Public debt vs Environmental debt: A long-run perspective[⋆]

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Abstract

The article focuses on the long-run relationship between public debt and environmental debt. The latter is defined as the difference between the "virgin state" which is the maximum stock of environmental quality that can be kept intact with natural regenerations and the current quality of the environment. A theoretical model of endogenous growth is built. We show that there is a unique well determined balanced-growth path along which the public debt-to-output ratio increases the environmental debt-to-output ratio. The basic mechanism is that unproductive public expenditures (debt burden) crowd out pollution abatement expenditures. Public debt and environmental debt are therefore complementary. This hypothesis is tested on a sample of 22 countries for the period 1990-2011. The environmental debt is measured by the cumulative CO_2 emissions per capita. We use panel time-series estimators which allow for heterogeneity in the slope coefficients between countries. It appears mainly that, in the long term, an increase of 100% in public debt ratio leads to an increase of 74% in cumulative CO_2 per capita. In addition, this positive long-run relationship is still present at the country and the sub-sample level, despite some differences in the short-term dynamics.

Keywords: environmental debt, public debt, endogenous-growth model, heterogenous panel data model
JEL codes: O44, Q52, Q58

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1. Introduction

Sustainable development has long been considered being backed on three pillars. Recent history, however, shed light on two distinguishing features of unsustainable development. They stem from global environmental degradation and especially from climate change and rising sovereign indebtedness. On the one side, energy-related CO_2 emissions rose a historic high of 33.1 Gt CO_2 in 2018 (International Energy Agency, 2019). This raised once more the issue of the environmental i.e. climatic debt that will be borne by future generations (Azar and Holmberg, 1995) with a major shift in responsibilities from developed to developing countries (Botzen et al., 2008). On the other side, indebtedness has been soaring, especially in the aftermath of the 2007-2008 crisis. Fast increase in public indebtedness is seen as "the most enduring legacies of the 2007-2009 financial

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crises" especially when it comes as a major impediment to economic growth (Reinhart and Rogoff, 2010; Eberhardt and Presbitero, 2015). Several authors, therefore, urged for both reforms of the fiscal and financial systems, which are deemed to prompt the right incentives to green growth (Aglietta and Hourcade, 2012). This is all the more necessary in the face of increasing concerns on the ability of NDCs, even if fully implemented, to meet the climate targets agreed in the 2015 Paris Agreement. For instance, promoting renewable energy is the most common mitigation strategy while agriculture and transport are seldom considered as key sectors for mitigation though, along with energy and industry, they are the largest contributors to GHG emissions (Pauw et al., 2018).

This paper contributes to the sparse literature on the interaction between environmental and macroeconomic policies while scrutinizing the relationship between sovereign and environmental debt.[2] One could argue that higher public indebtedness is legitimate for financing investments in low-carbon technologies or environmental R&D activities which will mainly benefit to future generations. This assertion can, however, be challenged when the government has run deficits for many years. Hence, one can wonder about the consequences of public debt stabilization on environmental policies and outcomes. Under the assumption that public debt initiates additional pressure on the environment, debt for nature swaps can generate positive environmental outcomes. This possibility has been explored in the case of deforestation.[3] It can also be argued that debt servicing crowds out private expenditures that can entail abatement expenditures. Fodha and Seegmuller (2014) show that public abatement partly financed by debt emission may even lead the economy to an environmental poverty trap under a stabilizing debt constraint.

This paper theoretically and empirically explores further the interdependencies between environmental and sovereign debt in a long term perspective. In Section 3, relaxing the balanced-budget rule assumption, a simple endogenous growth model establishes a *complement effect* between public and environmental debt along the balanced growth path of the economy. Unproductive public expenditures, i.e. the debt burden, crowd out pollution abatement expenditures. Relying on cumulative per capita consumption-based CO_2 emissions as a proxy of environmental debt in Section 4, our results show that in 22 countries increasing the debt-to-output ratio has a statistically and economically significant impact on the environmental debt in the long run.

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[2] See for a brief review e.g. (Combes et al., 2015).

[3] Kahn and McDonald (1995) provided econometric support for this hypothesis while Cassimon et al. (2011) cast some doubts on the possibility of scaling up debt for nature swaps.

2. The model

We consider a simple continuous-time endogenous-growth model with a representative individual, who consists of a household and a competitive firm, and a government. All agents are infinitely-lived and have perfect foresight.

2.1. Environmental debt

In the economy, environmental quality (Q_t) determines nature's capacity to grow and absorbs wastes from economic activity. 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

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

where a dot over a variable represents a time derivative.

In Eq. (1), P_t represents reduction in environmental quality, or natural resources, from the flow of emissions (say pollution), G_t is the public environmental abatement, with an efficiency $\delta \geq 0$, and $E(\cdot)$ is an environmental regeneration function and reflects the capacity of the environment to absorb pollution. We consider several standard assumptions.

