is significant only during the first year. Most

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importantly, government expenditure does not behave in a counter-cyclical way and increases slowly starting from the third year. This result is consistent with Mountford and Uhlig (2009) and reflects the choice of the government expenditure variable used in this study. In particular, the government spending variable used is not characterized by automatic changes during the business cycle, since it excludes transfer payments which vary counter-cyclically. On the other hand, monetary policy shocks lead to a significant rise in energy prices that lasts for four years. Furthermore, expansionary monetary policy is associated with marginally higher consumption in the short-term; however, its effect on output is insignificant throughout the examined period, a result that is in line with the findings of Uhlig (2005) who reports no clear direction for real GDP in response to a surprise change in interest rates.

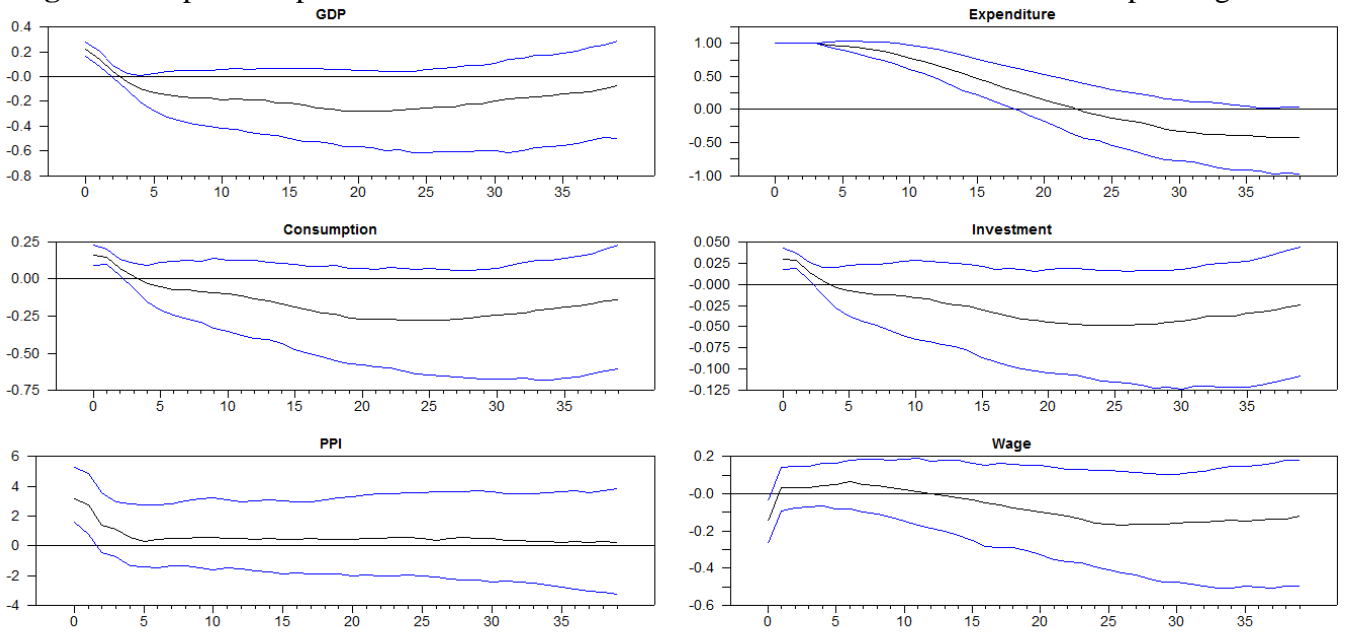**Figure 1**: Impulse responses of the main macroeconomic variables to the business cycle shock
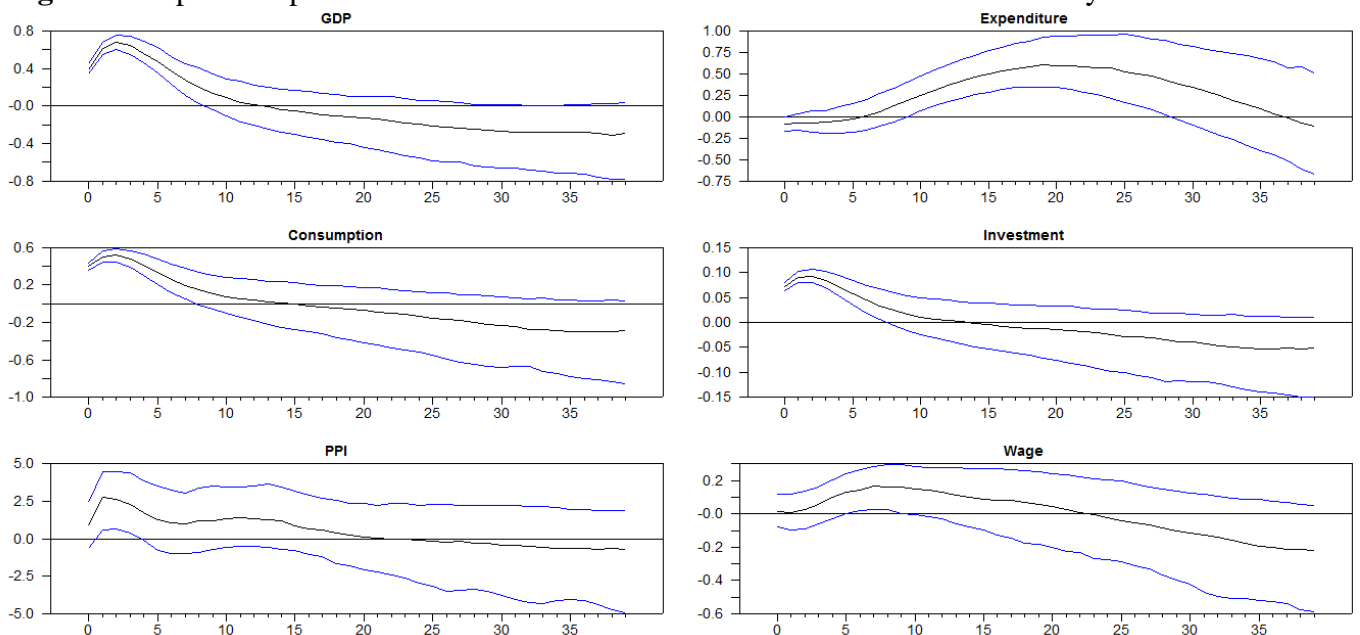
Responses to Business Cycle

