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Can Public Debt Mitigate Environmental Debt? Theory and Empirical Evidence[☆]

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Abstract

This paper investigates the relationship between public debt and environmental debt – reflecting CO₂ carbon concentration. First, using an endogenous growth model in which pollution abatement spending can be financed by public debt, we show that public debt and environmental debt are complement in the long term and usually substitute in the short run. Second, these predictions are empirically confirmed: in particular, a 1% increase in the public debt ratio leads to an increase of 0.74% in cumulative CO₂ per capita in the long term. Our findings emphasize the difficulty of defining policies that jointly serve both the economic (fiscal) and the environmental goals, due to the short- and long-run conflicting environmental effects of policies that either reduce or do not constrain public debt.

Keywords: environmental debt; public debt; CO₂ emissions; panel data; welfare.

JEL codes: O44, Q52, E62, H63, Q58.

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1. Introduction

The recent history emphasizes two distinguishing features of unsustainable development, stemming from global environmental degradation and from rising sovereign indebtedness. These two features are structural and are expected to persist well past the end of the Covid-19 pandemic: between 1960 and 2015 the time-profile of the debt-to-GDP ratio and the CO₂ emissions present a growing trend for OECD countries, as Figure 1 depicts.

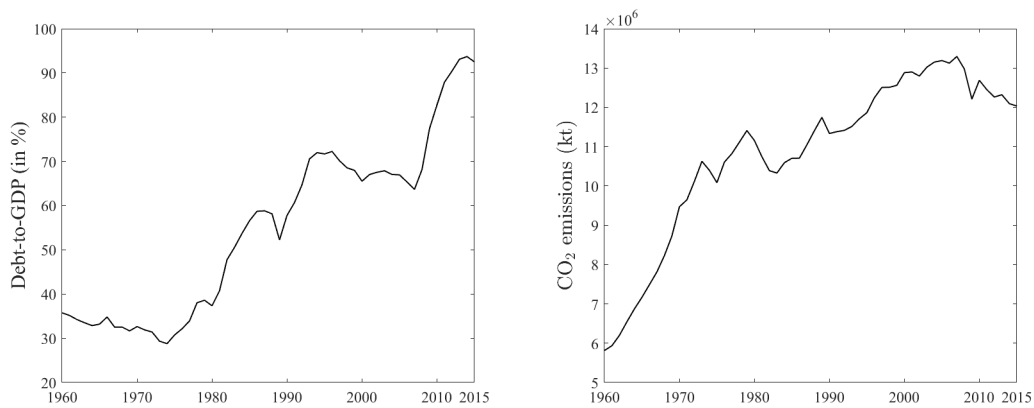


Figure 1: Debt-to-GDP ratio (in %) and CO₂ emissions (in kilotonnes) for OECD countries
Source: World Bank

On the climate side, energy-related CO₂ global emissions rose to a historically-high in 2018 ([International Energy Agency, 2019](#)). This reinforced the issue of the *environmental or climatic debt* that will be carried by future generations ([Azar and Holmberg, 1995](#)). According to the 2017 Annual report of the [Global Footprint Network](#), over 85% of the world population lives in countries with an "*ecological deficit*", due to polluting emissions above the nature's absorptive capacity. The accumulation of such deficits gives rise to an *environmental debt*, defined as "*the accumulation of past environmental impacts of natural resource depletion and environmental degradation, owed to future generations*" (OECD definition: <https://stats.oecd.org/glossary/detail.asp?ID=820>) and measured by

"the costs required to restore the environmental damage that is economically and technically restorable" (Jernelöv and Edenmark, 1992). On the fiscal policy side, the post-1970s oil shocks era is characterized by persistent deficits,¹ which fueled an increasing trend in the public debt-to-GDP ratios around the world and resulted into historically-exceptional indebtedness nowadays.

A fundamental debate concerns the environmental and climate consequences of these large indebtedness levels. One view is that high public debt may hurt economic growth (Reinhart and Rogoff, 2010; Eberhardt and Presbitero, 2015) and damage the natural environment by hindering the implementation of environmental protection programs. This could undermine the ability of indebted economies to engage in sustainable energy transition.² In particular, in developing countries public debt can limit the capacity to mobilize domestic resources and thus to invest in climate change adaptation (Van den Bergh, 2013; UNCTAD, 2017).³ In addition, the repayment of the debt burden can force highly-indebted economies to increase the pressure on the natural environment in order to raise public revenues (Combes et al., 2015). However, an alternative and more optimistic view suggests that public debt can increase the environmental quality by financing investments in low-carbon technologies, clean energy projects, or environmental R&D activities that will mainly benefit future generations (Bénassy-Quéré et al., 2010).⁴ In this case, thanks to public spending-financed investments in abatement knowledge, public

¹Indeed, even when we disregard the large deficit consequences of the recent Great Recession, the average public deficit-to-GDP ratio in OECD is not far from 3%.

²This idea echoes the *debt-for-nature swaps* suggesting that savings from reduced public debt burden could be invested in conservation projects. Relatedly, Fodha and Seegmuller (2014) show that a public debt decrease can improve environmental quality, since debt servicing crowds out private spending that can entail abatement expenditures.

³Van den Bergh (2013) points out that the financial crisis of 2007 raises obstacles to financing sustainable energy transition. Similar consequences can be expected from the health crisis of 2020.

⁴This point of view is supported by the proponents of a "Clean Energy Finance" who suggest to use sovereign bonds to finance clean energy public investments. This idea aims to mimic the tax credits ("Clean Renewable Energy Bond") that the US government offers to some private investors.

debt sustainability and environmental preservation could be compatible.

The goal of this paper is to shed light on the debate regarding the relationship between public debt and environmental debt by adopting an integrated strategy combining theoretical modelling and empirical evaluation.

Theoretically, we build an endogenous growth model with an environmental good modeled as a stock in the spirit of [Tahvonen and Kuuluvainen \(1991\)](#), [Bovenberg and Smulders \(1995\)](#), [Fullerton and Kim \(2008\)](#) and [Menuet et al. \(2020\)](#).⁵ As usual, the environmental quality that can be related to CO₂ concentration is a renewable resource that regenerates itself and depletes through CO₂ emissions. These emissions come from economic activity relying on fossil fuel energies for production – net of abatement spending provided by the government.

In this setup, we introduce two key ingredients. First, we relax the standard balanced-budget hypothesis to account for deficits and debt in the long run, consistent with the current state of public finances in most countries in the world. Second, we define the environmental debt as the gap between the natural capital at the *virgin state* (i.e. the state without economic activity) and at the current state. Following [Jernelöv and Edenmark \(1992\)](#), the environmental debt reflects economy’s obligations towards nature, namely the price that the society must pay to restore the virgin-state environmental quality. With this definition, environmental debt can be measured by cumulative CO₂ emissions.

Our findings are that public and environmental debt are complement in the long run, and usually substitute in the short run. The intuition is the following: an increase in public debt provides a flow of environmental-detrimental resources (the public debt

⁵Recent works support the usefulness of endogenous growth setups equally for dealing with continuous public debt growth in the long run ([Minea and Villieu, 2012](#); [Boucekkine et al., 2015](#); [Menuet et al., 2018](#)).

burden), and a flow of environmental-improving resources (the public deficit that finances abatement expenditure). In the long run, the first effect offsets the second, so that public debt has an adverse overall effect on abatement expenditure;⁶ while in the short run the second effect outweighs the first provided that public debt is not too high.