Assumptions.
(i) $E'(Q_t) < 0$ (*the law of entropy*)
(ii) there is a critical level $\bar{Q} > 0$, such that $E(\bar{Q}) = 0$ (*virgin state*)

Assumption (i) means that the higher the stock of natural resources, the higher the difficulties to maintain or increase this stock through natural regeneration processes (which is an implication of the entropy law from physics, see Smulders, 1995). Assumption (ii) states that, without pollution and abatement spending ($P_t = G_t = 0$), environmental quality reaches its highest possible (finite) level – the "*virgin state*" $\bar{Q}$ – which is the maximal stock of natural resources that can be kept intact by natural regeneration. As $E'(\bar{Q}) < 0$, $\bar{Q}$ is a stable steady state when $P_t = G_t = 0$, and thus characterizes the stationary natural resources without economic activity. However, this virgin-state natural resources can no longer be sustained, because production process will use polluting inputs ($P_t > 0$), and/or the government will implement abatement policy ($G_t > 0$), as we will see.

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

$$D_t = \bar{Q} - Q_t.$$

Finally, we assume that the flow of pollution is proportional to the level of production, i.e. $P_t = \phi Y_t$, where $\phi \geq 0$ represents the constant emission-output coefficient.

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 discount value of its lifetime utility

$$U = \int_0^\infty e^{-\rho t} u(C_t, Q_t)\, dt, \tag{2}$$

where $\rho \in (0,1)$ the subjective discount rate. To simplify, the instantaneous utility is assumed to be separable

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

where $\eta > 0$ captures environmental preferences.

The household enters period t with 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). He perceives wages ($w_t L$), pays taxes (where $\tau_w \in (0,1)$ is the proportional wage income tax rate), and decides how much to consume (C_t) and save during the period. The only forms of asset accumulation are capital ($\dot{K}_t$, we omit capital depreciation, without loss of generality) and government bonds ($\dot{B}_t$); hence the following budget constraint

$$\dot{K}_t + \dot{B}_t = r_t B_t + q_t K_t + (1 - \tau_y) w_t L - C_t. \tag{3}$$

First-order conditions give rise to the familiar Euler equation (with $q_t = r_t$ in competitive equilibrium)

$$\frac{\dot{C}_t}{C_t} = r_t - \rho, \tag{4}$$

and the optimal path must verify the set of transversality conditions

$$\lim_{t \to +\infty} \{\exp(-\rho t)\ K_t / C_t\} = 0 \text{ and } \lim_{t \to +\infty} \{\exp(-\rho t)\ B_t / C_t\} = 0,$$

which ensure that lifetime utility U is bounded.

2.3. Firms

Output of the representative firm (Y_t) is produced using three inputs: private capital (K_t), labor (L_t), and a polluting input (Z_t) that reflects effective input of 'harvested' environmental resources, according to the following Cobb-Douglas production function

$$Y_t = \tilde{A} K_t^\alpha Z_t^\beta (\bar{K}_t L_t)^{1-\alpha-\beta}, \tag{5}$$

where $\alpha \in (0,1)$ and $\beta \in (0,1)$ are the elasticity of output to the private capital and polluting input, respectively. $\tilde{A} > 0$ is a scale parameter, and K_t is the economy-wide level of capital that generates positive technological spillovers onto firms productivity (Romer, 1986).

The firm i chooses private factors (K_t, L_t and P_t) to maximize its profit

$$\Pi_t = Y_t - r_t K_t - w_t L_t - \tau_p Z_t,$$

where τ_p the constant environmental tax on polluting input. The first-order condition give rise to

$$r_t = \alpha \frac{Y_t}{K_t}, \tag{6}$$

$$w_t = (1 - \alpha - \beta) \frac{Y_t}{L}. \tag{7}$$

$$\tau_p = \beta \frac{Y_t}{Z_t}. \tag{8}$$

with, at equilibrium, $L_t = L$. We henceforth normalize $L = 1$.

In the production function (5), as usual, the returns to scale are constants between private factors (rival inputs), such that the output shares between the return of labor, capital and pollution.

2.4. The government

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

$$\dot{B}_t = r_t B_t + G_t - \tau_p Z_t - \tau_w w_t. \tag{9}$$

Contrary to standard models that assume a balanced-budget rule, we introduce the possibility of public debt financing in the long-run, so that public deficits may be permanently financed by the public debt accumulation. Effectively, many papers show that endogenous growth setups are compatible with the existence of a growing public debt in the long-run (Minea and Villieu, 2012; Boucekkine et al., 2015; Menuet et al., 2018).[4] At this stage the model is not closed, because there is one free variable in the government budget constraint (9). To close the model, the government must fix either the public spending or the public debt path. As public expenditure is an endogenous variable, we take the debt-to-output (B_t/Y_t) that determines the public debt path as the instrument. To this end, we specify the simple fiscal rule $B_t/Y_t = \theta$, where θ is the constant public-debt-to-output ratio. The paper aims to study the effect of θ on the environmental debt ratio at equilibrium.

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[4] The only requirement for the transversality condition to be verified is that the rate of growth of public debt must be less than the real interest rate at equilibrium.

