Environmental tax reform with public debt and emission abatement

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Abstract

This article analyzes the consequences on capital accumulation and environmental quality of environmental tax policies financed by public debt. A public sector of pollution abatement is financed by a tax and/or public debt. Using a simple overlapping-generations model, the paper finds that the tax reform stimulates steady-state investment. Then, both the environmental quality and the agregate consumption are increased if and only if (i) public emission abatement is large enough and (ii) there is under-accumulation of the per capita capital stock.

JEL Classification: Q5, H23, H63.

Keywords: Environmental tax reform, Debt, Public emission abatement, Double dividend.

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1 Introduction

The growing environmental concerns have forced several countries to adapt their tax structure by introducing new taxes on pollutants. France, following some Scandinavian countries like Sweden, has planned to adopt a carbon tax on energy use in the next few years. The revenues of these green taxes are used to limit the economic distortions of the reform by reducing other taxes, or alternatively, are allocated to pollution abatement programs. In France, the main environmental protection agency (ADEME) is entirely financed by revenues of taxes on pollutants, called General Tax on Polluting Activities. One of the advantages of the environmental tax is that it provides a public revenue which can be recycled. This is the reason why it is often preferred to subsidies or emission quotas. Several authors like Parry (1995) or Poterba (1993) argued that this revenue recycling could reduce or even annihilate the gross cost of the implementation of an environmental tax.

However, whatever the government's decision about distribution of the environmental tax revenues, public engagements in the environmental protection are often constrained by long-term fiscal objectives which impose to control public deficits and public debt evolution. Therefore, a pre-existing high level of public debt could be an obstacle for the launching of new environmental protection programs.

The aim of the paper is to analyze the interactions between environmental policy and public debt. More specifically, we study the long-term macroeconomic impacts of environmental tax policies under a debt stabilization constraint, when public actions to protect the environment are at least partially financed by public funds. Could public debt be an obstacle for the financing of environmental policies? Reversely, could the environmental tax reduce efficiently the public debt burden, and help the environment by the way?

We consider an overlapping generations model *à la* Diamond (1965) with an environmental intergenerational externality. Pollution emission occurs through polluting production processes which deteriorate the environmental quality, harming the welfare of all future generations. We assume that public environmental maintenance expenditure could be financed by issuing public debt, or by the environmental tax. Moreover, a debt stabilizing constraint imposes a constant level of debt per capita.

Wether an environmental tax reform can be designed without negatively affecting the economic welfare has given rise to a huge literature on the double dividend. Terkla (1984), Parry (1995), or Poterba (1993) first had the intuition that the recycling of the revenue of an environmental tax could reduce or even eliminate the gross cost of its implementation. As governments use the revenues from pollution taxes to decrease other distortionary taxes, environmental taxes may lead to a *double dividend*, according to Goulder's definition, by improving the environmental quality and achieving a less distortionary tax system (Goulder (1995)). Baumol and Oates (1988), Pearce (1991) and Oates (1991) suggested that these efficiency gains could be a powerful argument in favor of environmental taxation. After some prior refutations of the double dividend hypothesis (Bovenberg and de Mooij (1994) and their followers), Goulder (1994) and Ligthart (1998) showed that the existence of the double dividend essentially depends on the possibility of transferring the global tax burden from the wage earners to some fixed production factors or to other consumers, thus emphasizing the role of heterogeneity.

Beside these potential efficiency properties, environmental decisions have an impact on the welfare of both current and future generations, since environmental quality is a public good shared by different generations. These intergenerational issues on environmental externalities or on taxation have been quite widely studied in the economic literature. In an overlapping generations framework, John and Pecchenino (1994) and John *et alii* (1995) examine the effect of an environmental tax whose revenue is financing a public pollution abatement activity. Fisher and van Marrewijk (1998), using an endogenous growth model with pollution, derive the conditions for a pollution tax not to slow economic growth. Bovenberg and Heijdra (1998) examine the effects of a green tax on polluting capital when the tax revenue is redistributed by lump-sum intergenerational transfers and find that this tax benefits the younger generation but harms the older ones. Without studying the double dividend issue, all these papers conclude that environmental taxation implies such a welfare loss for older generations that its implementation can not be wished: one of the generation which would decide it would also bear the heaviest burden. The potential contradiction between efficiency and distributional concern has been already emphasized by some works in other frameworks. While the double dividend hypothesis is rejected when the economy is made of one productive sector, using only one productive factor (labor), and one representative consumer (Bosello *et alii* (2001)), when instead there are several productive factors and/or several consumer groups, the double dividend can be obtained but at the expense of distributive equity (Bovenberg and van der Ploeg (1996), Proost and van Regemorter (1995). Following this line, Chiroleu-Assouline and Fodha (2005), (2006) and (2014) studied the existence conditions of a long term double dividend, taking into account the distinction between wage earners and retired consumers, by means of OLG models.