Figure 2: Impulse responses of the main macroeconomic variables to the monetary policy shock
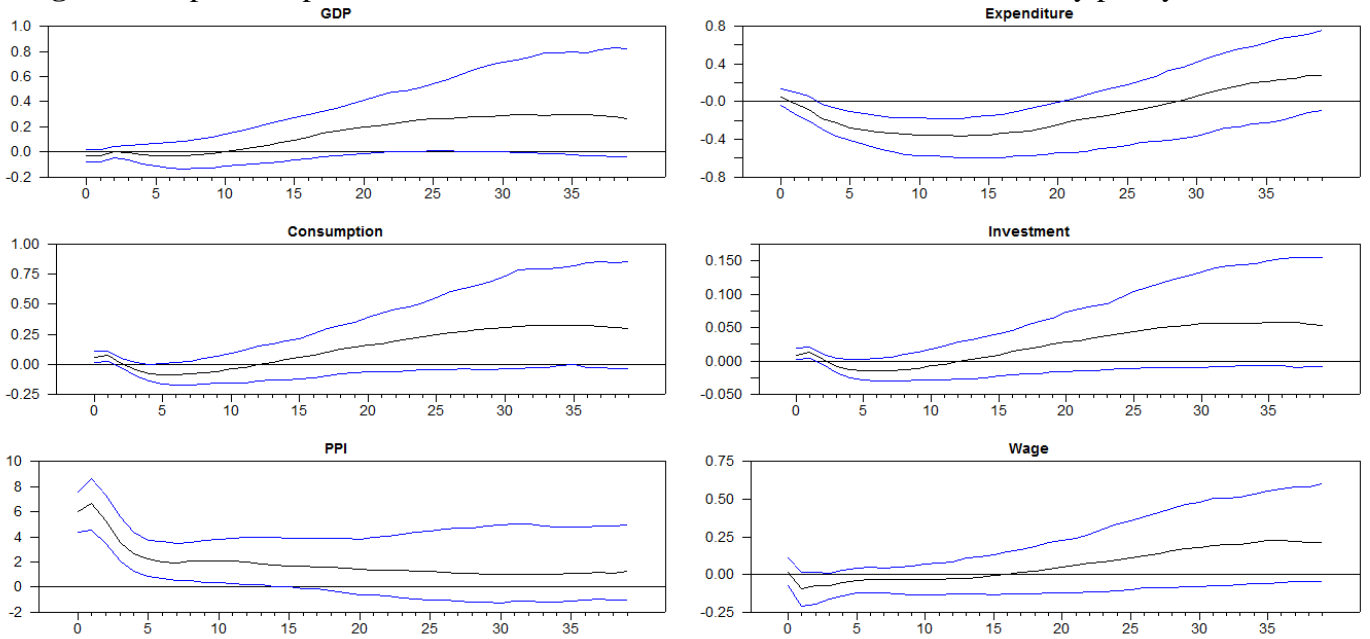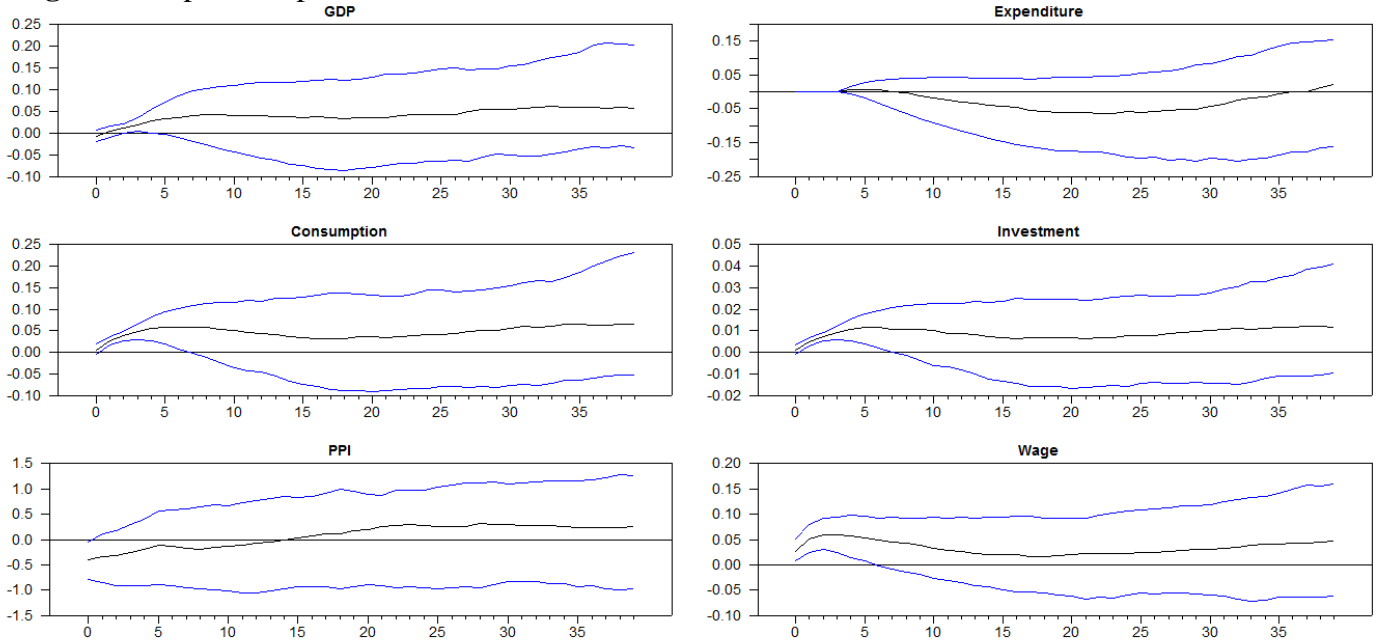

Responses to Monetary Policy

Figure 3: Impulse responses of the main macroeconomic variables to the deficit total spending shock

Responses to Deficit Total Spending

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Figure 4: Impulse responses of the main macroeconomic variables to the deficit tax cut shock

Responses to Deficit Tax Cut

Considering fiscal policy, the deficit government spending shock stimulates output during the first four quarters and also has a positive effect on private consumption. The response of energy prices to a spending shock is to increase during the first year, which is an intuitive result. Finally, a deficit-financed tax-cut slightly stimulates output and consumption for one and two years respectively, whereas it has no effect on energy prices. It is interesting to note that the results provide no evidence of a greater stimulative effect of tax-cuts on output, compared to an increase in government spending. This finding conforms to the standard Keynesian model but is not in line with recent studies which report a greater multiplier effect of tax-cuts compared to government spending (Romer and Romer, 2009; Mountford and Uhlig, 2009). Moreover, the result that both decreases in taxes and increases in government expenditure have a positive effect on private investment, is also in line with Keynesian theory, which predicts opposite effects of tax and spending increases on private investment. Finally, real wages do not rise in response to an increase in government spending and have a