Empirically, we test our predictions using cointegration techniques in a panel of 22 countries over 1990-2011. We define the environmental debt as cumulative CO₂ emissions.⁷ As our analysis is concerned with both short- and long-run effects, the use of the "carbon debt" as a proxy for the environmental debt is supported by the fact that CO₂ emissions persistently remain in the atmosphere. To account for the individual and time dimensions of our data, combined with the presence of a unit root, we rely on panel cointegration techniques that conveniently allow capturing the common long-run trend suggested by our model. Our empirical findings are twofold. First, we reveal a robust positive long-run relationship between public debt and environmental debt, confirming the long-run complementarity suggested by the theoretical model. Second, we mostly observe a negative relation between the two debts in the short run. However, additional estimations show that the substitution effect between public debt and environmental debt can be weakened when average public debt is relatively high.

Finally, we exploit the theoretical mechanism describing the interaction between public debt and environmental debt to derive normative policies from a welfare analysis. In particular, we unveil an inverted-U relationship between public debt and long run welfare,

⁶It relates to the long-run crowding-out effect of debt on public expenditure ([Minea and Villieu, 2012](#)).

⁷This definition is consistent with the existing literature suggesting that the main component of the environmental debt is CO₂ emissions ([Jernelöv and Edenmark, 1992](#); [Azar and Holmberg, 1995](#); [Botzen et al., 2008](#); [Matthews, 2016](#)). This strategy closely follows [Botzen et al. \(2008\)](#) and [Matthews \(2016\)](#), who measure climate debt by cumulative CO₂ emissions; although other GHG contribute to climate change, our focus on CO₂ is motivated by accumulated carbon debts as high as 250 billion tonnes of CO₂, namely 40% of cumulative world emissions since 1990 ([Matthews, 2016](#)). In addition, [Fuglestedt and Kallbekken \(2016\)](#) conclude that carbon debts are the main way to identify contributions to climate change.

in which environmental preferences affect the welfare-maximizing debt threshold.

Related literature. Relative to existing work, our paper provides theoretical, empirical, and policy contributions.

On the theoretical side, although many studies introduced an environmental module in endogenous growth models (see e.g. [Bovenberg and Smulders, 1995](#), [Chen et al., 2003](#); and the review of [Xepapadeas, 2005](#)), the papers that study the impact of fiscal policies on environmental outcomes (as, e.g., [Bovenberg and Smulders, 1996](#), [de Mooij and Bovenberg, 2007](#); [Rosendahl, 1997](#), [Fullerton and Kim, 2008](#), [Karydas and Zhang, 2019](#), [Barrage, 2020](#)) restrict government's abatement public spending to be financed exclusively by taxation (i.e. with zero deficit and public debt). By allowing for public debt in an environmental endogenous growth model, we are able to examine the impact of public debt on economic growth and climate debt both in the short and the long run.

Additionally, in the particular context of overlapping generations (OLG) setups, some authors (see, e.g., [Rausch, 2013](#); [Fodha and Seegmuller, 2014](#); [Fodha et al., 2018](#)) attempted to evaluate the consequences of environmental policies financed by public debt. In [Fodha and Seegmuller \(2014\)](#) and [Fodha et al. \(2018\)](#), there are two steady states with reverse properties: at the stable steady state, higher debt reduces capital but improves environmental quality; while opposite effects are observed at the unstable steady state. [Rausch \(2013\)](#) found that when a carbon tax serve to consolidate public debt, the environmental policies could generate sustained welfare gains.

Our model extends and challenges these results in three directions. First, in our endogenous growth setup, in the long run economic growth is strictly positive and public debt is endogenous, contrasting with OLG settings. Second, contrary to [Fodha and Seeg-](#)

muller (2014) and Fodha et al. (2018), we demonstrate the uniqueness of the steady state, and prove that the link between the debt-to-GDP ratio and the environmental quality depends on the time horizon. Third, while Rausch (2013) focused on the welfare-enhancing fiscal instrument to consolidate public debt, we focus instead on the level of public debt (as a ratio to GDP) and unveil the existence of a welfare-maximizing debt ratio.

On the empirical side, the few studies that attempt to measure the link between public debt and environmental quality concern the evaluation of debt-for-nature swaps. The consensus is that the link between public debt and environmental quality — most often measured by the amount of rainforest in the tropical zone — is unambiguously negative. For example, Kahn and McDonald (1995) or Didia (2001), using standard ordinary least squares regressions, have shown that a rise in debt leads to an increase in deforestation in tropical countries. By addressing the endogeneity problem with instrumental variable regressions, Sommer et al. (2020) confirmed that higher debt reductions are associated with lower rates of forest loss in the context of debt-for-nature swaps involving the United States. In our econometric analysis, we measure the environmental debt by the cumulative CO₂ emissions, and we show, using a cointegration technique, that the link between public debt and environmental debt is significant and positive in the long run, but can be negative in the short run.

On the policy side, we contribute to the literature on the interaction between macroeconomic policies and environmental policies – see recent examples in Combes et al. (2015), Edenhofer et al. (2017), or Siegmeier et al. (2018). Importantly, in our setup abatement technologies can overcome the conflict between environment and economic growth

(Van Ewijk and Van Wijbergen, 1995): higher abatement spending can lead to higher economic growth and lower carbon concentration (i.e., "double dividends"). Nevertheless, if the abatement technology is financed by public debt, we reveal an intertemporal trade-off: policies that do not constrain the increase of public debt may reduce carbon concentration and improve environmental quality in the short run. However, such policies may have detrimental environmental consequences in the long run. Instead, policies that limit public debt, such as tight fiscal rules, may result in lower environmental debt and better environmental quality in the long run, but with detrimental consequences in the short run. In addition, both types of policies could be equally questionable from a long-run perspective if they ultimately move away long-run public debt from its environmental-contingent welfare-maximizing value.

In a nutshell, our message is that the benefits from combining environmental and debt consolidation policies are limited.⁸ The complex public-environmental debt relationship that we unveil points to the absence of always-dominant policies, and calls for a careful use of public debt for reaching climate change goals in the long run.

The remainder of the paper is organized as follows. Section 2 presents the theoretical model, and section 3 explores the relationship between public debt and environmental debt. Section 4 details the empirical strategy, and section 5 provides empirical support for our theoretical findings. Further estimations in section 6 confirm the soundness of our theoretical setup, and motivate its use for the derivation of welfare-based normative policies in section 7. Finally, section 8 concludes the paper.

⁸Indeed, a higher debt raises abatement public spending today that positively affect the environmental quality but in the same time reduces the possibility to provide such public spending tomorrow.

2. The model

We consider a continuous-time endogenous growth model with a perfect-foresight infinitely-lived representative household, a competitive firm, and a government.

2.1. Environmental debt

Environmental quality (Q_t), such as e.g. the cleanliness of air or the soil, determines nature's capacity to grow and absorb wastes from economic activity (including from energy consumption). Specifically, the environmental quality (Q_t) can be inversely related to the carbon concentration (H_t) in the atmosphere (say, $H_t = 1 - Q_t$). Following [Tahvonen and Kuuluvainen \(1991\)](#) and [Bovenberg and Smulders \(1995\)](#), the evolution of environmental quality – or equivalently the evolution of the stock of environmental goods – is modeled as a renewable resource

$$\dot{Q}_t = E(Q_t) - P_t, \tag{1}$$

where a dot over a variable represents the time derivative.