Nevertheless, in all these studies, government cannot fund pollution abatement programs by issuing public debt. In consequence, they only consider tax financing schemes. Debt financing has already been introduced in dynamic models with environmental concerns (Bovenberg and Heijdra, 1998; Heijdra et alii, 2006), but these contributions focus on a different issue than ours. Instead of using debt to finance a share of pollution abatement, debt policy makes possible to redistribute welfare gains from future to existing generations. In our model, the role of the public debt is twofold: as usual, it redistributes welfare among young and old generations, but first of all, it finances the public pollution abatement sector.[1] Hence, the redistribution properties of the public debt

[1] This is also the case in a companion paper, Fodha and Seegmuller (2013). However, in this

are limited by the environmental actions of the government. Fodha and Seegmuller (2010) and (2013) have already analyzed the economic consequences of some environmental tax reforms under a public debt stabilization constraint. In Fodha and Seegmuller (2010) A public sector of pollution abatement is financed by a tax on pollutant emissions and/or by public debt. In the same time, households can also invest in private pollution abatement activities. We show that the economy may be characterized by an environmental-poverty trap if debt is too large or public abatement is not sufficiently efficient with respect to the private one. However, there exists a level of public abatement and debt for a stable steady state to be optimal. Using a close framework and taking into account endogenous life expectancy, Fodha and Seegmuller (2013) show that if the initial capital stock is high enough, the economy monotonically converges to a long-run steady state. On the contrary, when the initial capital stock is low, the economy is relegated to an environmental poverty trap. The article also explores the implications of public policies on the trap and on the long-run stable steady state. In particular, the authors find that government should decrease debt and increase pollution abatement to promote capital accumulation and environmental quality at the stable long-run steady state. Finally, a welfare analysis shows that there exists a level of public debt that allows a long run steady state to be optimal.

The present paper integrates both the efficiency and intergenerational distributional aspects of environmental taxes: like Bovenberg and Heijdra [1998], we examine whether a revenue-neutral increase in the pollution tax compensated by a change of the labor tax can yield a double dividend and whether a higher pollution tax can be Pareto welfare improving by benefiting all generations.

We show that the initial conditions on the capital stock, together with the level of the public abatement, are the key factors that explain the consequences of the tax reform. Namely, if the initial capital stock is low and the public emission abatement large enough, an increase of the environmental tax, compensated by a decrease of the individual income tax, will increase both the environmental quality and the aggregate households' consumption. We also show that these benefits of the reform are no longer available for the first generation that has to implement the policy. Moreover, we find conditions under which an increase of the environmental taxation budget-balanced by a variation of the debt-output ratio may also increase the environmental quality and the aggregate consumption. Hence, the fiscal policy allows to improve aggregate consumption and environmental quality by reducing the debt-output ratio.

The rest of this paper is organized as follows. Section 2 presents an OLG model in which environmental externalities are provided as a by-product of production, and the government issues debts and imposes taxes on personal income and production for financing public emission abatement. Section 3 shows the intertemporal equilibrium of this model and its stability. Section 4 studies

contribution, there is also private abatement and the results mainly depend on the efficiencies of private versus public abatement.

a possibility of the double dividend when the increase of the environmental tax is balanced through a decrease of the income tax. Section 5 considers the intergenerational distributive issues. Section 6 present the consequences of an environmental tax reform balanced by the debt-output ratio. The final section provides the conclusions.

2 The model

We consider an overlapping generation model with discrete time ($t = 0, 1, ..., +\infty$), capital accumulation, and environmental quality which degrades with production, but may be improved by public abatements. These government expenditures are financed by environmental taxation on production, labor income taxes, or public debt.

2.1 Household

At each period, a new generation is born. There is no population growth and population size of a generation is normalized to $N > 0$. Individuals live for two periods. They have preferences over their consumption bundle when young (c_t) and old (d_{t+1}), and environmental quality when young (E_t) and old (E_{t+1}). E_t is an externality for the household. The life-cycle utility is given by:

$$\ln c_t + \gamma \frac{E_t^{1-\sigma}}{1-\sigma} + \beta \left(\ln d_{t+1} + \gamma \frac{E_{t+1}^{1-\sigma}}{1-\sigma} \right)$$

where $\beta \in (0, 1)$ is the discount factor, $\gamma > 0$ the relative weight of the environmental quality and $1 - \sigma$ measures the elasticity of welfare to the environmental quality. The young born in period t inelastically supplies one unit of labor and receives real wage (w_t). A personal income tax (τ_t^w) is imposed on the real wage and the after-tax income is shared between present consumption and savings (s_t). When old, the household is retired and entirely consumes the remunerated savings ($R_{t+1}s_t$).[2] Budget constraints of an individual born in period t are given by:

$$c_t + s_t = (1 - \tau_t^w) w_t, \quad d_{t+1} = R_{t+1} s_t = (1 + r_{t+1}) \, s_t$$

where r_t is the real interest rate. Then, the savings function is derived as:

$$s_t = \frac{\beta}{1+\beta}(1 - \tau_t^w) w_t$$

Because labor is inelastically supplied, the income tax does not distort labor market.

[2] We assume complete depreciation of capital. Since the period length is quite long in overlapping generations model with two-period lived households, this assumption is not too restrictive.

2.2 Firms

A representative firm produces the unique final good using a Cobb-Douglas technology:

$$Y_t = K_t^{\alpha} L_t^{1-\alpha},$$

where Y_t, L_t, and K_t are output, labor, and capital stock, respectively. The intensive production function is given by $y_t = k_t^{\alpha}$, where k_t and y_t are per capita capital stock and output. Production process emits pollutions as by-products and, therefore, the government imposes an environmental tax (τ^e) on its product sales. Profits write $(1 - \tau^e)Y_t - w_t L_t - r_t K_t$. The first order conditions for profit maximization are derived as:

$$\begin{aligned} w_t &= (1 - \tau^e)(1 - \alpha)k_t^{\alpha}, \\ r_t &= (1 - \tau^e)\alpha k_t^{\alpha-1}. \end{aligned}$$

2.3 Government

The government imposes taxes on income and sales. Moreover, debt (B_t) is issued in order to finance a share of government spending for emission abatement (G_t). The government budget constraint is written as:

$$B_t = R_t B_{t-1} - (\tau_t^w w_t N + \tau^e Y_t) + G_t.$$

with $B_{-1} \geqslant 0$ given.