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negative response on impact[57]. Thus, taken together, these findings do not comply completely with the standard Keynesian approach, although they are also not the responses predicted by the benchmark real business cycle model.
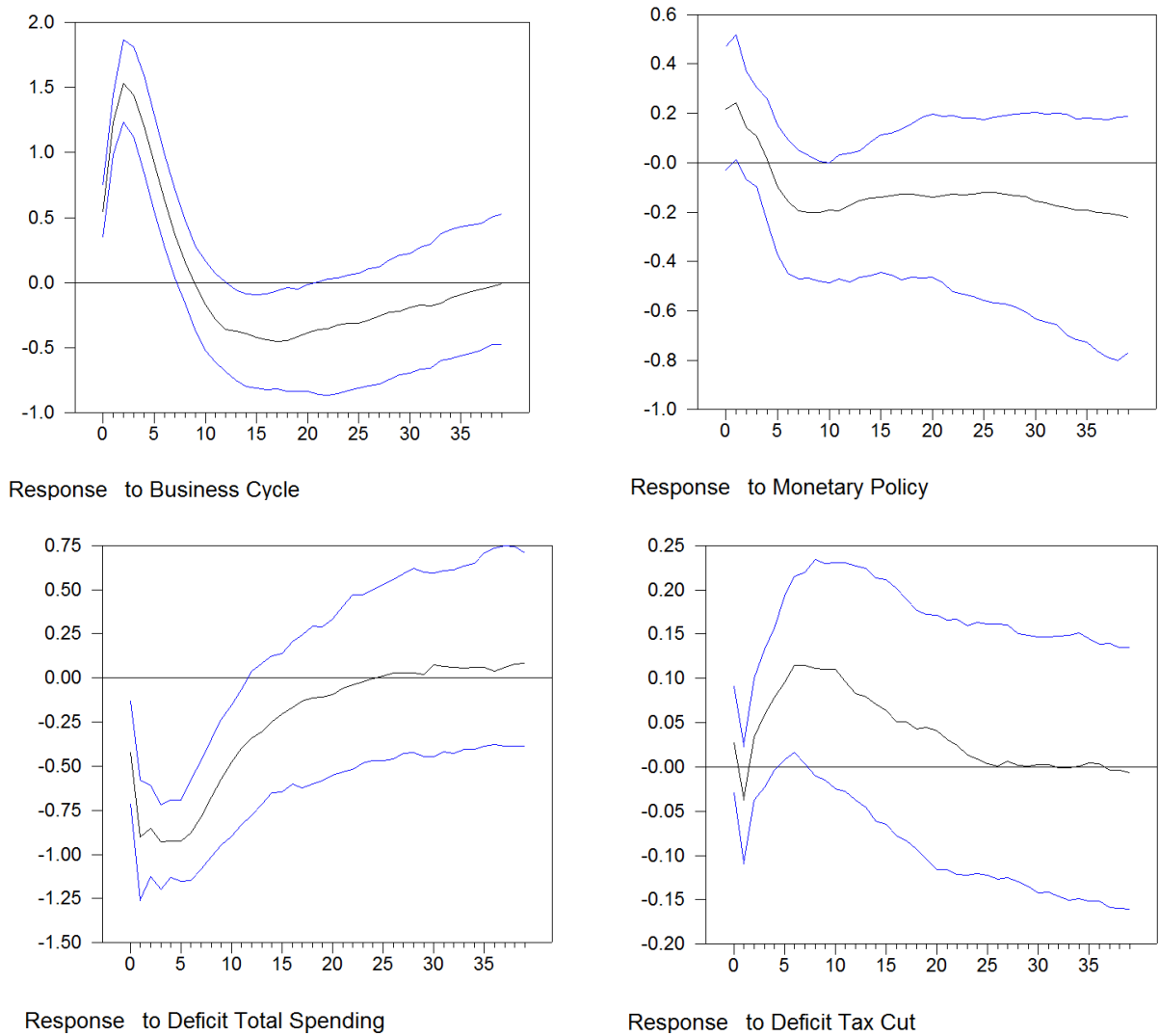
5.3.1.2 The effects on CO_2 emissions

The generalized impulse responses for the CO_2 emissions generated from production and consumption are depicted in Figures 5 and 6, respectively. Following a business cycle shock, production-generated emissions increase but this effect is significant only for two years after the shock. Furthermore, CO_2IC does not significantly respond to an expansionary monetary policy. Following an aggregate government expenditure shock, CO_2IC emissions decrease for three years with the effect reaching a maximum of -0.94% towards the end of the 1st year. However, there is little evidence of a statistically significant effect of government revenues on CO_2IC.