In (1), P_t is the reduction in environmental quality or natural resources from the net flow of carbon emissions (called "pollution"). $E(\cdot)$ is an environmental regeneration function that reflects the capacity of the environment to absorb pollution.⁹ We consider several standard assumptions: (i) $E(Q_t) \in C^1(\mathbb{R}_+)$, (ii) $E'(Q_t) < 0$, (iii) $E''(Q_t) \leq 0$, and (iv) there is a critical level $\bar{Q} > 0$, such that $E(\bar{Q}) = 0$ (*virgin state*). Assumption (i) states that the regeneration process is a smooth function. Assumption (ii) means that the higher the stock of natural resources, the higher the difficulties to maintain or increase it through natural regeneration processes. According to assumption (iii), the environmental

⁹ As concerns CO₂, vegetation and the ocean are two major natural carbon sinks that absorb more carbon than they release, and thereby lower the concentration of CO₂ from the atmosphere. According to the National Oceanic and Atmospheric Administration, when CO₂ is released into the atmosphere from the burning of fossil fuels (as in our model), approximately 50% remains in the atmosphere, while 25% is absorbed by land plants and trees and the other 25% is absorbed into certain areas of the ocean.

regeneration process exhibits decreasing returns. Assumption (iv) states that, without emission ($P_t = 0$), environmental quality reaches its highest possible (finite) level—the “*virgin state*” \bar{Q} , which is the maximum stock of natural resources that can be kept intact by natural regeneration (for identical assumptions, see e.g. [Fullerton and Kim, 2008](#)). This virgin state \bar{Q} leads to a constant level of carbon concentration ($\bar{H} = 1 - \bar{Q} > 0$).

However, this virgin state cannot be sustained because economic activity incurs polluting emissions, i.e. the production process uses energy from fossil fuels (the input Z_t) that results in carbon emissions. Nevertheless, this adverse effect can be (at least partially) neutralized by abatement spending. We assume that this abatement activity is provided by the public sector through government expenditure (G_t). Consequently, the net flow of emission¹⁰ is

$$P_t = \left(\frac{Z_t}{G_t} \right)^\mu, \quad (2)$$

where $\mu > 0$ measures the elasticity of emissions to the energy input. In this specification that follows [Fullerton and Kim \(2008\)](#), the input Z_t that provides energy services for the production depends both on emissions and the abatement spending: $Z_t = P_t^{1/\mu} G_t$; thus, the same level of Z_t can be achieved with less emissions if the economy has access to more abatement. The exponent μ denotes a pollution-conversion parameter: a lower μ makes emissions more effective, or equivalently makes abatement relatively less effective.

We define the gap between the virgin-state stock and the current environmental quality as the environmental debt (D_t), namely

$$D_t = \bar{Q} - Q_t. \quad (3)$$

In the long run, should the economy reach the virgin state ($Q^* = \bar{Q}$, where a star

¹⁰In our model, emissions of pollutants are closely related to the extraction of fossil fuels and are captured by the same variable P_t for notational convenience.

denotes steady-state values), the environmental debt would be zero ($D^* = 0$). Owing to economic activity, however, environmental quality is perpetually damaged, such that $Q_t < \bar{Q}$ even in the long run. We can then define the gap $\bar{Q} - Q_t$ as the obligations of the economy towards nature. This definition is consistent with previous studies stating that the environmental debt is "*the cost required to restore the environmental damage that is economically and technically restorable*" (Jernelöv and Edenmark, 1992).

The specification (3) is simple and serves our purposes. In terms of carbon concentration, the environmental debt can be written as $D_t = H_t - \bar{H}$. Ignoring the constant \bar{H} , the environmental debt can be measured as the cumulative CO₂ emissions, i.e. the sum of net emission flows ($H_t = \int_{s=0}^t \{P_s - E(Q_s)\} ds$). This is the definition that we consider in the empirical section. Indeed, an important literature emphasizes the existence of a robust linear relationship between climate change (or more precisely, temperature anomalies) and cumulative carbon concentration, known as the "Transient Climate Response to Cumulative Carbon Emissions" (see Brock and Xepapadeas, 2017).

2.2. Households

The representative household starts at the initial period with a positive stock of capital (K_0), and chooses the path of consumption $\{C_t\}_{t \geq 0}$, and capital $\{K_t\}_{t > 0}$, so as to maximize the present discounted value of her lifetime utility

$$U = \int_0^{\infty} e^{-\rho t} u(C_t, Q_t) dt, \quad (4)$$

where $\rho > 0$ is the subjective discount rate. By denoting η the environmental preference parameter, the instantaneous utility is assumed to be separable

$$u(C_t, Q_t) = \log(C_t) + \eta \log(Q_t). \quad (5)$$

The household enters period t with the initial (predetermined) stocks of private capital

(K_t) and government bonds (B_t), whose returns are respectively q_t (the rental rate of capital) and r_t (the real interest rate). She is endowed with L units of labor each period, perceives wages ($w_t L$), pays taxes (where $\tau_w \in (0, 1)$ is the proportional tax rate on wages), and decides how much to consume (C_t) and save during the period. The only forms of asset accumulation are capital (\dot{K}_t , for simplicity we omit capital depreciation) and government bonds (\dot{B}_t); hence the following budget constraint

$$\dot{K}_t + \dot{B}_t = r_t B_t + q_t K_t + (1 - \tau_w) w_t L - C_t. \quad (6)$$

The first-order conditions yield the familiar Euler equation

$$\frac{\dot{C}_t}{C_t} = r_t - \rho, \quad (7)$$

with $r_t = q_t$ in competitive equilibrium, and the set of transversality conditions

$$\lim_{t \rightarrow +\infty} e^{-\rho t} \frac{K_t}{C_t} = \lim_{t \rightarrow +\infty} e^{-\rho t} \frac{B_t}{C_t} = 0,$$

which ensure that lifetime utility U is bounded.

2.3. Firms

The output of the representative firm (Y_t) is produced using three inputs: a man-made private capital (K_t), labor (L_t), and the polluting input (Z_t), according to the following Cobb-Douglas production function

$$Y_t = \tilde{A} K_t^\alpha Z_t^\beta (\bar{K}_t L_t)^{1-\alpha-\beta}, \quad (8)$$

with $\alpha \in (0, 1)$ and $\beta \in (0, 1)$ the elasticity of output to private capital and the polluting input, respectively (with $\alpha + \beta < 1$). $\tilde{A} > 0$ is a scale parameter, and \bar{K}_t is the economy-wide capital level that generates positive technological spillovers onto firm's productivity (Romer, 1986).

The firm chooses private factors (K_t , L_t , and Z_t) to maximize its profit $\Pi_t = Y_t - r_t K_t - w_t L_t - \tau_p Z_t$, where τ_p is a tax rate on firm's energy consumption (an environmental carbon tax). The first-order conditions give rise to

$$r_t = \alpha \frac{Y_t}{K_t}, \quad w_t = (1 - \alpha - \beta) \frac{Y_t}{L_t}, \quad \tau_p = \beta \frac{Y_t}{Z_t}, \quad (9)$$

with $L_t = L$ in equilibrium; we henceforth normalize $L = 1$. The production function (8) depicts a constant return-to-scale technology relative to private factors (rival inputs), hence constant output-shares of each factor.

2.4. The government

The government provides public abatement expenditures G_t ,¹¹ receives taxes on labor income (τ_w) and on the carbon tax (τ_p), and borrows from households. Fiscal deficit is financed by issuing debt (\dot{B}_t); hence, the following budget constraint

$$\dot{B}_t = r_t B_t + G_t - \tau_p Z_t - \tau_w w_t. \quad (10)$$

For an appropriate analysis of the relationship between environmental debt and public debt, we must escape the balanced-budget rule hypothesis – *even in the long-run* – that is assumed by environmental growth models. To this end, we introduce the possibility for public deficits to be permanently financed by public debt accumulation.¹² Given that there is one free variable in the government's budget constraint (10), to close the model the government must fix either the public abatement spending or the public debt path. In our endogenous growth setup, public spending is an endogenous variable,¹³ so

¹¹Introducing other types of public spending (e.g. public consumption) does not change our results.

¹²As previously stated, endogenous growth setups are compatible with growing public debt in the long run. The only requirement to respect the transversality condition is that the public debt growth rate to be less than the real interest rate in equilibrium.