To avoid explosive path, we assume that the government spending-output G_t/Y_t and debt-output B_t/Y_t ratios are constant over time, i.e. equal to $g \geq 0$ and $\delta \geq 0$, respectively. Therefore, the government budget constraint is given as:

$$\delta Y_t = R_t \delta Y_{t-1} - (\tau_t^w w_t N + \tau^e Y_t) + g Y_t.$$

2.4 Environmental quality

Pollution emission occurs through polluting production processes while the government spends on public emission abatement. Because environmental quality evolves in opposite direction than pollution, its law of motion is given as:

$$E_{t+1} = (1 - \eta)E_t + \theta G_t - \epsilon Y_t, \text{ with } E_0 \text{ given},$$

where $\epsilon > 0$, $\theta > 0$, and $\eta \in (0, 1)$ are efficiency parameters measuring the pollution emission from production, the public emission abatement, and the capacity to converge to the natural environmental quality in the absence of any pollution flow.

3 Equilibrium, steady states and dynamics

The labor market equilibrium is given as $N = L_t$, for all t. Therefore, environmental quality per young household e_t satisfies:

$$e_{t+1} = (1-\eta)e_t + (\theta g - \epsilon)k_t^\alpha$$

and the government budget constraint rewrites:

$$\delta y_t = R_t \delta y_{t-1} - (\tau_t^w w_t + \tau^e y_t) + g y_t.$$

Since g, δ and τ^e are kept constant over time, the government must adjust the income tax rate to balance the government budget:

$$\tau_t^w w_t = R_t \delta y_{t-1} - (\tau^e + \delta - g)y_t. \tag{1}$$

The market-clearing condition for capital market is described as:

$$k_{t+1} = s_t - \delta y_t \tag{2}$$

Defining $z_{t+1} = k_{t+1}/k_t^\alpha$ as an investment factor, equation (2) can be rewritten as:

$$z_{t+1} = \phi(z_t) = \frac{\beta(\mu + \alpha\tau^e) - \delta}{1+\beta} - \frac{\alpha\beta\delta}{1+\beta}\frac{1-\tau^e}{z_t} \tag{3}$$

where $\mu \equiv 1 - \alpha - g \in (0,1)$, i.e. $0 \leqslant g < 1 - \alpha$. By direct inspection of this equation, we immediately see that the following assumption is required to have positive values of z_t:

Assumption 1 $\beta(\mu + \alpha\tau^e) > \delta$.

We are now able to define an intertemporal equilibrium:

Definition 1 *Under Assumption 1, an intertemporal equilibrium is characterized as a sequence of investment factors $(z_t)_{t=1}^\infty$, such that (3) is satisfied, given $z_0 \geqslant 0$.*

Dynamics are driven by a one-dimensional dynamic system, where z_t is a predetermined variable. Note that z_0 given implies two initial conditions k_0 and k_{-1}. In fact, the second initial condition comes from the initial condition on debt $B_{-1} \geqslant 0$ and the constant debt-output ratio $B_t = \delta Y_t$. Given the sequence (z_t), we are able to determine (k_t) defined by $k_{t+1} = z_{t+1}k_t^\alpha$. Finally, given (k_t), one deduces the dynamics of e_t.

The steady-state investment factors are solutions to:

$$P(z) = z^2 - \frac{\beta(\mu + \alpha\tau^e) - \delta}{1+\beta}z + \frac{\alpha\beta\delta(1-\tau^e)}{1+\beta} = 0 \tag{4}$$

Note that the corresponding stationary level of capital (k) and environmental quality (e) per capita are given by:

$$k = z^{\frac{1}{1-\alpha}} \tag{5}$$

$$e = \frac{\theta g - \epsilon}{\eta} z^{\frac{\alpha}{1-\alpha}} \tag{6}$$

Steady states and dynamics are determined as follows:

Proposition 1 *Let Assumption 1 be satisfied and $\bar{\delta}$ such that $\beta(\mu + \alpha\tau^e) = \bar{\delta} + 2\sqrt{\alpha\beta\bar{\delta}(1+\beta)(1-\tau^e)}$. When $\delta \in [0, \bar{\delta})$, there are two steady states, an unstable one $\underline{z}$ and a stable one $\overline{z}$, given as:*

$$\underline{z} = \frac{\beta(\mu + \alpha\tau^e) - \delta - \sqrt{\{\beta(\mu + \alpha\tau^e) - \delta\}^2 - 4(1+\beta)(1-\tau^e)\alpha\beta\delta}}{2(1+\beta)} \tag{7}$$

$$\begin{aligned} \overline{z} &= \frac{\beta(\mu + \alpha\tau^e) - \delta + \sqrt{\{\beta(\mu + \alpha\tau^e) - \delta\}^2 - 4(1+\beta)(1-\tau^e)\alpha\beta\delta}}{2(1+\beta)} \\ &\equiv \zeta(\tau^e, g, \delta) \end{aligned} \tag{8}$$

When $\delta = \bar{\delta}$, a saddle-node bifurcation occurs and no steady state exists when $\delta > \bar{\delta}$.