Consumption-generated CO_2 emissions also rise during a business cycle shock, with the effect being significant for three years after the shock. On the other hand, CO_2RTC falls after an expansionary monetary policy, a result that may be attributed to the hike of energy prices as depicted in Figure 2. In response to an increase in government expenditure, CO_2RTC decreases for almost two years, however, the effect is insignificant thereafter. Finally, consumption related CO_2 emissions slightly rise in the short-term following a government revenue shock, while the effect ceases to be significant towards the end of the 2nd year after the shock.
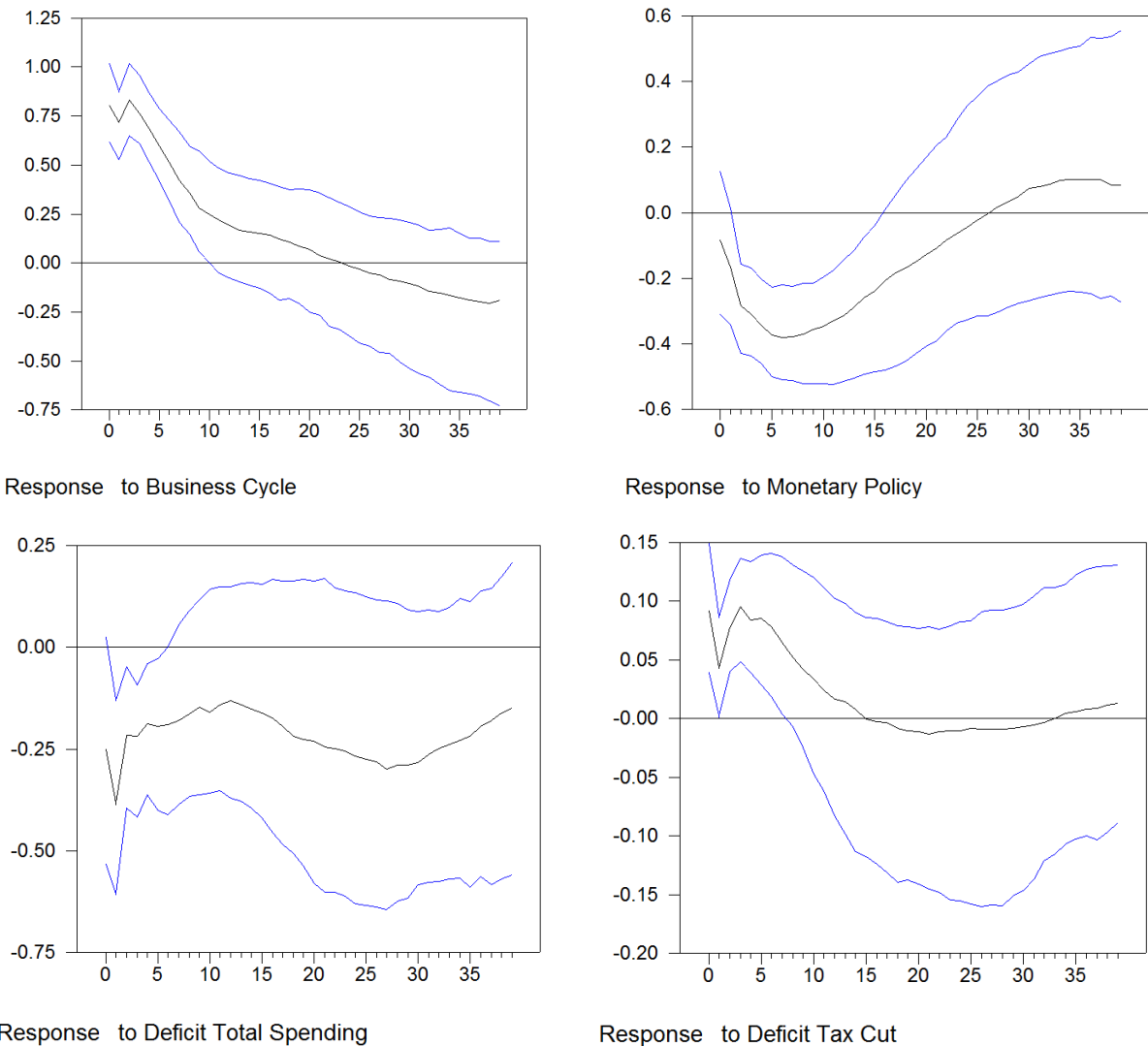
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[57] Mountford and Uhlig (2009) report a similar finding.

Figure 5: Impulse responses of CO_2IC to Business Cycle, Monetary Policy, Government Spending and Government Revenue Shocks

Response to Business Cycle

Response to Monetary Policy

Response to Deficit Total Spending

Response to Deficit Tax Cut

Note: The figures plot the 16th, 50th and 84th quantiles of the impulse responses, calculated at each horizon between 0 and 40 quarters after the shocks.

Figure 6: Impulse responses of CO_2RTC to Business Cycle, Monetary Policy, Government Spending and Government Revenue Shocks

Response to Business Cycle

Response to Monetary Policy

Response to Deficit Total Spending

Response to Deficit Tax Cut

Note: The figures plot the 16th, 50th and 84th quantiles of the impulse responses, calculated at each horizon between 0 and 40 quarters after the shocks.

Table 5 summarizes the forecast variance of CO_2 emissions induced by innovations of the system variables at different time periods and depicts the relative contribution of the innovations to explaining movements of CO_2 emissions. The results show that the most significant determinant of CO_2IC emissions in the long-term is the energy price, which explains 34% of emissions variation, a finding that is similar to other studies (Mahadevan and Asafu-Adjaye, 2007; Salim et al., 2008). Aggregate government expenditure is also an important factor accounting for more than 20% of CO_2IC emissions variation over the

forecast period and reaching a maximum of 30% during the 3rd year after the shock. On the other hand, government revenues do not explain more than 3% of CO_2IC variation during the examined period. It is interesting to note that household consumption explains a larger percentage of CO_2IC emissions than GDP, confirming the result reported by Islam and Lopez (2015) that, for production-generated pollution, the income effect dominates the scale effect in the U.S. Finally, in the long-term, less than 25% of CO_2IC variation is due to its own innovations.

Table 5: Variance decomposition results

Variance Decomposition of CO2IC

Quarter	S.E.	CO_2	Spending	Revenues	Energy Price	Consumption[58]	GDP
1	0.020	88.854	0.330	1.614	0.191	4.613	4.399
4	0.041	44.220	29.580	2.768	0.292	4.815	18.325
12	0.074	27.204	30.482	1.917	19.212	10.282	10.903
20	0.097	25.952	25.196	1.379	28.040	11.796	7.637
28	0.114	25.401	23.061	1.160	31.639	12.437	6.302
40	0.137	24.982	21.475	0.997	34.325	12.917	5.305

Variance Decomposition of CO2RTC

Quarter	S.E.	CO_2	Spending	Revenues	Energy Price	Consumption[55]	GDP
1	0.020	92.071	0.706	0.001	0.059	7.131	0.033
4	0.031	80.436	4.345	0.986	3.067	9.487	1.678
12	0.058	71.618	3.785	0.529	12.158	11.144	0.766
20	0.077	69.986	2.797	0.351	15.119	11.307	0.440
28	0.092	69.390	2.409	0.282	16.237	11.369	0.313
40	0.111	68.960	2.132	0.233	17.040	11.414	0.221

Note: The ordering of variables for Cholesky decomposition, from first to last is: Energy prices, energy consumption, GDP, consumption, government expenditure, government revenue, CO_2IC, CO_2RTC.

The most important contributor for CO_2RTC emissions is also energy prices, contributing to more than 17% of emissions variation in the long-term. Moreover, private consumption explains 11% of CO_2 emissions movement during most of the examined period, while

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[58] Includes energy consumption.

government expenditure is the third most important factor accounting for less than 4.5%. However, as much as 69% of CO_2RTC variation is attributed to its own innovations.

Overall, the results suggest that a deficit-financed increase in aggregate spending reduces CO_2 emissions from the production sector in the short- and mid-term, and CO_2 emissions from the residential and transport sectors in the short-term. On the other hand, a deficit-financed tax-cut causes a small short-run increase in consumption-generated emissions, a result that may be associated with an easing of environmental regulations, for example by reducing fuel taxes. Hence, considering the impact on CO_2 emissions, a fiscal expansion based on deficit-financed spending is preferable to a deficit-financed tax-cut.