¹³In Eq. (10) there are two exogenous parameters (the tax rates: τ_w and τ_p), and two endogenous policy instruments: public debt (B_t) and public spending (G_t). The public debt path is exogenously specified by the fiscal rule (11), while public spending serve to adjust the government's budget constraint.

we consider that the public debt path follows a simple rule that links the debt-to-output ratio ($b_t := B_t/Y_t$) to a long-run target (θ), namely

$$\dot{b}_t = \nu(\theta - b_t), \quad (11)$$

where $\nu > 0$ is the speed of adjustment of the debt ratio to its long-run value.¹⁴ This rule serves our purpose for two reasons. First, it reproduces the fact that many fiscal rules implemented since the 1980s require an exogenous target of the debt-to-output ratio (see [Lledó et al., 2017](#)), which can illustrate either institutional constraints (for example, $\theta = 60\%$ in the Maastricht Treaty) or the government's fiscal behavior. Second, it allows assessing the effects of the target θ on the time profile of environmental debt.

3. Equilibrium

By (8), in equilibrium ($\bar{K}_t = K_t$), the output is $Y_t = AK_t$, where $A := [\tilde{A}(\frac{\beta}{\tau_p})^\beta]^{1/(1-\beta)}$. Thanks to constant-returns at the social level, endogenous growth can emerge despite decreasing returns of private capital from the individual firm's perspective. Therefore, using (9), the real interest rate is simply $r_t = \alpha A$.

To obtain long-run stationary ratios, we deflate variables by output and use lowercase to depict ratios, namely: $c_t := C_t/Y_t$, $g_t := G_t/Y_t$. The capital stock path is given by the goods market equilibrium, namely

$$\frac{\dot{K}_t}{K_t} = A(1 - g_t - c_t). \quad (12)$$

By (11), with $\lambda := \beta + \tau_w(1 - \alpha - \beta)$, the government's budget constraint (10) leads to¹⁵

$$g_t = \frac{1}{1 + Ab_t} [\lambda + \nu(\theta - b_t) + Ab_t(1 - c_t - \alpha)]. \quad (13)$$

¹⁴Such a fiscal rule is consistent with the unconditionally optimal fiscal policy ([Horvath, 2011](#)).

¹⁵We compute $g_t = \nu(\theta - b_t) + \frac{\dot{K}_t}{K_t}b_t + \beta + \tau_w(1 - \alpha - \beta) - \alpha Ab_t$.

From (9), it follows that $Z_t/Y_t = \beta/\tau_p$. Using (1), (2) and (3), the law of motion of the environmental debt writes

$$\dot{D}_t = \left(\frac{\beta}{\tau_p g_t} \right)^\mu - E(Q_t). \quad (14)$$

Finally, from (7), (12), and (14), the reduced-form of the model is

$$\begin{cases} \dot{b}_t = \nu(\theta - b_t) & \text{(a)} \\ \frac{\dot{c}_t}{c_t} = \frac{\dot{C}_t}{C_t} - \frac{\dot{K}_t}{K_t} = \alpha A - \rho - \frac{A}{1+Ab_t} (1 - c_t - \lambda - \nu(\theta - b_t) + \alpha Ab_t) & \text{(b)} \\ \dot{D}_t = \left(\frac{\beta}{\tau_p g_t} \right)^\mu - E(\bar{Q} - D_t). & \text{(c)} \end{cases} \quad (15)$$

We define a balanced-growth path (BGP) as a path on which (i) consumption, capital, output, and public debt grow at the same endogenous rate, namely (we omit time indexes) $\gamma^* := \dot{C}/C = \dot{K}/K = \dot{Y}/Y = \dot{B}/B$, and (ii) environmental debt is constant ($\dot{D} = 0$).

The following proposition computes the steady-state by setting $\dot{c} = \dot{b} = \dot{D} = 0$ in (15).

Proposition 1. *(Existence and Uniqueness) If $\rho < \min(\alpha A, \lambda/\theta)$, there is a unique well-determined BGP with positive economic growth, environmental debt, and consumption and public spending ratios.*

Proof: See Appendix A.

Proposition 1 shows that there is a unique BGP, which is well-determined, i.e. saddle-path stable. The following subsection addresses the relationship between the public debt and the environmental debt in the short run and the long run.

3.1. Environmental debt and public debt: analytical results

Based on the previous analysis of dynamics, the following proposition establishes the main result of our theoretical model by assessing the effect of changes in the debt target (θ) on public debt (b_t) and environmental debt (D_t).

Proposition 2. *Following a change in the debt target (θ), public debt and environmental debt are (i) complements in the long run, and (ii) substitute in the short run provided that $b_0 < \underline{b}_0 := \nu/A\rho$.*

Proof: See Appendix A.

Proposition 3 reveals that the time profile of the environmental debt intimately depends upon the behavior of government abatement spending.

In the long run, an increase in the debt target generates new deficits that produce two opposite effects: (i) a permanent flow of new resources for abatement activity (\dot{B}_t), and (ii) a permanent flow of new unproductive expenditures (the debt burden $r_t B_t$). In the steady state, the transversality condition ($r^* > \gamma^* = \dot{B}/B^* \Leftrightarrow r^* B^* > \dot{B}$) means that the latter effect always dominates the former; hence public debt has an overall adverse effect on abatement expenditure over the balanced-growth path.

In the very short run (at $t = 0$), in contrast, the deficit provides new resources for abatement public spending (public debt is predetermined at b_0). Simultaneously, an increase in the debt target (θ) raises the initial consumption ratio c_0 to its long-run value (see Appendix A), which reduces public spending abatement in the goods market equilibrium – see Eqs. (12) and (13). Hence, the impact of the deficit target on abatement public spending depends on the relative strength of these two effects. If the initial public debt ratio is low ($b_0 < \underline{b}_0$), the former effect dominates the latter and abatement expenditures increase initially and in the short run, making public debt and environmental debt to be substitute in the short run. Instead, this short-run substitution effect may be reversed if $b_0 > \underline{b}_0$, since the discount rate ρ is usually very low. This configuration is likely to appear only when the initial public debt ratio is very high.

3.2. A calibration exercise

We now assess the numerical magnitude of these theoretical results. We perform a calibration exercise based on realistic values of parameters (see Table 1).

(i) Regarding the household, we choose a typical discount rate of $\rho = 0.01$ to match with the risk-free real interest rate long-run historical data (as in the [Stern, 2006](#) review). The preference parameter is set to $\eta = 5$ in our baseline calibration (η does not affect the dynamics but only the welfare, see section 7) and is examined over different magnitudes.

(ii) Regarding the technology, we set $\tilde{A} = 0.16$ to obtain realistic economic growth rates, and the capital share in the production function is $\alpha = 0.31$, corresponding to the average long-run capital share in OECD countries (0.308 in the US from 1929 to 2020, see BEA data: <https://taxfoundation.org/labor-share-net-income-within-historical-range>). Parameter β reflects both the elasticity of output to the energy input and the ratio of carbon taxes to output, according to a cost-share mechanism (as $\tau_p Z/Y = \beta$ in the profit maximization). To match with OECD data, we consider $\beta = 0.1$ in the baseline calibration but allow for other values in the simulations in Table 2.

(iii) Regarding the Government, the tax rate on wages is $\tau_w = 0.3$, and we fix the anti-pollution tax rate at its optimal value derived in Appendix B, namely $\tau_p = 0.04$. In addition, the speed of adjustment of the debt ratio to its long-run value is set to $\nu = 0.05$ (ν does not affect the equilibrium values), and the debt-to-output ratio equals its long-run average in the US data, namely $\theta = 0.54$ during 1950-2015.