3. Equilibrium

At equilibrium, we have $\bar{K}_t = K_t$, and using (5),

$$Y_t = AK_t,$$

where $A := [\tilde{A}(\tau_p\beta)^\beta]^{1/(1-\beta)}$.

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 (6), the real interest rate becomes, at equilibrium

$$r_t = \alpha A. \tag{10}$$

To obtain long-run stationary ratios, we deflate variable by output and we use minuscule letters to depict ratios, namely: $c_t := C_t/Y_t$, $b_t := B_t/Y_t$, $d_t := D_t/Y_t$.

The path of the capital stock is given by the goods market equilibrium

$$\frac{\dot{K}_t}{K_t} = A(1 - g_t - c_t). \tag{11}$$

The government's budget constraint (9) leads to, using $\gamma_{y,t} =: \dot{Y}_t/Y_t$,

$$g_t = \theta\gamma_{y,t} + \beta + \tau_w(1 - \alpha - \beta) - \alpha A b_t. \tag{12}$$

As $\gamma_{y,t} = \gamma_{k,t} := \dot{K}_t/K_t$, it follows that

$$g_t = \frac{1}{1+\theta A}\left[\theta A(1 - c_t) + \lambda - \alpha A b_t\right], \tag{13}$$

where $\lambda := \beta + \tau_w(1 - \alpha - \beta)$. From (9), we obtain

$$\frac{\dot{b}_t}{b_t} = \frac{\dot{B}_t}{B_t} - \frac{\dot{Y}_t}{Y_t} = A\left(\frac{1 - c_t - \lambda + \alpha A b_t}{1+\theta A}\right)\left(\frac{\theta}{b_t} - 1\right). \tag{14}$$

Regarding the law of motion of the environmental quality (1), for a balanced-growth path to emerge, the environmental regeneration process $E(Q_t)$ should grow at the same rate as output along that path. To this end, we will assume that there is a function $\Phi(d_t)$ such that $E(\bar{Q} - D_t) = E(\bar{Q} - D_t) = Y_t\Phi(D_t/Y_t)$. As $E(Q_t)$ is assumed to be decreasing, $\Phi(d_t)$ is increasing in the environmental-debt-to-output ratio.

From (1), (4), (10), (11), and (14), the reduced-form of the model is

$$\begin{cases} \dfrac{\dot{c}_t}{c_t} = \alpha A - \rho - A\left(\dfrac{1 - c_t - \lambda + \alpha A b_t}{1 + \theta A}\right) & \text{(a)}, \\[2ex] \dot{b}_t = A\left(\dfrac{1 - c_t - \lambda + \alpha A b_t}{1 + \theta A}\right)\left(\dfrac{\theta}{b_t} - 1\right) & \text{(b)}. \\[2ex] \dot{d}_t = \phi - \delta g_t - \Phi(d_t) - A\left(\dfrac{1 - c_t - \lambda + \alpha A b_t}{1 + \theta A}\right) & \text{(b)}. \end{cases} \tag{15}$$

3.1. Steady states

We define a balanced-growth path (BGP) as a path on which consumption, capital, output, public debt, environmental debt grow at the same (endogenous) rate, namely (we henceforth omit time indexes)

$$\gamma^* := \dot{C}/C = \dot{K}/K = \dot{Y}/Y = \dot{B}/B = \dot{D}/D.$$

Proposition 1. *(Existence and Uniqueness) There is a non-empty set of parameter such that there is a unique BGP.*

Proof: Steady state is computed by setting $\dot{c}_t = \dot{b}_t = \dot{d}_t = 0$ in (15). Using the Keynes-Ramsey relationship (4) and the real interest rate (10), we obtain that $\gamma^* = \alpha A - \rho$. This steady state growth level is positive if and only if $A > \rho/\alpha$, which is true as ρ is small enough. From (15.b), as $\gamma^* > 0$, we have $b^* = \theta$. Using (15.a), $\dot{c}_t = 0$ leads to

$$1 - c^* = \frac{(\alpha A \ - \rho)(1 + \theta A)}{A} - \alpha A\theta + \lambda,$$

hence, using $\lambda := \beta + \tau_w(1 - \alpha - \beta)$, $c^* = (1 - \tau_w)(1 + \beta - \alpha) + \rho(1 + \theta A)/A > 0$, as $\alpha \leq 1$. From (13), we derive $g^* = \lambda - \rho\theta > 0$. Finally, using (15.c), the steady state environmental debt ratio d^* is such that

$$\Phi(d^*) = \phi - \delta g^* - (\alpha A - \rho) = \phi + \delta\theta\rho - \lambda\delta - (\alpha A - \rho), \tag{16}$$

which is positive under the mild assumption that $\phi > \underline{\phi} := \lambda\delta - \delta\theta\rho + (\alpha A - \rho)$. $\square$

To complete the characterization of the equilibrium, we must ensure that the unique BGP is well determined, i.e. saddle-path stable. To this end, we linearize system (15) at the neighborhood of the steady state, and focus on the sign of eigenvalues of the jacobian matrix ($\mathbf{J}$). The reduced-form includes one jump variable (the consumption ratio c_0) and two pre-determined variables (the public-debt ratio b_0 and the environmental debt ratio d_0). Thus, the following proposition ensures that $\mathbf{J}$ contains one positive and two negative eigenvalues, hence the saddle-path property.