## 5.3.2 Comparison of the effects of different spending categories

It should be highlighted that the major objective of a government spending expansion is the stimulation of the real economy rather than the improvement of environmental quality. In this regard, some components of government expenditure may be neutral to environmental quality or even inadvertently deteriorate it by counterbalancing the efficiency of other programs. The results of the previous section merely provide evidence that increasing aggregate government spending, in a similar way that the U.S. government did during the examined period, leads to short- and medium-term reductions in CO_2 emissions. Moreover, the alleviating effect of aggregate government expenditure on CO_2 pollution levels is greater in the production rather than the residential sector. However, these findings do not offer guidance to the policy makers on which spending categories to increase in order to optimize the abatement of CO_2 emissions. Therefore, basing the analysis on aggregate spending expansions could lead to erroneous conclusions regarding the potential effect of government expenditure on CO_2 emissions.

Fiscal policy can be designed to have a large and sustained impact on reducing air pollution, or alternatively on increasing emissions, depending on its design. As shown by Lopez et al. (2011), it is the composition of government expenditure that matters more than aggregate spending. For example, certain government spending in infrastructure such as public transportation, energy efficiency or improved environmental regulations are expected to have a greater and more persistent alleviating effect on emission levels than a general increase in aggregate spending. Moreover, to the extent that the effects of such targeted investments apply equally to residential and industrial sectors, the estimated effects should be of comparable size in both production- and consumption- generated CO_2 emissions. Figure 7 portrays the impulse responses of CO_2 emissions to shocks in two different spending categories, namely government expenditure on public goods and spending on environmental protection.

The measure for spending on public goods used here follows the taxonomy proposed by Lopez and Galinato (2007) and comprises components of spending on health, higher education, transportation, housing and community services, recreation and culture, income security and environmental protection. Several recent studies have given credibility to the hypothesis that a reallocation of government spending composition towards social and public goods leads to significant enhancements of environmental quality, while the magnitude of aggregate government spending is not so important (Lopez et al. 2011; Galinato and Islam, 2014; Islam and Lopez, 2015). The impulse response functions show that a 1% increase in spending on public goods reduces production-generated CO_2 emissions from the 2nd year until the beginning of the 5th year, reaching a maximum of -0.79% during the 3rd year after the shock. Regarding consumption-generated emissions, the estimated effect is significant

from the 1st year, albeit small in absolute values, however it progressively increases after the 1st year, peaks at -0.59% during the 5th year and is sustained until the end of the 8th year.

Figure 7: Impulse responses of CO_2 emissions to Government Spending on public goods and environmental protection.
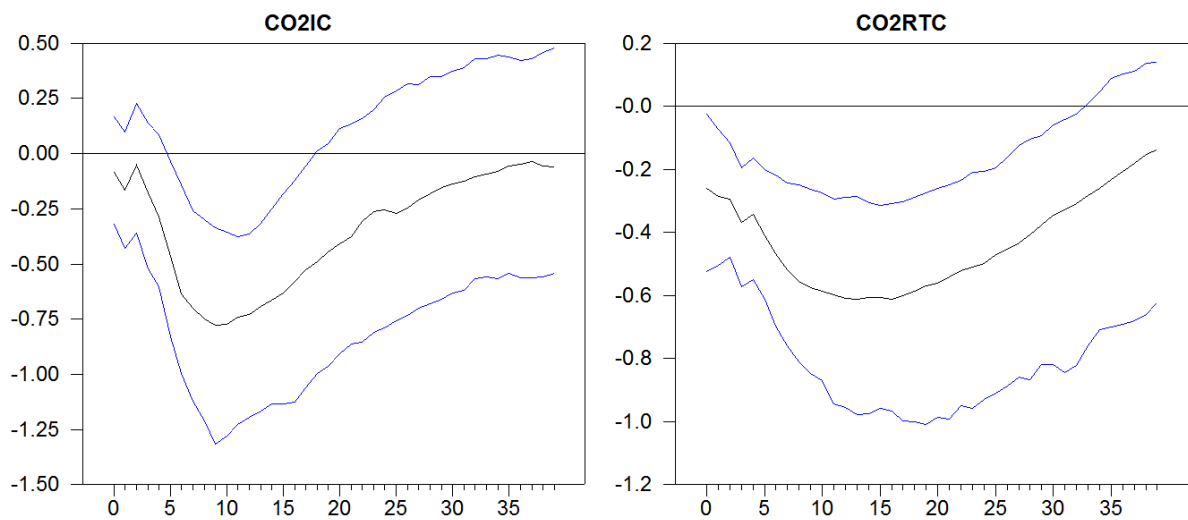
Responses to Deficit Spending on Public Goods
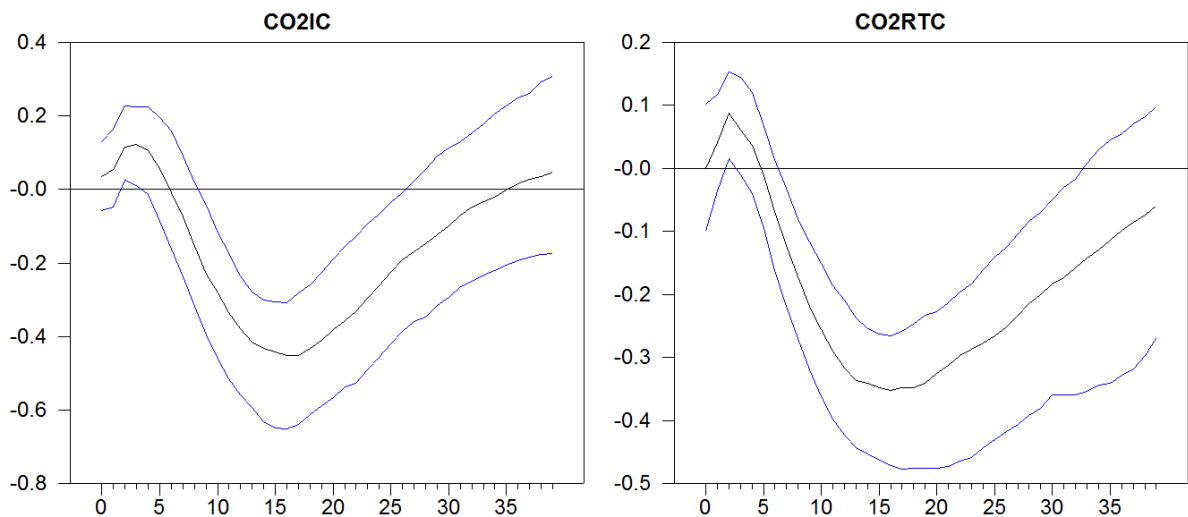
Responses to Deficit Spending on Environmental Protection

Note: The figures plot the 16th, 50th and 84th quantiles of the impulse responses, calculated at each horizon between 0 and 40 quarters after the shocks.