(iv) Finally, regarding the environment, we use $\mu = 0.05$ and consider a standard regeneration function $E(Q_t) = \varepsilon(\bar{Q} - Q_t)$, where $\varepsilon = 0.05$ as in [Fullerton and Kim \(2008\)](#).

Households		
ρ	0.01	Discount rate
η	5	Environmental preference parameter
Technology		
\tilde{A}	0.16	Productivity parameter
α	0.31	Share of capital in the production function
β	0.1	Share of polluting input in the production function
Government		
τ_w	0.3	Tax rate on the wage
τ_p	0.04	Pollution tax rate
ν	0.05	Speed of adjustment
θ	0.54	Long-run debt-ratio
Environment		
μ	0.05	Elasticity of emissions to the polluting input
ε	0.05	Parameter on the regeneration function

Table 1: Baseline Calibration

Despite the highly-stylized nature of our model, the baseline calibration allows us to replicate some salient facts characterizing the US economy. As shown by Table 2, the BGP is characterized by a 3.48% long-run rate of economic growth (3.3% in the data), and by a 27.16% public spending ratio (23% in the data).

β	0.02	0.05	0.1 (baseline calibration)	0.15	0.2
η	1	2.5	5 (baseline calibration)	8	10
τ_p (optimal value)	0.03	0.0431	0.04	0.0332	0.0299
g^*	0.2156	0.2366	0.2716	0.3066	0.3416
γ^*	0.0374	0.0354	0.0348	0.0368	0.0405

Table 2: Steady-state values of variables for different values of parameters

Using the baseline calibration, we quantitatively assess the effect of changes in the public debt ratio. Figure 2a illustrates the behavior of the environmental debt (the top graph) and the public debt ratio (the bottom graph). Following an increase in the debt target from $\theta = 50\%$ to $\theta = 80\%$, the two variables are substitute until $\bar{t} \approx 13$, and complement from \bar{t} onward. Figure 2b depicts the same mechanism, but in terms of growth rate of variables. Following an increase in the debt target, the growth rate of the

environmental debt (the top graph) starts to decrease from $t > \bar{t} \approx 13$, while the growth rate of the public debt ratio (the bottom graph) is always decreasing.

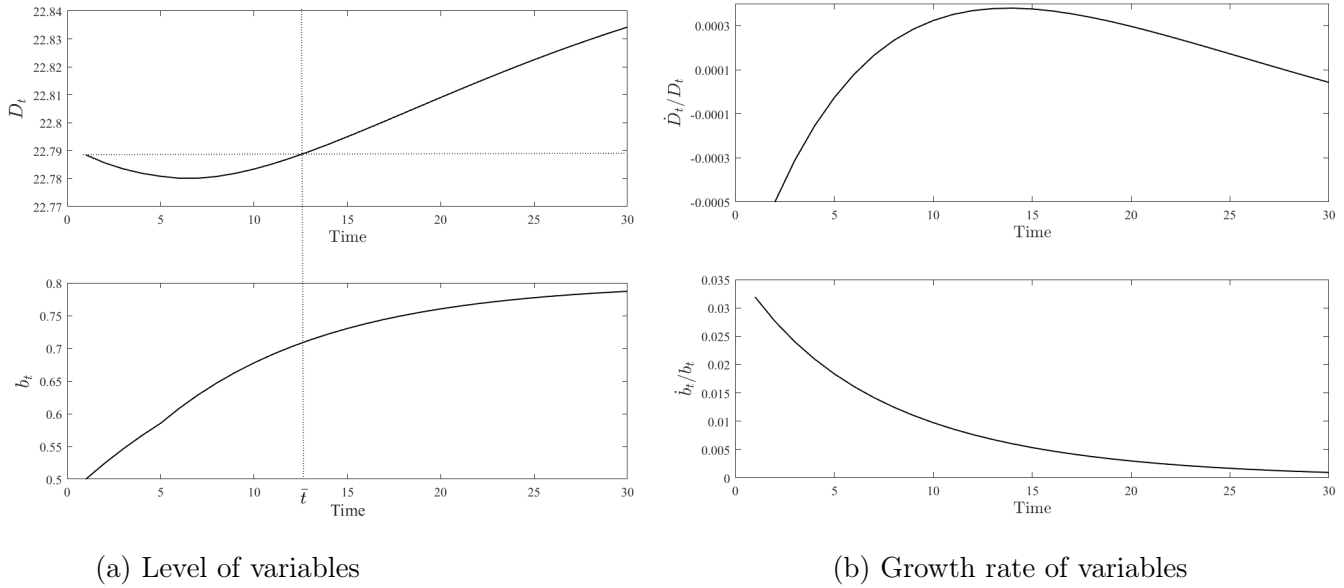


Figure 2: Dynamic adjustment following an increase in θ

The analytical proofs and the calibration exercise convey the main message of our paper in a direct and transparent way: public debt and environmental debt are complement in the long run and can be substitute in the short run. The heart of the mechanism is related to the crowding out effect of public debt on abatement expenditure. In the short run, public debt generates new resources that can be invested in abatement activities, improving the environmental quality. In the long term, in contrast, the government must pay back the public debt burden and has to reduce abatement public expenditure. In the following, we will test the predictions of our model.

4. The empirical strategy

In this section, we test the predictions of our theoretical model: (i) the complementarity between public debt and environmental debt in the long run, and (ii) the likely substitutability between them in the short run.

We define the environmental debt as the carbon concentration at the atmosphere by computing cumulative CO₂ emissions. Such a definition is consistent with our theoretical assumptions,¹⁶ and it matches with previous studies that measure the ecological debt as "*the total amount of environmental damage that past and present generations have caused*" (Azar and Holmberg, 1995).¹⁷ Indeed, as we focus on both the short- and the long-run ecological impacts of the public debt, the "carbon debt" is a convenient proxy of the environmental debt, since CO₂ emissions have a long lifetime in the atmosphere.¹⁸

4.1. Data

Environmental Debt. We rely on cumulative CO₂ emissions to measure environmental debt. To compute cumulative historical CO₂ emissions, we use annual data from the Global Carbon Project, and particularly consumption-based emissions that have the advantage of incorporating emissions from international transportation as well as carbon leakages. The data are available from 1990 and are measured in million tons of carbon (MtC); we convert annual carbon emissions in tonnes of CO₂, using 1 MtC=3.664 million tonnes of CO₂, before dividing them by the population to obtain per capita CO₂ emissions (CO_2). Thus, the environmental debt for country i at year t is $D_{it} = \sum_{j=1990}^t (CO_{2i})_j$.

Public Debt. Following Mauro et al. (2015), we draw upon the IMF Historical Public Finance dataset to obtain cross-country-consistent data on gross public debt (measured in % of GDP). The starting year of emissions data (1990) and the ending year of debt

¹⁶Indeed, as we assumed $\dot{D}_t = \dot{H}_t$, where \dot{H}_t is the net flow of CO₂ emissions at time t , the environmental debt $D_t \approx \int_0^t P_s ds$ can be measured by the sum of CO₂ emissions over time.

¹⁷Following the pioneering work of Jernelöv and Edenmark (1992), Azar and Holmberg (1995) estimate the global generational environmental debt for CO₂ emissions at around 10,000 billion USD. Consequently, even if many features can affect the ecological debt—including the increase of cadmium, the decrease of humus on agricultural land, or the handling of (radioactive) waste—the cumulative CO₂ emission is a convenient ecological debt proxy, i.e. of the "*damages that past and present generations have caused*".

¹⁸Relatedly, using cumulated CO₂ projects, Botzen et al. (2008) concluded that the responsibility for "climate debt" will be shared by the largest emitters, i.e. Western Europe, the US, and large developing countries (e.g. China and India).

data (2011) define the time span for our sample; in addition, due to some data limitations among the high- and upper-middle-income countries,¹⁹ we end up with a balanced panel of 22 countries over 1990-2011 (Appendix C provides the list of countries and statistics).