Proposition 2. *(Stability) The unique BGP is saddle-path stable (well-determined).*

Proof: See Appendix A.

Proposition 2 states that the model is locally and globally well determined. From any pre-determined values of public debt (b_0) and environmental debt (d_0) ratios, the initial consumption (c_0) jumps to put the economy on the unique saddle-path trajectory that converges towards the BGP.

Interestingly, at the BGP, both the environmental debt ratio (d^*) and the public debt ratio ($b^* = \theta$) are positive. We can now address the relationship between the equilibrium level of public debt ($b^* = \theta$) and the environmental debt (d^*). The following subsection deals with this relationship from a theoretical perspective using comparative static results, and the section 4 examines this issue from an empirical point of view.

3.2. Comparative statics

We first establish the effect of the public-debt-to-output ratio (θ) and the abatement-spending-to-output ratio (g).

Proposition 3. *In equilibrium, the public-debt-to-output ratio (θ) decreases the abatement-spending-to-output ratio.*

Proof. From Eq. (12), we have $g^* = \theta(\gamma^* - r^*) + \lambda$. As the standard transversality condition ensures $r^* > \gamma^*$, it follows that $\partial g^* / \partial \theta < 0$. $\square$

The basic mechanism driving this crowding-out effect is the following. The public deficit generates (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 steady state, the transversality condition ($r_t > \gamma_t \Leftrightarrow r_t B_t / Y_t > \theta \dot{Y}_t / Y_t$) means that the latter dominates the former, thereby any rule that permit permanent deficits involves net long-run costs for public finance, irrespective of the precise nature of this rule. Consequently, public debt has always adverse effect for public abatement activity, and thus for environmental quality, as stated the following proposition.

Proposition 4. *Public debt and environmental debt are complement in equilibrium.*

Proof. From (16), as $\Phi' > 0$, it follows that $\partial d^* / \partial \theta > 0$. $\square$

Proposition 4 reveals an increasing relationship between public debt and environmental debt at equilibrium. This feature is related to the crowding-out effect of public debt on abatement public spending. Indeed, the steady state output and pollution flow do not depend on the public debt ratio (θ), so that the equilibrium quality of environment depends on θ through the public spending only. Consequently, according to proposition 3, the higher the public debt, the lower the abatement public spending, the lower the quality of environment, and the higher the environmental debt.

4. Empirical Methods

4.1. Data

Environmental Debt. We rely on cumulative carbon emissions to measure environmental debt. We calculate cumulative historical carbon emissions, using annual data from the Global Carbon Project. We use consumption-based emissions which 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 tonnes of carbon (MtC)[5]. We convert annual carbon emissions in tonnes of CO_2 before reporting them to population. Thus, the environmental debt for country i at year t is given by

$$D_{it} = \sum_{j=1990}^{t} (CO_{2i})_j$$

Where CO_2 stands for per capita CO_2 emissions. We take the natural logarithm of D_{it} for the econometric analysis.

Public Debt. Data on Gross public debt come from the IMF Historical Public finance dataset which is used in Mauro et al. (2015) and which goes back far into the past. Public debt is measured in percent of GDP. The data on debt-to-output ratio go up to the year 2011 for each country, therefore limiting our maximum time period length to 22, when combined to emissions data which start from 1990. Moreover, there were some gaps for both variables in some countries; since our sample consists in high income and upper-middle income countries[6] and because of data limitations, we end up with a balanced panel of 22 countries over the period 1990-2011. Summary statistics of our variables, as well as the list of countries, are reported in appendix B.

4.2. Methodology

In line with Pesaran et al. (1999), let's assume an autoregressive distributed Lag model (ARDL), with p lags for Environmental debt and q lags for our RHS variable, namely public debt

$$LogD_{it} = \sum_{j=1}^{p} \alpha_{ij} LogD_{i,t-j} + \sum_{j=0}^{q} \delta'_{ij}\theta_{i,t-j} + \mu_i + \epsilon_{it}, \tag{17}$$

with $i = \overline{1, N}$ countries, $t = \overline{1, T}$ periods, D environmental debt, θ the debt-to-output ratio, μ_i country-specific effects, and ϵ_{it} the error term. If we assume that the variables

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[5] 1MtC= 3.664 million tonnes of CO_2

[6] Income groups defined according to the World Bank definition. We also consider CO_2 emissions as an issue of less importance in developing countries, which motivates our choice to work on countries of the upper-middle and high income groups.

are I(1) and cointegrated, equation 12 can be reparameterized into the following error correction model (Pesaran et al., 1999)

$$\Delta LogD_{it} = \Phi_i(LogD_{i,t-1} - \beta_i^{'}\theta_{it}) + \sum_{j=1}^{p-1} \alpha^{*}_{ij}\Delta LogD_{i,t-j} + \sum_{j=0}^{q-1} \delta^{*'}_{ij}\Delta\theta_{i,t-j} + \mu_i + \epsilon_{it}, \quad (18)$$

where

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

The second part in differences of Eq. (18) 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.