The effect of spending in environmental protection on CO_2 emissions is an obvious relationship to investigate. According to the international Classification of Functions of

Government (COFOG) and the U.S. Bureau of Economic Analysis, environmental protection spending in the U.S. is included in expenditure on housing and community services, energy and natural resources. The magnitude of the alleviating effect on CO_2 emissions per dollar spent is expected to be the greatest in this category. The results suggest that an increase of environmental protection spending significantly reduces production-generated CO_2 emissions starting from the 3rd year while the effect peaks during the 5th year at -0.48% and lasts until the 7th year after the shock. Concerning consumption-generated pollution, the observed pattern is very similar. In particular, consumption related CO_2 emissions begin to decline during the 2nd year after the shock, this effect reaches a maximum of -0.36% during the 4th year and persists as long as the end of the 9th year after the shock.

5.3.2.1 Measures of the effects of different spending categories

To further examine the effects of the different spending categories, a measure of the effect of each scenario along the entire path of the responses up to a given period is useful. Table 6 presents the cumulative elasticity multipliers, which capture the cumulative percentage effect on CO_2 emissions for every 1% cumulative increase in the different categories of expenditure during the examined period. Therefore, this measure also takes into account the responses of the spending variables to their own shocks. Following Mountford and Uhlig (2009), this study calculates the multiplier using the following formula:

$$\textit{cumulative elasticity multiplier at lag } k = \frac{\sum_{j=0}^{k} CO_{2j}}{\sum_{j=0}^{k} f_j}$$

where $CO2_j$ is the response of CO_2 emissions at period j and f_j is the response of the fiscal variable at period j. The median multiplier is used in all cases.

Table 6: Cumulative elasticity multipliers and relative efficiency of the deficit spending scenario on CO_2 emissions for the different expenditure categories

	1 qrt	4 qrts	12 qrts	28 qrts	40 qrts	Last significant	Relative Efficiency
CO2IC							
Total spending	-0.39*	-0.77*	-0.78*	-0.77*	-0.63	-0.73* (qrt 34)	1.00
Public goods	-0.06	-0.13	-0.72*	-1.27	0.25	-1.68* (qrt 24)	7.67
Environmental protection	0.02	0.08	-0.08	-0.63*	-0.72	-0.71* (qrt 38)	19.45
CO2RTC							
Total spending	-0.26*	-0.25*	-0.19*	-0.45*	-0.62	-0.54* (qrt 31)	1.00
Public goods	-0.27*	-0.29*	-0.66*	-0.96	1.16	-1.46* (qrt 23)	9.01
Environmental protection	0.02	0.05	-0.10*	-0.60*	-0.65	-0.75* (qrt 36)	27.78

Note: * indicates significance at the 5% level. The multipliers presented are the median values. The relative efficiency is calculated at the last significant estimate of the multiplier for each category and represents the magnitude of the effect of a one dollar increase in each spending category, compared to a one dollar increase in total expenditure.

In general, the cumulative elasticity multipliers of the spending categories are greater for production-generated pollution compared to consumption pollution, however the difference is small. This finding is in line with other recent studies (Halkos and Paizanos, 2013; Islam and Lopez, 2015). Moreover, combining the results of this section it is evident that the effects of government expenditure on emissions from the production sector occur earlier and accumulate relatively faster, while the effect on residential pollution is sustained for several more years following the spending shock. It is important to mention at this point that some of the short-term effect on emissions may be attributed, apart from the channels discussed in section 5.2, to the increase in energy prices that follows a government spending shock, as depicted in Figure 3[59]. This increase in prices may directly reduce CO_2 emissions by dropping demand for energy consumption and also by inducing energy efficiency improvements which are relatively more cost efficient and are implemented more quickly in the production sector rather than in the consumption sector (Glatt and Schwentker 2010; Chittum, 2011). Furthermore, according to the stylized facts of business cycle theory,

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[59] The finding that the effect of government expenditure on the environment begins already from the 1st year is consistent with the findings by Islam and Lopez (2015) who report significant effects on emissions in the U.S. from both the current and lagged fiscal variables.

variation in consumption levels and preferences is much smoother compared to changes in the production sector.

Related to the above, an interesting finding is that spending on environmental protection begins to have an effect on production and consumption related emissions only during the 3rd and 2nd year, respectively. A plausible explanation for this result is that investments on improved environmental regulations can take several years to complete and thus their main effect on CO_2 emissions occurs in the mid- to long-term horizon.

It should be noted that the magnitude of the different spending categories, in dollar terms, varies substantially as depicted in Table 1. For example, at the sample average level, a 1% increase corresponds to a \$55 and \$2.83 rise in aggregate spending and environmental protection expenditure, respectively. Therefore, to directly compare the efficiency between the different categories of spending on reducing CO2 emissions, the size of the expenditure is taken into account and an appropriate measure using the following formula is calculated:

$$\textit{relative efficiency of spending category } c = \frac{1}{s_c} \times \frac{CO_{2c\,last}}{CO_{2t\,last}}$$

where s_c is the average share of spending category c to aggregate spending, $CO_{2c\,last}$ is the last significant cumulative elasticity multiplier of spending category c and $CO_{2t\,last}$ is the last significant cumulative elasticity multiplier of total spending. In particular, the relative efficiency measure captures the effect on CO_2 emissions of a one dollar increase in each spending category and compares it to a one dollar increase in aggregate spending as implemented in the U.S. during the examined period. The last column of Table 6 summarizes these relationships.

The results suggest that spending on public goods and environmental protection have a much greater and sustainable effect on CO_2 emissions for production- and residential-generated pollution while, as expected, the most efficient spending policy for reducing CO_2 emissions is government expenditure targeted at environmental protection. For each dollar spent in the public goods expenditure category there is a 7.67 times greater reduction of production-generated emissions and a 9.01 times greater alleviating effect on residential related emissions, compared to the same dollar increase in aggregate government expenditure. On the other hand, a one dollar increase of government expenditure targeted at the environmental protection category results in an estimated 19.45 and 27.78 times larger reduction in production- and consumption-generated emissions, respectively.

5.3.3 Robustness check: Environmental policies

Omitted time-varying variables may bias the coefficients of the fiscal policy variables if they are correlated with each other. A particular concern is the omission of time-varying environmental regulations that are difficult to measure and may be correlated with government expenditures or revenues. For this reason, a robustness check is performed by enhancing the model with structural change dummy variables which correspond to several environmental policies announced and followed during the examined period. Specifically, the null hypothesis that there is no structural break in the model is tested by employing the following likelihood ratio test:

$$LR = (T - m) * \left(\ln \left| \sum r \right| - \ln \left| \sum u \right| \right) \sim \chi^2(q),$$

where T is the number of observations; m the number of parameters to be estimated; Σ_r and Σ_u are the determinants of the covariance matrix of the residuals of the restricted and

unrestricted models, respectively and q represents the degrees of freedom equalling the number of dummies multiplied by the number of equations in the model.