4.2. Methodology

We draw upon the [Pesaran et al. \(1999\)](#) autoregressive distributed lag model (ARDL), with p lags for environmental debt (D) and q lags for the public debt-to-output ratio (θ)

$$\log D_{it} = \sum_{j=1}^p \alpha_{ij} \log D_{i,t-j} + \sum_{j=0}^q \delta'_{ij} \theta_{i,t-j} + \mu_i + \epsilon_{it}, \quad (16)$$

with $i = \overline{1, N}$ and $t = \overline{1, T}$ the country and time indexes respectively, μ_i the country-specific effects, and ϵ_{it} the error term. Assuming that variables are I(1) and cointegrated, Eq. (16) can be reparameterized into the error correction model ([Pesaran et al., 1999](#))

$$\Delta \log D_{it} = \Phi_i (\log D_{i,t-1} - \beta'_i \theta_{it}) + \sum_{j=1}^{p-1} \alpha^*_{ij} \Delta \log D_{i,t-j} + \sum_{j=0}^{q-1} \delta^*_{ij} \Delta \theta_{i,t-j} + \mu_i + \epsilon_{it}, \quad (17)$$

with $\Phi_i = -(1 - \sum_{j=1}^p \alpha_{ij})$, $\beta_i = \frac{\sum_{j=0}^q \delta_{ij}}{1 - \sum_k \alpha_{ik}}$, $\alpha^*_{ij} = - \sum_{m=j+1}^p \alpha_{im}$, and $\delta^*_{ij} = - \sum_{m=j+1}^q \delta_{im}$.

The second part – in differences – of Eq. (17) illustrates the short-run adjustment to the long-run equilibrium, while the first part – in levels – captures the long-run relationship. The speed of adjustment is given by the error-correcting term Φ_i , which should be negative and significant to validate the presence of a long-run relationship.

4.3. Preliminary tests: stationarity and cointegration

We investigate the time-series properties of our variables using the popular Fisher-ADF and IPS unit root tests. In the auto-regressive specification of each test we include both the trend and the intercept, and we remove cross-sectional means to mitigate the

¹⁹Income groups are defined according to the World Bank definition. The focus on upper-middle and high income countries is motivated by the importance of their CO₂ emissions from a global perspective.

effects of cross-sectional correlation. As shown by Table 3, we cannot reject the null hypothesis of the presence of a unit root for our variables in levels; moreover, since the null is rejected for our variables in first-difference, we conclude that they are integrated of order one, namely $I(1)$. Given that they are integrated of the same order, we look next for a potential cointegration relation between public and environmental debts.

Table 3: Unit root tests

Variables	ADF		IPS	
	Statistic	p-value	Statistic	p-value
Log(Environmental Debt)	Z: 1.65 Pm: -0.05	0.95 0.52	W-T-bar: 1.38	0.92
Δ (Log Environmental Debt)	Z: -7.60 Pm: 13.68	0.00 0.00	W-T-bar: -6.63	0.00
Gross Public Debt	Z: 2.31 Pm: -1.04	0.99 0.85	W-T-bar: 2.68	0.99
Δ (Gross Public Debt)	Z: -2.21 Pm: 2.79	0.01 0.00	W-T-bar: -5.26	0.00

Note: Pm is the modified inverse chi-squared and Z is the inverse normal statistic. The null hypothesis is "all panels contain unit roots". We use 1 lag following the AIC. We include a trend and an intercept.

Table 4: Westerlund (2007) cointegration tests

Statistic	Value	Z-value	P-value
Gt	-6.223	-18.384	0.000
Ga	-47.487	-20.205	0.000
Pt	-10.324	-2.450	0.007
Pa	-31.742	-14.408	0.000

Note: Gt and Pt correspond respectively to the group mean test and the panel mean test. Ga and Pa are their respective asymptotic versions. The null assumption is "no cointegration". We use 3 lags following the AIC.

For this purpose, we draw upon [Westerlund \(2007\)](#)'s tests in which the null hypothesis of no cointegration is assumed against four different specifications of the alternative hypothesis: the group mean test and its asymptotic version, which assume cointegration for the panel as a whole, and the panel mean test and its asymptotic version, which assume cointegration for at least one cross-section unit. The results of these tests—carried using bootstrap with 400 replications to preserve size accuracy and consistency in the case of potential cross-sectional dependence—reported in Table 4 support the presence

of cointegration between public debt and environmental debt in levels.

5. Estimations and empirical findings

Since our variables are I(1) and cointegrated, we estimate an error correction model – with $p = 1$ and $q = 1$ in (17) in light of the AIC – to assess the effect of public debt on environmental debt. One major advantage of Pesaran et al. (1999) ARDL model – particularly useful to test our theoretical findings – is that it provides three different ways to estimate (17): (i) the dynamic fixed-effects estimator (DFE) that assumes common long- and short-run coefficients; (ii) the pooled mean group estimator (PMG) that assumes common long-run coefficients, but different short-run coefficients across countries, and (iii) the mean group estimator (MG) that allows for different long- and short-run coefficients across countries (Pesaran and Smith, 1995).

Table 5: Public Debt and Environmental Debt—the main empirical results

Dependent Variable	Log (Environmental Debt)	
	DFE	PMG
Error correction term	-0.180*** (0.0033)	-0.193*** (0.0061)
<i>Long run coefficients</i>		
Gross public debt	0.0028** (0.0011)	0.0074*** (0.0004)
<i>Short run coefficients</i>		
Δ (Gross public debt)	-0.0009*** (0.0003)	-0.0017** (0.0007)
Obs./Countries	462/22	462/22
Log likelihood		724
Hausman Test p-value		0.5246

Note: Unreported constant included. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$;

In light of our theoretical analysis, the existence of a unique steady-state rules out the MG estimator and supports the DFE and the PMG estimators that consider a common long-run dynamic. As shown by the first column of Table 5 in which we use the DFE estimator, the error correction term is negative and significant, thus supporting our modeling choice. Turning to the main results, a higher public debt is associated with (i) a higher environmental debt in the long run, and (ii) a lower environmental debt in the short run, consistent with our theoretical findings.

However, these estimated effects may be criticized for being valid only if the assumptions of the DFE estimator hold. Therefore, as a first robustness test, we allow for different short-run dynamics together with a common long-run path using the PMG estimator. The high p-value (equal to 0.5246) of the Hausman Chi-2 test presented at the bottom of column 2 of Table 5 does not reject the null of a common long-term coefficient (against the alternative of different long-term coefficients). Besides, the error correction term is negative and significant, supporting once again our modeling choice. Turning to the main results, column 2 of Table 5 shows that higher public debt is associated with higher environmental debt in the long run, and lower environmental debt in the short run.²⁰

²⁰The short-run coefficient for the PMG estimator is computed as the average of country-individual short-run coefficients; we discuss this issue in the next section.

Table 6: Public Debt and Environmental Debt—robustness

Dependent Variable	Log(Environmental Debt)	
Period	1990-2011	1990-2006
Error Correction term	-0.280*** (0.0205)	-0.304*** (0.0243)
<i>Long-run coefficients</i>		
Gross public debt	0.0065*** (0.0003)	0.0071*** (0.0004)
Log GDP per capita	2.236*** (0.0530)	2.569*** (0.0615)
<i>Short-run coefficients</i>		
Δ (Gross public debt)	-0.0021** (0.0009)	-0.0049*** (0.0017)
Δ (Log GDP per capita)	-0.636*** (0.160)	-0.668*** (0.139)
Obs./Countries	462/22	352/22
Log likelihood	923.8	745.0

Note: Unreported constant included. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Finally, we consider two more robustness checks. On the one hand, we alter the structure of the model by extending the number of variables in the cointegrating vector to the presence of what seems to be the most natural candidate, namely the level of economic activity measured by GDP per capita.²¹ On the other hand, we alter our sample by removing the aftermath of the 2007-2008 crisis during which many countries experienced important public debt increases. PMG estimations reported in Table 6 reveal—once again—a positive relationship between public debt and environmental debt in the long run and a negative relationship between these two variables in the short run.