There are three main approaches in the literature to estimate Eq. (18): (i) the dynamic fixed effects estimator (DFE) that allows only different intercepts across units but which turns out to be inconsistent if the common slope assumption fails to hold; (ii) the pooled mean group estimator (PMG) which assumes common long-run coefficients across units while allowing short-run coefficients to differ across units, and (iii) the mean group estimator (MG) which allows slope coefficients, intercepts and errors variances to be different across groups (Pesaran and Smith, 1995).

We start using the DFE estimator in a first stage, since we are interested in capturing long-run dynamics, and further use the PMG estimator to also assess the short-run dynamic while still controlling for the long-run relationship between our variables. Following AIC, we use an ARDL(1,1) meaning that we set $p = 1$ and $q = 1$ in Eq. 12.

4.3. Results

4.3.1. Stationarity and cointegration

To assess the stationarity of our variables, we rely on the Fisher-ADF and IPS unit root tests. The results are reported in Table 1. 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 effects of cross-sectional correlation. As we see in table 1, irrespective of the test, we cannot reject the null hypothesis of the presence of a unit root for our variables. Moreover, we also see that there are stationary in first-difference, meaning that there are I(1). Since they are integrated of the same order, we therefore look for potential cointegration relations among them.

For this purpose, we draw upon Westerlund (2007)'s tests. In these tests, the null hypothesis of no cointegration is assumed against four different specifications of the alternative hypothesis: the group mean test and its asymptotic version, that both consider the

Table 1: 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 represents 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 AIC. We include both trend and intercept.

alternative assumption that there is cointegration for the panel as a whole, and the panel mean test with its asymptotic version, which consider that the variables are cointegrated for at least one cross-section unit in the alternative assumption. We carry out these tests using bootstrap with 400 replications, in order to preserve size accuracy as well as consistency in the case of cross-sectional dependence. The results of testing a potential cointegration between environmental debt and public debt are provided by table 2. The low p-values support the presence of cointegration between our variables in level.

Table 2: 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". 3 lags determined by AIC.

Since they are I(1) and co-integrated, in the following we draw upon an error correction model to assess the effect of public debt on environmental debt.

4.3.2. Public Debt and Environmental Debt: Full sample

Table 3 reports the results of the error correction model; the first column presents the results of the dynamic fixed effects (DFE) estimator. The error correction term is negative and significant, thus justifying our modelling choice.

As we previously mentioned, the DFE estimator rests on an assumption of both common long-run and short-run dynamics for all countries. The assumption of a common short-run dynamic seems unrealistic, insofar as the increase of public debt in the short-run, resulting from higher expenditure, does not necessarily lead to the same level of abatement expenditure among countries with different environmental policies. However, for the long-run, it is possible to assume a common path since an increase in public debt leads to lower spending, including abatement expenditure, which in turn results in higher environmental debt.

Table 3: Environmental Debt response

Dependent Variable	Log (Environmental Debt)	
	DFE	PMG
Error correction term	-0.180***	-0.193***
	(0.0033)	(0.0061)
Long run coefficients		
Gross public debt	0.0028**	0.0074***
	(0.0011)	(0.0004)
Short run coefficients		
Δ(Gross public debt)	-0.0009***	-0.0017**
	(0.0003)	(0.0007)
Constant	0.844***	0.840***
	(0.0112)	(0.0341)
Observations	462	462
Countries	22	22
Log likelihood		724
Hausman Test p-value		0.5246

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

We therefore decide to allow for different short-run dynamics while still assuming a common long-term path: to do so we rely on the Pooled Mean Group (PMG) estimator, which results are presented in column 2 of table 3. We test its common long-term coefficient assumption against the alternative hypothesis of different coefficients, using the Hausman Chi-2 test which p-value is reported in the bottom of table 3. Since we are not rejecting the null hypothesis of a common long-run path for countries in our sample (p-value=0.5246), we keep the specification using the PMG as our baseline for the following.

The error correction term is also negative and significant, and the results in column 2 are consistent with our theoretical predictions: more public debt results in higher environmental debt in the long run. To illustrate, an increase of 100 units in the debt-to-output ratio leads to an increase of 74% in cumulative per capita CO_2 in the long-run. More public debt leads to higher environmental debt in the long run, since it implies lower abatement expenditure in the long run. But in the short run, since higher public debt is linked to higher expenditure, we have a negative effect on cumulative CO_2 because of higher abatement expenditure. We see that a 100 units increase in public debt leads to a reduction of 17% in cumulative emissions.

4.3.3. Public Debt and Environmental Debt: country evidence

Beyond full sample estimates, it could also be interesting to look at country estimates of the short-run impact of public debt, given that it might differ across countries. Thus, using PMG estimates from table 3, we report short-run impacts for each country in table 4 and table 5. Regarding sign differences, most of our short-run coefficients are negative even though many of them are non-significant. We even have a positive effect in United States, suggesting a positive short-run relationship between public debt and environmental debt in this country.