Firstly, Table 7 presents the effects of the Kyoto Protocol. The U.S. signed the Protocol in 1998 but did not ratify it and thus is not forced to legally binding reductions in emissions of greenhouse gases. Two related variables are used, one for the initial period 1998-2004 and one for the period 2005-2013 during which the Protocol was in force, expecting both of them to be insignificant. Furthermore, the effect of environmental policies undertaken by the two latest government administrations is examined. In particular, the 2001-2008 administration announced a U.S. policy for climate change that relied on domestic, voluntary, actions to reduce the "greenhouse gas intensity" (in particular, the ratio of emissions to economic output) of the U.S. economy by 18% over the period 2002-2012, while the 2009-administration aims to reduce U.S. greenhouse gas emissions in the range of 17% below 2005 levels by 2020. Finally, Table 7 presents the effect of the Regional Greenhouse Gas Initiative (RGGI) founded in January 2007, which is a state-level emissions cap and trade program by nine north-eastern U.S. states where permits are allowed to be traded, aiming to the reduction of greenhouse gases. Finally, the case where all the regulation dummy variables are simultaneously included into the model is also analyzed.

Table 7: Environmental policies: structural change dummy variables

Environmental Policy	Base	Kyoto 1998	Kyoto 2005	2001-2008 admin.	2009- admin.	RGGI	All
Determinant resid cov	3.92E-46	3.76E-46	3.85E-46	3.79E-46	3.50E-46	3.71E-46	3.45E-46
Akaike	-68.54	-68.52	-68.50	-68.52	-68.59	-68.54	-68.37
Schwarz	-62.24	-61.98	-61.96	-61.97	-62.05	-62.00	-60.90
Likelihood Ratio test	-	6.13	2.65	4.96	16.67	8.09	18.77
Reject at 0.01 level	-	NO	NO	NO	NO	NO	NO

Overall, the results indicate that there is no evidence against the null hypothesis of no structural break in the model related to the various environmental policies followed.

5.4. Conclusions and policy implications

This chapter examines the effects of fiscal policy on pollution, using quarterly data for the U.S. economy for the period 1973 – 2013. The study employed Vector Autoregression methods and applied the novel identification approach by sign restrictions. The use of CO_2 emissions as the environmental variable of the model was dictated by data availability, since it is the only pollutant for which quarterly data are available for a large period of time. To identify fiscal policy shocks only the information in the macroeconomic time series of the vector autoregression were taken into account, together with minimal assumptions. In particular, no restrictions were imposed on the signs of the responses of the key variables of interest - CO_2 emissions, GDP, private consumption and private non-residential investment - to fiscal policy shocks.

The analysis provides comprehensive evidence regarding the relationship between fiscal policy and CO_2 emissions by analyzing various realistic fiscal policy scenarios, like deficit-financed spending and deficit-financed tax-cut policies. In particular, the results suggest that there is a significantly negative effect of government expenditure on both production- and consumption-generated CO_2 emissions, in line with recent studies. On the other hand, there is little support to the hypothesis that a deficit-financed tax-cut affects production-generated pollution, while the results suggest that this policy is associated with an increase in consumption related CO_2 emissions in the short-run. Thus, efforts to stimulate the real economy through a deficit-financed tax-cut should be accompanied by more strict environmental regulations in order to counterbalance the increase of CO_2 emissions.

In addition, the analysis suggests that the alleviating effect of government expenditure on environmental pollution can be considerably enhanced by focusing on specific spending categories. Consistent to recent literature findings, the results show that spending on public goods leads to greater reduction of CO_2 emissions than aggregate spending, for both production- and consumption-generated emissions. Moreover, as expected, spending targeted on environmental protection proves to be the most efficient form of the considered spending categories, resulting in an estimated 19.45 and 27.78 times greater emissions reduction of production- and consumption- generated CO_2 emissions, than the same dollars amount spent on aggregate government spending. Finally, the aforementioned effects on CO_2 emissions are similar in magnitude for both sources of the pollutant, but occur more quickly on production-generated emissions.

Nevertheless, there are several unique characteristics in the U.S. that may limit the direct applicability of the findings to other jurisdictions. In particular, some characteristics of the U.S. might emphasize the alleviating effect of government spending on CO_2 emissions. The U.S. is the world's largest national economy, with a particularly high GDP per capita and the highest average household and employee income among OECD countries[60]. For example, in developed countries, the income effect that follows an increase in government expenditure is more likely to exceed the scale effect and therefore contributes to a greater reduction in production-generated pollution levels. Moreover, the degree of democracy in the U.S. is among the highest worldwide, while the degree of corruption is among the lowest. Therefore, particularly for consumption-generated emissions, after an increase of government expenditure the regulation effect is expected to outweigh the effect through income and

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[60] According to the 7th edition of Society at a Glance 2014: OECD Social Indicators, 2014.

subsequently lead to significant enhancements of environmental quality that would not be observed in an autocratic regime.

On the other hand, there are a couple of factors that might lessen the influence of government expenditure on CO_2 emissions in the U.S., compared to other countries. In particular, there are some reasons to expect that the effect of government expenditure on environmental quality is expected to be even greater in developing countries, due to larger market failures and the relatively higher portion of the population that depends on government expenditure for public goods such as education and health (Lopez et al. 2010). Furthermore, the sector composition of the economy constitutes an important related factor, with the service sector in the U.S. contributing 80% of total GDP in 2014[61]. Considering that the industrial sector generates more pollution than the service sector, the effect of government expenditure in public goods which substitute pollution intensive activities is expected to be greater at economies that rely more on industrial production.

The importance of this study is highlighted taking into consideration the extensive use of expansionary macroeconomic policies as a tool to stimulate the economy or to address market failures. Public expenditure increased sharply in many countries during previous years in response to the recent economic crisis. In this regard, the results provide evidence that increasing government expenditure is not associated with higher levels of CO_2 emissions and in fact can reduce emissions, complementing the efforts to enhance environmental quality. Despite this reassurance, it should be mentioned that there are several other factors that ought to be taken into consideration in developing fiscal policies, like the cumulative effect of each

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[61] According to U.S. Bureau of Labor Statistics, Available at http://www.bls.gov/ .

policy on the real economy and on the sustainability of government debt, which may have a

long-run impact on environmental quality.