Consequently, our empirical analysis confirms the long-run complementarity between public debt and environmental debt suggested by our theoretical model. Besides, although estimations suggest a substitution effect between public debt and environmental debt on average, the following section aims at refining this effect.

²¹Prior to the estimations, we established the presence of cointegration among the three variables.

6. A closer look at the public debt-environmental debt short-run link

To take a closer look at the short-run relationship between public debt and environmental debt, we extend our empirical analysis on two grounds.

6.1. Country evidence

Our stylized model may overlook a wide range of variables; while unobserved variables are accounted for in the empirical analysis by country-fixed effects, we investigate if country-differences may alter the public debt—environmental debt link in the short run.

Table 7: Public debt and Environmental debt—country evidence

	Short run coefficients by country										Long run	
	Argentina	Austria	Brazil	China	Colombia	Finland	France	Germany	Greece	Italy	Japan	
Public Debt												0.0074*** (0.0004)
Error correction term	-0.1979*** (0.0206)	-0.1775*** (0.0155)	-0.1943*** (0.0138)	-0.1563*** (0.0168)	-0.2126*** (0.0126)	-0.1655*** (0.0218)	-0.2099*** (0.0165)	-0.1968*** (0.0151)	-0.1997*** (0.0155)	-0.1724*** (0.0174)	-0.3042*** (0.0130)	
Δ (Public Debt)	-0.0013** (0.0005)	-0.0028 (0.0052)	-0.0019 (0.0016)	-0.0011 (0.0033)	-0.0054** (0.0025)	0.0026 (0.0029)	-0.0022 (0.0039)	-0.0052 (0.0033)	-0.0004 (0.0015)	0.0019 (0.0033)	-0.0016* (0.0008)	
Obs./Countries	462/22											
Log likelihood	724											

Note: Unreported constant included. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 8: Public debt and Environmental debt—country evidence (continued)

	Short run coefficients by country										Long run	
	Korea, Rep.	Norway	Portugal	Romania	Spain	Switzerland	Thailand	Turkey	Un. Kingdom	United States	Uruguay	
Public Debt												0.0074*** (0.0004)
Error correction term	-0.1804*** (0.0132)	-0.2048*** (0.0137)	-0.1892*** (0.0140)	-0.1781*** (0.0186)	-0.1738*** (0.0168)	-0.2006*** (0.0170)	-0.1887*** (0.0142)	-0.1898*** (0.0198)	-0.1913*** (0.0153)	-0.1841*** (0.0126)	-0.1756*** (0.0148)	
Δ (Public Debt)	-0.0074 (0.0064)	-0.0033 (0.0021)	0.0026 (0.0024)	0.0006 (0.0030)	-0.0012 (0.0025)	-0.0080** (0.0033)	-0.0031** (0.0015)	-0.0023 (0.0017)	0.0005 (0.0025)	0.0040* (0.0021)	-0.0020** (0.0009)	
Obs./Countries	462/22											
Log likelihood	724											

Note: Unreported constant included. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

To this end, we report in Tables 7 and 8 the extended results of the PMG estimator from the second column of Table 6. Under the established result of a long-run complementarity between public debt and environmental debt (the coefficient equals 0.0074), the short-run relationship between the two variables is mostly negative at country-level (the quality of our estimations is supported by significantly-negative error correction terms in all columns). However, compared with the results for the full panel, the short-run public debt-environmental debt relationship must be amended on two grounds. On the

one hand, despite presenting a negative sign, the link between the two variables is not significant in several countries, and even reversed in the United States. On the other hand, even among countries in which a significant substitution effect is at work, the size of this effect varies considerably between 0.13 and 0.80 (in absolute value). In the following, we look for channels that may explain these heterogenous short-run effects.

6.2. Various structural characteristics

Table 9: Public Debt and Environmental Debt—structural characteristics

Dependent Variable	Log(Environmental Debt)						
	Full Sample	Public Debt		Income Level		Openness Degree	
		Low	High	Upper-Middle	High	Low	High
Error correction term	-0.193*** (0.0061)	-0.186*** (0.0043)	-0.203*** (0.0150)	-0.189*** (0.0079)	-0.195*** (0.0079)	-0.198*** (0.0108)	-0.188*** (0.004)
<i>Long run coefficients</i>							
Gross public debt	0.0074*** (0.0004)	0.0069*** (0.0017)	0.0074*** (0.0004)	0.0084*** (0.0022)	0.0073*** (0.0004)	0.0073*** (0.0004)	0.0081*** (0.0025)
<i>Short run coefficients</i>							
Δ (Gross public debt)	-0.0017** (0.0007)	-0.0024*** (0.0008)	-0.0004 (0.0011)	-0.0023*** (0.0008)	-0.0015* (0.0009)	-0.0011* (0.0007)	-0.0024** (0.0012)
Obs./Countries	462/22	294/14	168/8	126/6	336/16	252/12	210/10
Log likelihood	724.0	445.9	278.2	192.9	531.2	400.7	323.3

Note: Unreported constant included. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The short-run substitution relationship between public debt and environmental debt illustrated by our theoretical model rests upon a condition on the initial stock of public debt, which must not be too high (see *Proposition 3* and the discussion below it). Conjecturing that the lack of a significant short-run substitution effect between public debt and environmental debt in some countries may reproduce differences in their public debt levels, we oppose estimations in the groups of countries with "low" and "high" public debt respectively, where the two groups are defined by comparing the average debt-to-GDP ratio with the institutional 60% threshold suggested by the Maastricht Treaty (see Appendix C for the list of countries in each group and descriptive statistics). Compared with results for the full sample (reminded in column 1 of Table 9), estimations in columns 2-3 of Table 9 confirm that public debt and environmental debt are complement in the long

run for both groups of countries (both coefficients are positive and significant), while a robust substitution effect (i.e. a negative and significant coefficient) is at work exclusively in the group of countries with "low" public debt, as predicted by our theory.

However, if extending the empirical analysis by accounting for differences in public debt confirmed our theoretical predictions, it would be equally interesting to see if our theoretical predictions still hold when extending the empirical analysis to include scenarios that are unaccounted for by our stylized theoretical model – a "*falsification*" test. Two appealing such empirical extensions consider the role of (i) the domestic conditions, which we capture by distinguishing between upper-middle income and high-income countries, and (ii) the external conditions, which we capture by distinguishing between countries with a "low" and a "high" openness degree with respect to the sample median of the average trade-to-GDP ratio. Remarkably, the last four columns of Table 9 show that the long-run complementarity and the short-run substitutability between public debt and environmental debt predicted by our theoretical model are insensitive to differences in the income level or the openness degree.

To summarize, our empirical analysis reveals (i) a robust public-environmental debt long-run complementarity; (ii) in general, a public-environmental debt short-run substitutability; and (iii) this short-run substitutability may be weakened depending on the public debt size—as predicted by our theory—but not by other variables absent from our model, such as the income level or the openness degree. These findings confirm the soundness of our theoretical model, and support exploiting the mechanism describing the public-environmental debt interaction for the normative analysis of the next section.

7. Welfare analysis

From a theoretical perspective, the main innovation of our paper is to introduce public debt as a source of abatement public spending financing; as such, a natural issue is related to the choice of the optimal long-run public debt target. To obtain such normative results, we compute the effect of the debt ratio on long-run welfare from a second-best perspective. To this end, we focus on steady-state welfare effects in a permanent regime—we compare different BGPs associated with different values of θ ; in other words, we perform comparative statics among different BGPs.