Proof. The existence of two steady states requires that the discriminant of $P(z)$ must be positive, that is, $\{\beta(\mu + \alpha\tau^e) - \delta\}^2 > 4\alpha\beta\delta(1+\beta)(1-\tau^e)$. Under Assumption 1, this condition can be reduced to $\{\beta(\mu + \alpha\tau^e) - \delta\} > 2\sqrt{\alpha\beta\delta(1+\beta)(1-\tau^e)}$. This defines an upper bound $\bar{\delta}$ lower than $\beta(\mu + \alpha\tau^e)$ (Assumption 1). When $\delta < \bar{\delta}$ there exist two steady states, given by (7) and (8). When $\delta = \bar{\delta}$, the two steady states merge, and disappear for $\delta > \bar{\delta}$.
We deduce the stability properties from the features of (3). Since

$$\lim_{z_t \to 0} \phi(z_t) = -\infty, \quad \lim_{z_t \to +\infty} \phi(z_t) = \frac{\beta(\mu + \alpha\tau^e) - \delta}{1+\beta} > 0, \ \phi(z_t)' > 0, \ \phi(z_t)'' < 0$$

the lower steady state is unstable, whereas the larger one is stable (see Figure 1). ■

The configuration where there are two steady states ($\delta < \bar{\delta}$) is represented in Figure 1.[3] The lower steady state $\underline{z}$ is unstable, while the higher one $\overline{z}$ is stable. Therefore, for z_t lower than $\underline{z}$, the economy is relegated to a poverty trap, where z_t decreases to 0. Otherwise, the economy converges to the steady state $\overline{z}$. Note that since $k_{t+1} = z_{t+1}k_t^{\alpha}$, the convergence of the investment factor to a stationary value corresponds to the convergence of the capital stock k_t to its steady state level.

By direct inspection of (4), we see that without debt ($\delta = 0$), the trap disappears. The dynamics become $z_{t+1} = \frac{\beta(\mu+\alpha\tau^e)}{1+\beta}$. The dynamics may be explicitly

[3] Recall that, as established in the proof of the proposition, δ lower than $\bar{\delta}$ satisfies Assumption 1.

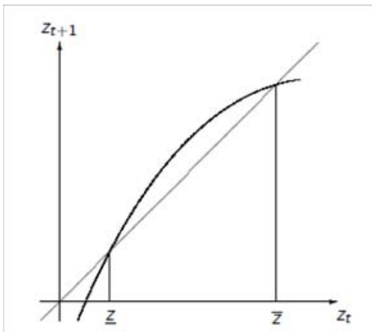

Figure 1: Dynamics: the two steady states case.

given by a sequence of per capita capital (k_t) satisfying $k_{t+1} = \frac{\beta(\mu+\alpha\tau^e)}{1+\beta}k_t^\alpha$. Therefore, the higher steady state $k = \left(\frac{\beta(\mu+\alpha\tau^e)}{1+\beta}\right)^{1/(1-\alpha)}$ is globally stable, whereas the lower steady state $k = 0$ is unstable. There is no more any poverty trap. Indeed, the trap comes from a crowding-out effect due to the existence of public debt.

Using (3), we also deduce that a larger public spending-output ratio reinforces the level of the trap. Indeed, we can show that $\partial\overline{z}/\partial g < 0$, $\partial\underline{z}/\partial g > 0$ and $\partial\phi(z_t)/\partial g < 0$ for all $z_t > 0$. A larger income taxation is needed to balance the budget, implying a lower saving. For $g > \epsilon/\theta$, the associated level of environmental quality always raises at the low steady state, whereas it raises at the high steady state if the efficiency of public spending θ is large enough.

In contrast, because we can show that $\partial\overline{z}/\partial\tau^e > 0$, $\partial\underline{z}/\partial\tau^e < 0$ and $\partial\phi(z_t)/\partial\tau^e > 0$ for all $z_t > 0$, an increase of the environmental tax reduces the trap. Indeed, the induced decrease of income taxation promotes savings. Moreover, when $g > \epsilon/\theta$, environmental quality moves in the same direction than z at steady states. It increases at the high steady state, but decreases at the low steady state.

In next sections, we will focus on the effect of fiscal policy on a steady state. Because z_t is a predetermined variable, we focus on the stable steady state $\overline{z}$.[4]

4 Environmental tax reform balanced by labor income taxation

In this section, we are interested in the effect of an increase of environmental taxation, given that public spending-output and debt-output ratios are constant. Therefore, income taxation will vary to balance the budget, modifying the level of the investment factor. We will focus on a possible improvement of both

[4] To clarify notations, $\overline{x}$ will denote in the following the value of the variable x_t evaluated at the steady state $\overline{z}$.

environmental quality and macroeconomic variables, i.e. capital accumulation, aggregate consumption.

As a preliminary step, we examine the effects of such an increase of environmental taxation on the investment factor and the labor income tax rate.