Table 4: Heterogeneity in short-run coefficients

	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***	-0.1775***	-0.1943***	-0.1563***	-0.2126***	-0.1655***	-0.2099***	-0.1968***	-0.1997***	-0.1724***	-0.3042***	
	0.0206	0.0155	0.0138	0.0168	0.0126	0.0218	0.0165	0.0151	0.0155	0.0174	0.0130	
Δ(Public Debt)	-0.0013**	-0.0028	-0.0019	-0.0011	-0.0054**	0.0026	-0.0022	-0.0052	-0.0004	0.0019	-0.0016*	
	0.0005	0.0052	0.0016	0.0033	0.0025	0.0029	0.0039	0.0033	0.0015	0.0033	0.0008	
Constant	0.7202***	0.8764***	0.5910***	0.6184***	0.6652***	0.8909***	0.9568***	1.0016***	0.8682***	0.7688***	1.2242***	
	0.0614	0.0652	0.0325	0.0504	0.0319	0.1020	0.0653	0.0657	0.0569	0.0663	0.0333	
Observations							462					
Countries							22					
Log likelihood							724					

Table 5: Heterogeneity in short-run coefficients (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***	-0.2048***	-0.1892***	-0.1781***	-0.1738***	-0.2006***	-0.1887***	-0.1898***	-0.1913***	-0.1841***	-0.1756***	
	0.0132	0.0137	0.0140	0.0186	0.0168	0.0170	0.0142	0.0198	0.0153	0.0126	0.0148	
Δ(Public Debt)	-0.0074	-0.0033	0.0026	0.0006	-0.0012	-0.0080**	-0.0031**	-0.0023	0.0005	0.0040*	-0.0020**	
	0.0064	0.0021	0.0024	0.0030	0.0025	0.0033	0.0015	0.0017	0.0025	0.0021	0.0009	
Constant	0.9263***	0.9741***	0.8182***	0.7986***	0.7988***	1.0063***	0.7004***	0.7358***	0.9528***	0.9890***	0.5943***	
	0.0543	0.0562	0.0485	0.0711	0.0646	0.0738	0.0412	0.0635	0.0648	0.0589	0.0383	
Observations							462					
Countries							22					
Log likelihood							724					

We also find differences in terms of magnitude across short-run impacts: for instance, the short-run negative effect for Switzerland is four times more important than the Uruguay's. These findings shed light on possible short-run heterogeneities across our sample: for some countries, the results are in line with the theoretical predictions of substitution in the short run and complementarity in the long-run between the two debts. However, for some countries, we find no significant impact for the short-run relationship. Even more, for a country like United States, we find a positive relation suggesting that more public debt does not necessary lead to higher abatement expenditure in the short run.

Thus, even if we expect countries in our sample to converge toward a common steady state in the long run, one could assume that the short-run dynamic of their environmental debt can differ. Such findings invite us to explore more closely particularities at play in our sample.

4.3.4. Public Debt and Environmental Debt: conditionality upon structural characteristics

Short-run differences we emphasized in the previous section could be linked to countries' economic and structural differences. Thus, in the following the analyze the sensitivity of our short-run coefficients to such differences. We consider five structural characteristics; first we capture differences in terms of environmental preferences through income (Grossman and Krueger, 1995) by considering alternatively upper-middle income and high income countries. Second, we also consider the fiscal stance and so the leeway in terms of public debt, using the average debt to GDP ratio over the period. We take a 60% threshold (as suggested by the Maastricht Treaty) to split countries.

Third, we take the openness degree into account through average trade in percentage of GDP; we therefore split our countries into groups with relatively low and high openness, based on the sample median. Finally, we also look at the average environmental debt over the period [7] and we use its sample median to divide the sample into countries with low and high environmental debt. Tables in appendix B present descriptive statistics and the countries for each group.

Table 6: Environmental Debt response (conditionality upon structural characteristics)

Dependent Variable	Log(Environmental Debt)								
	Full Sample	Income group		Public Debt		Openness		Env. Debt	
		Upper-Middle	High	Low	High	Low	High	Low	High
Error correction term	-0.193***	-0.189***	-0.195***	-0.186***	-0.203***	-0.198***	-0.188***	-0.180***	-0.197***
	(0.0061)	(0.0079)	(0.0079)	(0.0043)	(0.0150)	(0.0108)	(0.004)	(0.0057)	(0.0094)
Long run coefficients									
Gross public debt	0.0074***	0.0084***	0.0073***	0.0069***	0.0074***	0.0073***	0.0081***	0.0039***	0.0076***
	(0.0004)	(0.0022)	(0.0004)	(0.0017)	(0.0004)	(0.0004)	(0.0025)	(0.0014)	(0.0004)
Short run coefficients									
Δ(Gross public debt)	-0.0017**	-0.0023***	-0.0015*	-0.0024***	-0.0004	-0.0011*	-0.0024**	-0.0018***	-0.0015
	(0.0007)	(0.0008)	(0.0009)	(0.0008)	(0.0011)	(0.0007)	(0.0012)	(0.0006)	(0.001)
Constant	0.840***	0.684***	0.898***	0.802***	0.908***	0.794***	0.892***	0.685***	0.932***
	(0.0341)	(0.0314)	(0.0358)	(0.0404)	(0.0569)	(0.0545)	(0.0312)	(0.0269)	(0.0311)
Observations	462	126	336	294	168	252	210	168	294
Countries	22	6	16	14	8	12	10	8	14
Log likelihood	724.0	192.9	531.2	445.9	278.2	400.7	323.3	253.2	473.1