On a BGP, household's welfare (5) writes

$$U = \int_0^{+\infty} e^{-\rho t} u(C_t^*, Q^*) dt = \int_0^{+\infty} e^{-\rho t} \{\log(C_t^*) + \eta \log(Q^*)\} dt, \quad (18)$$

where C_t^* increases at the growth rate γ^* , and Q^* is constant in the steady state. Using $C_t^* = c^* K_0 e^{\gamma^* t}$, we compute $U = \frac{1}{\rho^2} \{\rho [\log(c^*) + \log(K_0) + \eta \log(Q^*)] + \gamma^*\}$, with K_0 the initial capital stock (normalized to one in our simulations), and Q^* the environmental quality in the steady state. Since a change in the debt target (θ) impacts consumption and environmental debt through abatement public spending in the steady state, its effect on welfare might differ from its effect on growth. Similarly, the pollution tax rate (τ_p) affects the growth rate (through coefficient A), the environmental debt, and consumption.

Using benchmark parameters' values, Figure 3 depicts the dynamics of the different variables of the model at the steady state, following a change in the debt target θ . We observe that an increase in the debt target rises consumption, while it decreases the environmental quality. Indeed, the higher θ , the lower the abatement public spending, and the higher the environmental debt at the steady state, due to the crowding-out effect discussed above. In addition, as the economic growth rate and public spending decrease,

consumption rises according to the IS equilibrium ($\gamma = A(1 - g^* - c^*)$). These mechanisms generate a non-linear effect on welfare. The first mechanism is driven by the increase in consumption, while the second is linked to the environmental degradation. It results a welfare-maximizing debt-to-output threshold ratio around 76% in the benchmark case.

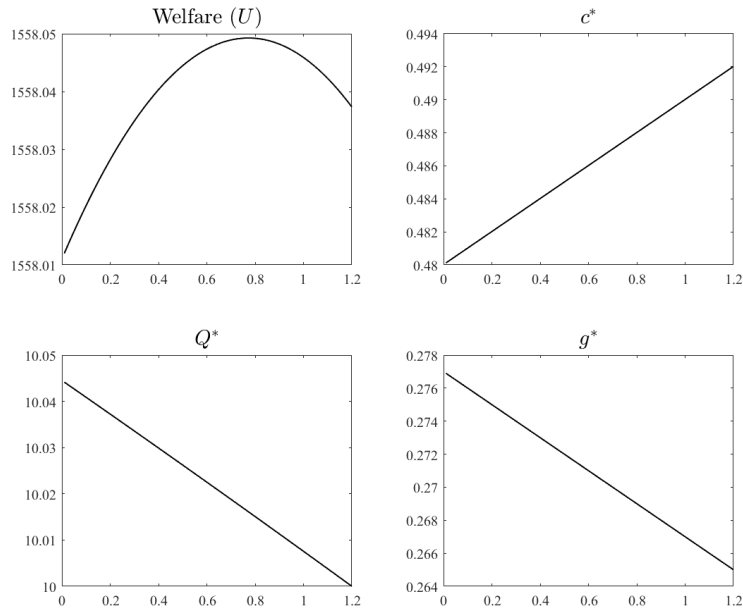


Figure 3: Response of variables to changes in the debt target (benchmark calibration)

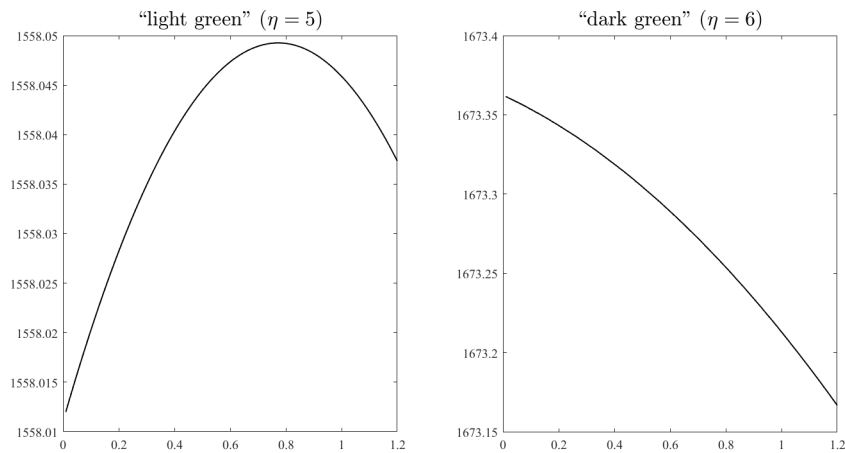


Figure 4: Welfare-maximizing debt ratios and greenness of preferences

Interestingly, the welfare-maximizing debt ratio crucially depends on household’s preference parameter in the utility function (η). We investigate two scenarios in Figure 4: a

"*light green*" preference ($\eta = 5$, as in the baseline calibration), and a "*dark green*" preference ($\eta = 6$). As Figure 4 highlights, the higher the household's environmental preference, the lower the critical debt threshold. In the case of "dark green" preferences that strongly value the environment, the welfare-maximizing debt threshold is zero ($\theta = 0$), so that the welfare-maximizing fiscal rule is the balanced budget rule (associated with a zero deficit). Indeed, as previously emphasized, the decreasing part in the welfare function is driven by the decrease of the environmental quality. Therefore, if the valuation of the environmental quality rises, the welfare-maximizing debt ratio shifts to the left.

These results extend our previous findings and reveal the difficulties of defining optimal public debt targets. Indeed, implementing an environmentally-friendly public debt target, in addition to generating a trade-off between short- and long-run environmental debt effects, may not coincide with the target that maximizes household's welfare.

8. Conclusion and extensions

[Hartwick \(1997\)](#)'s point of view is that paying down the environmental debt is a process similar to paying down the public debt: both tasks mobilize large amounts of resources disbursed over decades to meet targets either agreed in multilateral environmental agreements or set by the fiscal policy. By adopting a similar perspective, the goal of this paper was to study the relationship between public debt and environmental debt using a theoretical analysis and an empirical evaluation.

Departing from the existing literature through considering the presence of endogenous public indebtedness in the long run, our theoretical model allowed deriving two main results: public debt and environmental debt are complement in the long run, and usually substitute in the short run. These theoretical predictions were confirmed by our empirical analysis conducted in a panel of 22 countries over 1990-2011.

Regarding the policy implications of our analysis, they usually depend on the government's objective. If the government has a green objective, namely a long-term plan for protecting nature and biodiversity, it needs to engage into debt consolidation programmes (by, e.g., implementing tax-increases, cuts in public spending, or arrangements for debt relief). Indeed, in the long run, debt services hampers the government's capacity to provide abatement expenditures, which degrades environmental quality and boosts climate debt. By reducing the public debt, the government provides more fiscal space to finance long-term nature protection policies. However, from the households' perspective, such a policy can be costly in the short run, as sharp spending cuts or large tax increases can depress short-term economic growth and reduce private consumption. Hence, if the government has rather a social welfare objective, it will prefer to issue more public debt, even if this means reducing the environmental quality in the long run. In particular, we revealed the presence of a long-term debt-to-GDP ratio that maximizes the intertemporal social welfare.

Among the several directions in which our analysis could be extended, we believe that two would deserve particular attention. First, from a theoretical perspective, one should account for other types of public spending aside from those abatement spending. Second, from an empirical perspective, one could go beyond global pollution towards other forms of global environmental degradation, or towards more disaggregated measures of local pollution, whose impact could be estimated using spatial econometric techniques.

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