Proposition 2 *Let Assumption 1 be satisfied and assume $\delta \in [0, \bar{\delta})$. Following a raise of the environmental tax rate τ^e, the investment factor $\bar{z}$ increases, while the labor income tax rate τ^w evaluated at this steady state decreases.*

Proof. The effect on the steady state investment factor is derived by differentiating (8):

$$\left.\frac{d\bar{z}}{d\tau^e}\right|_{d\delta=dg=0} = \frac{\partial\zeta(\cdot)}{\partial\tau^e} = \frac{\alpha\beta(\bar{z}+\delta)}{\sqrt{\{\beta(\mu+\alpha\tau^e)-\delta\}^2 - 4\alpha\beta\delta(1-\tau^e)(1+\beta)}} > 0 \quad (9)$$

The steady state income tax rate is derived as a function of other policy instruments from the government budget constraint (1):

$$\tau^w = \frac{\alpha}{1-\alpha}\frac{\delta}{\bar{z}} + \frac{g-\tau^e-\delta}{(1-\tau^e)(1-\alpha)} \quad (10)$$

Using $\bar{z} = \zeta(\tau^e, g, \delta)$, this can be defined as $\tau^w \equiv \tau(\tau^e, g, \delta)$. By differentiating (10) with respect to τ^e, we obtain:

$$\left.\frac{d\tau^w}{d\tau^e}\right|_{dg=d\delta=0} = -\frac{1}{(1-\alpha)(1-\tau^e)}\left(\frac{1-g+\delta}{1-\tau^e} + \frac{\alpha(1-\tau^e)\delta}{\bar{z}^2}\frac{\partial\zeta(\cdot)}{\partial\tau^e}\right) < 0 \quad (11)$$

■

The environmental tax, in principle, imposes additional costs on polluting behavior, which reduces the steady state investment factor. However, recycling revenues provided from the increase of the environmental tax rate leads to lower income tax rates. Because the latter effect is greater than the former, this environmental tax reform will increase the steady state investment factor. Alternatively, income taxation is more harmful to investment or capital accumulation than environmental taxation. Note that the decrease of τ^w comes from two direct effects and a general equilibrium effect. The first one is explained by the increase of government revenue coming from a larger environmental tax rate. The second direct effect goes through the fact that a higher environmental tax rate directly decreases the interest rate. Finally, the general equilibrium effect goes in the same direction: a higher level of capital induces a decrease in the interest rate. This leads to a smaller amount of debt reimbursement in the future and, thereby, lowering the income tax rate.

We focus now more specifically on the possible improvement of both environmental quality and macroeconomic variables of the model. Beside an increase in the amount of environmental quality per capita (i.e. $d\bar{e}/d\tau^e > 0$), we are interested in an increase in total amount of consumption per capita $\overline{C} \equiv \bar{c} + \bar{d}$

(i.e. $d\overline{C}/d\tau^e > 0$). Using the resource constraint $\overline{y} = \overline{c} + \overline{d} + \overline{k} + g\overline{y}$, $\overline{C}$ is given by:

$$\overline{C} = (1-g)\overline{k}^{\alpha} - \overline{k} \tag{12}$$

Given the government policy, $k = \overline{k}_g$ maximizes $\overline{C}$, where:

$$\overline{k}_g = [\alpha(1-g)]^{\frac{1}{1-\alpha}} \tag{13}$$

From (5), the stationary investment factor corresponding to $\overline{k}_g$ is $\overline{z}_g = \alpha(1-g)$. This allows us to show:

Proposition 3 *Let Assumption 1 be satisfied and assume $\delta \in [0, \overline{\delta})$. The environmental tax reform produces positive environmental and macroeconomic effects if and only if (i) the public emission abatement is large enough ($g > \epsilon/\theta$), and (ii) there exists under-accumulation at the stable steady state ($\overline{k} < \overline{k}_g$).*

Proof. Differentiating (6) with $d\delta = dg = 0$, we get:

$$\left.\frac{d\overline{e}}{d\tau^e}\right|_{d\delta=dg=0} = \frac{\alpha(\theta g - \epsilon)}{\eta \overline{z}} \left.\frac{d\overline{k}}{d\tau^e}\right|_{d\delta=dg=0}$$

From (5) and (9), the positive environmental effect is obtained if and only if the public emission abatement is large enough, that is, $g > \epsilon/\theta$.
Differentiating now (12) with $d\delta = dg = 0$, and using (5) and (13), one obtains:

$$\left.\frac{d\overline{C}}{d\tau^e}\right|_{d\delta=dg=0} = \frac{(\overline{z})^{\frac{\alpha}{1-\alpha}}}{1-\alpha}\left(\frac{\overline{z}_g}{\overline{z}} - 1\right)\left.\frac{d\overline{z}}{d\tau^e}\right|_{d\delta=dg=0}$$

From (9), the macroeconomic effect is obtained if and only if $\overline{z} < \overline{z}_g$. ■

The environmental tax reform cuts the personal income tax, allowing a larger level of capital per capita. This raises aggregate consumption when there is under-accumulation, explaining the macroeconomic effect. Note that the requirement of under-accumulation of capital seems to be quite realistic, since this is equivalently ensured by a not too low real interest rate, which is experienced by most developed countries in the last decades. Recall that under-accumulation also means dynamic efficiency, which is a feature supported by the findings of Abel et alii. (1989). Public emission abatements play an important role for the environmental effect. The public spending-output ratio g or efficiency of public emission abatements θ has to be large enough to ensure negative pollution flows. In this case, environmental quality is positive at the steady state and positively varies with the level of capital.

At this stage, public debt has no yet an explicit role on our results. However, since the macroeconomic effect occurs if and only if there is under-accumulation of capital, we now discuss its implication on the level of debt-ouput ratio δ.