Chapter 6

Concluding Remarks

In the existing literature much attention has been given to the toolbox of regulatory policy instruments at the disposal of policy makers for addressing environmental concerns (Islam and Lopez, 2015). On the other hand, while the effects of several economy-wide policies such as trade policies have been extensively studied, little efforts have been devoted to the study of the impact of fiscal expenditure policies on environmental quality. This is particularly surprising in view of the immense importance of government expenditure in many economies worldwide.

The aim of the current thesis is to contribute to the small, but growing, literature on the relationship between fiscal policy and environmental quality. In particular, five different features not so far captured sufficiently in the existing literature are recognized and incorporated explicitly in the analysis. First, existing research neglects the indirect effect of government spending on pollution, which operates through the impact of government expenditure on economic growth and the subsequent effect of the level of economic development on the environment. The research undertaken for this thesis estimates both the direct and indirect effects and reports the total effect of government expenditure on pollution (Chapter 3). Second, the majority of the studies in this field do not take into account how the magnitude of the direct effect of government expenditure on environmental quality may

differ conditional on several characteristics of a country, such as the level of economic development and the quality of institutions. The research in this dissertation takes into account these channels and examines how the magnitude of the estimated effect is affected by such factors (Chapter 4). Third, different characteristics of the pollutants, such as whether they are production- or consumption-generated and whether they are characterized by local or global externalities, may also influence the significance and magnitude of the effect of government spending on pollution. The analysis in this thesis examines several pollutants and provides estimates between the different indicators of environmental quality, which can be directly compared (Chapter 3-5). Furthermore, the related literature in its whole, deals with the effect of fiscal policy on the environment using reduced-form models and thus estimates the long-term effect of government expenditure. In Chapter 5, Vector Autoregression methods, which are solely based on minimal hypotheses about the signs of the impacts of certain shocks, are employed and offer insights concerning the short-term interrelationships between government expenditure and government revenues with air pollution. Finally, the importance of employing appropriate dynamic econometric techniques in this framework is emphasized throughout the empirical analysis and the dynamic nature of the examined relationships is explicitly taken into consideration (Chapter 3-5).

The main findings, which have been already discussed in the three empirical chapters of this thesis, are summarized below as follows:

- Government expenditure has a negative or non-positive direct effect on the different indicators of environmental degradation (Chapters 3-5).

- The alleviating direct effect of government spending on pollution is significantly reinforced in developed countries and democratic regimes (Chapter 4).

- In addition, the estimated direct effect is greater in significance and in magnitude on pollutants that are characterized by shorter atmospheric life times, local geographical range and therefore more immediate impact on human health like SO_2 and NO_x emissions, compared to pollutants with externalities that are more global and their impact occurs mostly in the future like CO_2 and N_2O (Chapter 3-4).

- Moreover, there is evidence that the estimated direct effect is larger in significance and magnitude on production-generated pollution compared to consumption-related pollution (Chapter 3-5).

- The total effect of government expenditure on environmental quality depends on the relationship between government spending and economic growth, as well as the relationship between economic growth and the environment (i.e. the indirect effect). The analysis in this thesis suggests that for SO_2, the total effect is negative for low levels of income, although decreasing in absolute value, and then becomes positive for more developed countries. Likewise, for CO_2 the total effect is also negative for low income levels and turns positive only for very high income levels (Chapter 3).

- The alleviating direct effect of government expenditure on environmental degradation can be considerably enhanced by directing spending on specific functional categories, such as spending on public goods (e.g. health and education) and spending targeted on environmental protection (Chapter 5).

- An attempt to stimulate the economy through tax-cuts is associated with an increase in consumption-related CO_2 emissions in the short-run, while there is little evidence of an effect on production-generated CO_2 emissions (Chapter 5).

With regard to policy implications, the results suggest that fiscal spending may be used to complement the efforts to improve environmental quality, rendering these efforts easier and more cost efficient. Nevertheless, it should be emphasized that the effectiveness of fiscal policy on environmental degradation significantly depends on the impact these policies have on economic growth. In particular, if an increase in government size is associated with lower economic growth then it may deteriorate environmental quality in developed countries with income levels at the downward slope part of the EKC. Therefore, governments should restructure government expenditure composition and reform tax systems in order to ensure that these are not linked with a slowdown of economic growth. This could be achieved by promoting spending in categories that alleviate market failures such as investments in human capital, R&D and health. Related to this, many studies have reported that government spending on subsidies to fossil fuel production, input subsidies, subsidies to energy consumption and other subsidies targeting specific industries or firms, are ineffective in enhancing productivity and private investment and substitute rather than complement private expenditures (Lopez et al., 2011; Fakin, 1995; Lee, 1996).

Furthermore, the weak direct effect of government spending on environmental quality in developing countries and autocratic regimes can be enhanced by enforcing property rights on natural resources which may promote the internalization of environmental externalities. Related to this, there is also an important need for technological and knowledge diffusion to developing countries in order to advance the abatement methods used and encourage the use of environmental cleaner production methods. Concerning the mitigation of pollutants with more global impact, the adoption of international environmental treaties which will internalize such externalities is required, since the results suggest that government spending is ineffective in this case. Finally, concerning the implementation of expansionary fiscal policies to stimulate the economy in the short-run in developed countries like the US, the

research undertaken in this thesis provides reassurance to macroeconomic policy makers that increasing government expenditure does not deteriorate CO_2 related air pollution and in fact is associated with improvements of environmental quality. On the other hand, a fiscal expansion based on tax-cuts increases consumption-generated CO_2 emissions in the short-run and should be accompanied by stricter environmental regulations.

A significant implication of the research in this thesis is that, in order to capture the total effect of government expenditure on the environment, the analysis should be conducted in a joint framework with two other bodies of literature, namely the literature linking fiscal policy to economic performance, as well as the literature on the growth-pollution relationship. In particular, regarding the relationship between government spending and economic growth the evidence in the literature remains indeterminate. As Angelopoulos et al. (2008) point out, this ambiguity may be attributed to the omission from the analysis of several elements that shape the government size-growth relationship, such as the efficiency of the public sector. Therefore, future research on the relationship between government expenditure and environmental degradation should follow the advancements in the fiscal spending-growth literature closely. Another limitation in this field is the lack of data on the composition of government expenditure for a large sample of countries and for a long period of time. Moreover, analysis of the short-run link between fiscal policy and environmental degradation is also limited by data paucity in most countries and thus prevents a more representative study on this relationship. Finally, in the literature there is a lack of theoretical models that examine the underpinnings of the relationship between fiscal policy, output and environmental quality; however, for the establishment of such models, the results occurring from this thesis can provide a useful starting point.

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