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6 presents the results obtained for the different country groups. As we can see, the positive long-run relationship between our variables remains robust among the different sub-samples. Concerning the magnitudes of the long-run coefficients, we find no significant differences between the sub-groups for income, public debt and openness.

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[7] It its worth to mention that since we are considering averages, some of the biggest contemporary polluters like China could appear in the group of countries with low environmental debt. This because their emissions started increasing strongly only over recent periods; moreover, environmental debt is calculated using consumption-based emissions rather than production-based emissions.

These coefficients are very similar to the long-run impact we found for whole sample. However, we find that the long-run effect for countries with an important environmental debt is about twice the one we obtain for countries with a low environmental debt. As in the baseline result, we also find negative and significant short-run coefficients for most of the sub-samples, except for countries with high levels of debt, both public and environmental.

4.3.5. Additional Robustness Checks

Table 7 provides additional robustness checks of our relation. In the first column, we control for the level of economic activity through GDP per capita[8], while in column 2 we alter our sample to remove the aftermath of the 2007-2008 crisis during which there was an important increase in public debt.

Table 7: Additional robustness checks

Dependent Variable	Log(Environmental Debt)		
Estimator	PMG		MG
Period	1990-2011	1990-2006	1990-2011
Error Correction term	-0.280***	-0.304***	-0.383***
	(0.0205)	(0.0243)	(0.0142)
Long-run coefficients			
Gross public debt	0.0065***	0.0071***	0.0019**
	(0.0003)	(0.0004)	(0.0009)
Log GDP per capita	2.236***	2.569***	0.545**
	(0.0530)	(0.0615)	0.231
Short-run coefficients			
Δ(Gross public debt)	-0.0021**	-0.0049***	-0.0018**
	(0.0009)	(0.0017)	(0.0008)
Δ(Log GDP per capita)	-0.636***	-0.668***	-0.580***
	(0.160)	(0.139)	(0.186)
Constant	-5.032***	-6.510***	-7.670***
	(0.365)	(0.505)	2.8401
Observations	462	352	462
Countries	22	22	22
Log likelihood	923.8	745.0	-
Ajd. R^2	-	-	0.81

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

To do so, we consider the period prior to 2007. Even though the Hausman test in table 3 suggests us to prefer the common long-run path assumption i.e to rely on PMG estimates, we however run a specification using Mean-group estimator in column 3. This,

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[8] We checked again for the existence of cointegration before running estimates

to test whether its results are qualitatively different from PMG estimates. It also includes cross-sectional averages to account for potential cross-sectional dependence. The results we obtain are again similar and support the presence of a complement effect in the long-run and a substitution effect in the short-run.

5. Conclusion

Hartwick (1997) rightly argued that paying down the environmental debt is a similar process than paying down public debt: both tasks mobilize billions of dollars to be disbursed over decades to meet targets either agreed in multilateral environmental agreements or set by fiscal rules. This paper builds on this idea while theoretically and empirically showing that public debt and environmental debt are complements in the long run. Our econometric results, however, evidenced some differences in short run environmental debt dynamics. In the USA for instance, there is a positive link between environmental and public debts in the short run. Given the fact that the USA is a still major CO_2 emitter, the sharp increase in the US public debt results in higher CO_2 emissions in the short run. In the long run, however, our results support the idea that stricter climate policies can generate environmental benefits but can also correlate to better macroeconomic performance, as measured by debt stabilization.

Our results support the idea that, in the long run, there is no-trade-off between debt stabilization that is a major concern, especially since the 2007-2008 crisis, and environmental performance. Our findings can, however, have some theoretical and econometric limitations. First, we have only taken public debt and public abatement expenditures. Private debt is not accounted for despite the fact that several emerging countries already seem to exhibit high levels of private indebtedness. Second, we assumed no composition effect of public expenditures. One could argue that the complementarity between environmental and public debt is conditional on the relative importance of investment and abatement expenditures. Third, we focused on global pollution as measured by cumulative past CO_2 emissions because of data limitations. Other global environmental degradation measures should also be taken into account, as well as local pollution with huge health consequences.