Because $\partial\zeta(\tau^e, g, \delta)/\partial\delta < 0$ for all $\delta < \overline{\delta}$, there exists at most a unique debt-output ratio $\delta = \delta_g$ that corresponds to the maximized level of total consumption per capita:

$$\zeta(\tau^e, g, \delta_g) = \overline{z}_g = \alpha(1-g). \tag{14}$$

We deduce that there is under-accumulation if and only if $\delta > \delta_g$. Then, considering the three cases, (i) $\delta_g \leq 0$, (ii) $\delta_g \geq \bar{\delta}$, and (iii) $\delta_g \in (0, \bar{\delta})$, we clarify in which configuration there are both positive macroeconomic and environmental effects:

Proposition 4 *Let Assumption 1 be satisfied and assume $\delta \in [0, \bar{\delta})$. There is under-accumulation, and both positive macroeconomic and environmental effects may apply, if one of the following conditions is satisfied:*

(i) $\tau^e \leqslant 1 - \frac{1-g}{\alpha\beta}[\beta - \alpha(1+\beta)]$;

(ii) $\frac{\beta}{1+\beta} < 4\alpha(1-\alpha)$ *and* $\delta \in (\delta_g, \overline{\delta})$.

Proof. When $\delta_g \leq 0$, there is under-accumulation for all $\delta \in [0, \bar{\delta})$. However, because $\partial\zeta(\tau^e, g, \delta)/\partial\delta < 0$, $\delta_g \leq 0$ is equivalent to $\zeta(\tau^e, g, \delta_g) \geqslant \zeta(\tau^e, g, 0)$. Using (8) and (14), we deduce case (i) of the proposition.
To prove case (ii), we begin by determining $\overline{\delta}$. From Proposition 1, we recall that $\overline{\delta}$ is the lowest root of:

$$
\begin{aligned}
& [\beta(\mu + \alpha\tau^e) - \delta]^2 - 4\alpha\beta\delta(1+\beta)(1-\tau^e) = 0 \\
\Leftrightarrow \quad & \delta^2 - 2\beta[\mu + \alpha\tau^e + 2\alpha(1+\beta)(1-\tau^e)]\delta + [\beta(\mu + \alpha\tau^e)]^2 = 0
\end{aligned}
$$

We deduce that:

$$
\begin{aligned}
\overline{\delta} \quad = \quad & \beta[\mu + \alpha\tau^e + 2\alpha(1+\beta)(1-\tau^e)] \\
& -2\beta\sqrt{\alpha(1+\beta)(1-\tau^e)[\mu + \alpha\tau^e + \alpha(1+\beta)(1-\tau^e)]}
\end{aligned} \tag{15}
$$

Note that $\delta_g < \overline{\delta}$ is equivalent to $\zeta(\tau^e, g, \delta_g) > \zeta(\tau^e, g, \overline{\delta})$. Using (8) and (14), this inequality rewrites $\overline{\delta} > \beta(\mu + \alpha\tau^e) - 2(1+\beta)\alpha(1-g)$. Substituting (15), one obtains $P(1-\tau^e) > 0$, with:

$$
\begin{aligned}
P(1-\tau^e) \quad \equiv \quad & \alpha\beta^2(1-\tau^e)^2 + \beta(1-g)[2\alpha(1+\beta) - \beta](1-\tau^e) \\
& +\alpha(1+\beta)(1-g)^2
\end{aligned}
$$

The discriminant of this polynomial of degree 2 is given by $\beta^3(1-g)^2[\beta - 4\alpha(1-\alpha)(1+\beta)]$. When $\frac{\beta}{1+\beta} < 4\alpha(1-\alpha)$, it is negative, which shows that $P(1-\tau^e) > 0$ for all τ^e. This ensures that $\delta_g < \overline{\delta}$. Therefore, for $\delta \in (\delta_g, \overline{\delta})$, the steady state is characterized by under-accumulation.
Finally, note that of course, the configuration where $\delta_g \geq \bar{\delta}$ is not relevant to get under-accumulation. ■

The second configuration of this proposition is of special interest. Our result requires a sufficiently large level of debt-output ratio. Therefore, debt plays a role. It is also useful to notice that under a standard parametrization, the saving rate $\beta/(1+\beta)$ is smaller than 1/2, while the capital share in income α

belongs to $(1/4, 1/2)$. In this case, the inequality $\frac{\beta}{1+\beta} < 4\alpha(1-\alpha)$ is fulfilled and configuration (ii) of Proposition 4 may apply.

Configuration *(i)* of Proposition 4 is also of interest. Under-accumulation requires a sufficiently low environmental tax rate. Following Proposition 2, this implies a sufficiently large labor income tax rate. As we have seen, this last one has a dominant effect on savings, and therefore capital accumulation. This explains that a low τ^e may ensure under-accumulation.

5 Distributive issues

We now focus on the distributive issues of the fiscal reform balanced by labor income taxation. Two kinds will be investigated. First, we analyze if following the implementation of the fiscal reform at a given period, the total amount of consumption increase during all the dynamic path converging to the stable steady state. Second, we study if the fiscal reform always implies an increase of consumption of both young and old at the steady state.

We start by extending our analysis considering an intertemporal equilibrium which is no more stationary, but converges to the stable steady state. The question we address is the following. Assuming that the steady state $\overline{z}$satisfies the positive effects of the fiscal reform and we apply the fiscal reform at some given date, should the fiscal reform be detrimental for some generations and for the consumption at some periods? Can we determine which generations will benefit from the fiscal reform? These issues are solved in the following proposition:

Proposition 5 *Let Assumption 1 be satisfied and assume that $\delta \in [0, \bar{\delta})$. Furthermore, consider that Propositions 3 and 4 are satisfied, and $z_0 > \underline{z}$. Following an increase of τ^e at date t_0, the positive effects of the fiscal reform fails at $t = t_0$, but there exists $t_1 > t_0$ such that for all $t > t_1$, they apply.*

Proof. Assume that τ_0 increases permanently at $t = t_0$. By direct inspection of equation (3) and Figure 1, we deduce that z_t raises for all $t \geqslant t_0 + 1$. Since $k_{t+1} = z_{t+1}k_t^\alpha$, the same happens for k_t for all $t \geqslant t_0 + 1$.
At $t = t_0$, we have $c_t + d_t = (1-g)k_t^\alpha - k_{t+1} = k_t^\alpha(1 - g - z_{t+1})$. Since k_t is predetermined and z_{t+1} increases, aggregate consumption fails, which means that the positive effects of the fiscal reform fail.
Considering now that $t \geqslant t_0 + 1$, $d(c_t + d_t) = (1-g)\alpha k_t^{\alpha-1}dk_t - dk_{t+1}$. For t sufficiently large, namely $t > \widetilde{t}$, the capital stock is characterized by under-accumulation,[5] i.e. we have $(1-g)\alpha k_t^{\alpha-1} > 1$, which implies that $d(c_t + d_t) > dk_t(1 - \frac{dk_{t+1}}{dk_t})$. Since at a stable equilibrium with $z_t = \overline{z}$ we have $k_{t+1} = \overline{z}k_t^\alpha$, there exists $t > \widehat{t}$ such that $dk_{t+1}/dk_t < 1$.
Therefore, when $t > t_1 = \max\{\widetilde{t}, \widehat{t}\}$, $d(c_t + d_t) > 0$ because $dk_t > 0$ for all $t \geqslant t_0 + 1$. Since $e_{t+1} = (1-\eta)e_t + (\theta g - \epsilon)k_t^\alpha$ also raises, the positive effects of the fiscal reform apply for all $t > t_1$. ■

[5] This is always the case if the sequence of (k_t) is increasing though time.

One may note that aggregate consumption decreases at some periods, because consumption when old does. In fact, at $t = t_0$, consumption when young raises because, given the level of capital, the increase of the environmental tax rate reduces the labor income tax rate, which enhances the after-tax income to consume. In contrast, consumption when old goes down, because a higher environmental tax rate reduces the interest rate, i.e. the remunerated saving. At the following periods, the increase of c_t is reinforced by the raise of capital, which pushes up the wage and pushes down labor income taxation. Indeed, the interest rate becomes even lower because of the larger capital accumulation. After some periods, this mechanism allows to get a positive effect on aggregate consumption.

This intergenerational issue on environmental externalities and taxation has already been widely studied (John and Pecchenino (1994), John et alii. (1995), Howarth (1996), Fisher and van Marrewijk (1998)). The main result of all these studies is that environmental taxation implies such a welfare loss for the older generations experiencing the fiscal reform that its implementation can not be wished because the generation which would decide it would also bear the heaviest burden. This result of the literature originates in the fact that balanced environmental fiscal reforms have generally not been considered. We show here that this negative result for the political feasibility can be generalized to the balanced-budget reform case.

We now focus on the distributive effect of the policy between consumptions when young and old at the stable steady state. Should the fiscal reform not only improve aggregate consumption but also both $\overline{c}$ and $\overline{d}$? This is an important issue because if this occurs, utility for consumption of young and old consumers increase. Moreover, since under Proposition 4, the environmental tax reform increases utility for environmental quality, this leads to a double dividend.

Proposition 6 *Let Assumption 1 be satisfied and assume that $\delta \in [0, \overline{\delta})$. Furthermore, consider that Propositions 3 and 4 are satisfied. Following an increase of τ^e, the consumption of young $\overline{c}$ is increasing at the stable steady state. For $1 - \alpha > g > 1 - \alpha - \frac{\alpha^2}{1-\alpha}$ and $\tau^e < \alpha - \frac{1-\alpha}{\alpha}\mu$, there exists $\widetilde{\delta} > 0$, such that for all $\delta < \widetilde{\delta}$, the consumption of old $\overline{d}$ is increasing in τ^e too.*

Proof. At the stable steady state, consumption when young $\overline{c}$ is given by:

$$\overline{c} = \frac{1}{1+\beta}\overline{k}^{\alpha}\left[\mu + \alpha\tau^e + \delta - \frac{\alpha\delta(1-\tau^e)}{\overline{z}}\right]$$

Because $\partial\overline{z}/\partial\tau^e > 0$ (see Proposition 2) and $\overline{k} = \overline{z}^{1/(1-\alpha)}$, we deduce that $\partial\overline{c}/\partial\tau^e > 0$.

Using the fact that saving is equal to $\overline{k} + \delta\overline{y}$, consumption when old $\overline{d}$ is equal to:

$$\overline{d} = (1-\tau^e)\alpha\left(\overline{z}^{\frac{\alpha}{1-\alpha}} + \delta\overline{z}^{\frac{2\alpha-1}{1-\alpha}}\right)$$

For $\delta = 0$, we have $\partial\overline{z}/\partial\tau^e = \alpha\overline{z}/(\mu + \alpha\tau^e)$. We deduce that:

$$\frac{\partial\overline{d}}{\partial\tau^e} = \frac{\alpha\overline{z}^{\frac{\alpha}{1-\alpha}}}{(1-\alpha)(\mu+\alpha\tau^e)}\left[\alpha^2 - (1-\alpha)\mu - \alpha\tau^e\right]$$

Therefore, for $\delta = 0$, $\delta\overline{d}/\partial\tau^e > 0$ if and only if $\mu < \frac{\alpha^2}{1-\alpha}$, or equivalently $1-\alpha > g > 1-\alpha-\frac{\alpha^2}{1-\alpha}$, and $\tau^e < \alpha - \frac{1-\alpha}{\alpha}\mu$.
In this case, by continuity, there exists $\widetilde{\delta} > 0$, such that for all $\delta < \widetilde{\delta}$,[6] we have $\delta\overline{d}/\partial\tau^e > 0$. ■

If this proposition applies, welfare is increasing. Indeed, following an increase of the environmental tax rate, environmental quality, consumptions when young and old become larger. We get a double-dividend. Note that this requires a sufficiently low debt-output ratio. Otherwise, the increase of the environmental tax rate that decreases the return of assets, directly and through the raise of capital, implies a too large decrease of the remunerated debt. In this case, remunerated saving, i.e. consumption when old, decreases.