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Appendix A. Proof of Proposition 2

By linearization, in the neighborhood of steady state, the system (15) behaves according to $(\dot{c}_t, \dot{b}_t, \dot{d}_t) = \mathbf{J}(c_t - c^*, b_t - b^*, d_t - d^*)$, where $\mathbf{J}$ is the Jacobian matrix. As the reduced-form includes one jump variable (the consumption ratio c_0) and two predetermined variables (the public-debt ratio b_0 and the environmental-debt ratio d_0), for the BGP to be well determined, $\mathbf{J}$ must contain two negative and one positive eigenvalues. Using (15), we compute

$$\mathbf{J} = \begin{pmatrix} CC & CB & 0 \\ BC & BB & 0 \\ DC & DB & DD \end{pmatrix}$$

where

$$\begin{aligned}
CC &= c^* A/(1+\theta A), \\
CB &= -\alpha A^2 c^*/(1+\theta A), \\
BB &= -\theta/(b^*)^2 - \alpha A^2(1+\theta A), \\
BC &= A/(1+\theta A), \\
DC &= A(\delta\theta + 1)/(1+\theta A), \\
DB &= \alpha A\ (\delta - A)/(1+\theta A), \\
DD &= -\Phi'(d^*)
\end{aligned}$$

Thus, we have one eigenvalue $\lambda_1 = -\Phi'(d^*) < 0$. In addition, $\det(\mathbf{J}) = DD(BB * CC - CB * BC) = \Phi'(d^*)\theta A c^*/[(1+\theta A)(b^*)^2) > 0$. Thus, as $\det(\mathbf{J}) = \lambda_1\lambda_2\lambda_3 > 0$ and $\lambda_1 < 0$, it follows that $\lambda_2\lambda_3$ is negative, namely $\text{sign}(\lambda_2) = -\text{sign}(\lambda_3)$. Consequently, there are two negative eigenvalues and one positive eigenvalue, hence the (local) determinacy of the model.

Appendix B. Empirical analysis

Table B.1: Descriptive statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
Cumulated CO_2 (tonnes per capita)	484	91.5038	80.1105	1.5847	417.2603
Gross public debt (% GDP)	484	56.2993	35.1934	1.0267	229.61
Trade (% GDP)	484	54.067	24.3395	13.7531	140.437

Table B.2: Summary statistics of cumulated CO_2 in tonnes per capita (by category)

	Mean	Std. Dev
Full model	91.5038	80.1105
Upper-middle Income	32.9866	24.9241
High Income	113.4477	82.6358
Low Debt	74.8888	69.5637
High Debt	120.5799	88.8118
Low Openness	76.4705	79.2713
High Openness	109.5436	77.5130
Low Env. Debt	32.45173	23.5689
High Env. Debt	125.2478	81.4784

Table B.3: Summary statistics of public debt in % of GDP (by category)

	Mean	Std. Dev
Full model	56.2993	35.1934
Upper-middle Income	31.4658	19.4508
High Income	65.6118	35.2743
Low Debt	40.3523	19.8290
High Debt	84.2065	38.7023
Low Openness	66.1645	41.5005
High Openness	44.4611	20.1304
Low Env. Debt	37.9689	25.1961
High Env. Debt	66.7738	35.8338

Table B.4: Summary statistics of trade in % of GDP (by category)

	Mean	Std. Dev
Full model	54.067	24.3395
Upper-middle Income	52.923	30.4532
High Income	54.496	21.6426
Low Debt	58.2233	24.6436
High Debt	46.7934	22.0468
Low Openness	38.1846	12.9786
High Openness	73.1258	20.8637
Low Env. Debt	48.9801	28.0558
High Env. Debt	56.9738	21.4485

Table B.5: List of countries

- Argentina
- Austria
- Brazil
- China
- Colombia
- Finland
- France
- Germany
- Greece
- Italy
- Japan
- Korea, Rep.
- Norway
- Portugal
- Romania
- Spain
- Switzerland
- Thailand
- Turkey
- United Kingdom
- United States
- Uruguay

Table B.6: List of countries by characteristics

Income group		**Public Debt**		**Openness**		**Env. Debt**	
Upper-middle	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Brazil	Argentina	Brazil	Argentina	Argentina	Austria	Argentina	Austria
China	Austria	China	Austria	Brazil	Finland	Brazil	Finland
Colombia	Finland	Colombia	Germany	China	Germany	China	France
Romania	France	Finland	Greece	Colombia	Korea, Rep.	Colombia	Germany
Thailand	Germany	France	Italy	France	Norway	Romania	Greece
Turkey	Greece	Korea, Rep.	Japan	Greece	Portugal	Thailand	Italy
	Italy	Norway	Portugal	Italy	Romania	Turkey	Japan
	Japan	Romania	United States	Japan	Switzerland	Uruguay	Korea, Rep.
	Korea, Rep.	Spain		Spain	Thailand		Norway
	Norway	Switzerland		Turkey	United Kingdom		Portugal
	Portugal	Thailand		United States			Spain
	Spain	Turkey		Uruguay			Switzerland
	Switzerland	United Kingdom					United Kingdom
	United Kingdom	Uruguay					United States
	United States						
	Uruguay						