Because the environmental tax reform positively affects the steady-state investment factor $\overline{z}$, the conditions for the double dividend differ from those in the literature. Ono (2005) considers an environmental tax reform that cuts the social security tax in the absence of public emission abatement. Therefore, the environmental dividend is produced only when the capital per capita decreases. Moreover, the non-environmental dividend is obtained because there is over-accumulation at the steady state and capital per capita decreases.

6 Environmental tax reform balanced by debt-output ratio

In our model, the government issue debt to finance current deficits. Instead of assuming that a larger environmental tax rate may be used to reduce income taxation, the environmental policy can also be used to modify the debt-output ratio. We will address this issue now and investigate if such a policy may induce both the positive environmental and macroeconomic effects at the stable steady state.

To be more specific, we consider that following an increase of τ^e, the government budget is balanced by a modification of δ, taking the labor income tax rate as constant. Differentiating (10) with $d\tau^w = dg = 0$, the policy change is described as:

$$\left.\frac{d\delta}{d\tau^e}\right|_{d\tau^w=dg=0} = -\frac{\partial\tau(\cdot)/\partial\tau^e}{\partial\tau(\cdot)/\partial\delta} \tag{16}$$

[6] Note that even if this condition may not be compatible with case (*ii*) of Proposition 4, it is in accordance with its case (*i*).

Using (6) and (12), we note that debt-output ratio affects aggregate consumption and environmental quality only through the investment rate z. Therefore, using Proposition 3, the positive environmental and macroeconomic effects of the fiscal reform may be obtained if $\overline{z}$ is increasing following the new policy.

Proposition 7 *Let Assumption 1 be satisfied and assume $\delta \in [0, \overline{\delta})$. Consider an increase of environmental taxation budget-balanced by a variation of the debt-output ratio. If $\tau^e > 1-(1-g)\beta/\alpha$, there is $\widehat{\delta} \in (0, \overline{\delta})$, such that $\overline{z}$ is increasing in τ^e if $\delta < \widehat{\delta}$. This goes through a decrease of δ. In this case, the environmental tax reform produces positive environmental and macroeconomic effects if and only if (i) the public emission abatement is large enough ($g > \epsilon/\theta$), and (ii) there exists under-accumulation at the stable steady state ($\overline{k} < \overline{k}_g$).*

Proof. To investigate the effect of the increase of τ^e on $\overline{z}$, we first note that:

$$\left.\frac{d\overline{z}}{d\tau^e}\right|_{d\tau^w=dg=0} = \frac{\partial\zeta(\cdot)}{\partial\tau^e} + \frac{\partial\zeta(\cdot)}{\partial\delta}\left.\frac{d\delta}{d\tau^e}\right|_{d\tau^w=dg=0}$$

where $\partial\zeta(\cdot)/\partial\tau^e > 0$ is given by (9) and

$$\frac{\partial\zeta(\cdot)}{\partial\delta} = -\frac{\overline{z} + \alpha\beta(1-\tau^e)}{\sqrt{\{\beta(\mu+\alpha\tau^e)-\delta\}^2 - 4\alpha\beta\delta(1-\tau^e)(1+\beta)}} < 0 \tag{17}$$

Therefore, a sufficient condition to have $d\overline{z}/d\tau^e > 0$ is $d\delta/d\tau^e < 0$. Using (11) and (16), we deduce that $d\delta/d\tau^e$ and $\partial\tau(\cdot)/\partial\delta$ have the same sign. To find it, a derivative of (10) with respect to the debt-output ratio gives:

$$\frac{\partial\tau(\cdot)}{\partial\delta} = \frac{\alpha}{1-\alpha}\frac{1}{\overline{z}}\left(1 - \frac{\delta}{\overline{z}}\frac{\partial\zeta(\cdot)}{\partial\delta}\right) - \frac{1}{(1-\tau^e)(1-\alpha)} \tag{18}$$

Using (17) and (18), $\partial\tau(\cdot)/\partial\delta < 0$ is equivalent to $\psi(\delta) < 1$, with:

$$\psi(\delta) \equiv \frac{\alpha(1-\tau^e)}{\overline{z}}\left[1 + \delta\frac{1+\alpha(1-\tau^e)\beta/\overline{z}}{\sqrt{[\beta(\mu+\alpha\tau^e)-\delta]^2 - 4\alpha\beta\delta(1-\tau^e)(1+\beta)}}\right]$$

We can easily show that $\psi'(\delta) > 0$. Moreover, using (8), we have:

$$\begin{aligned}
\psi(\overline{\delta}) &= +\infty \\
\psi(0) &= \frac{\alpha(1+\beta)(1-\tau^e)}{\beta(\mu+\alpha\tau^e)}
\end{aligned}$$

Therefore, if $\psi(0) < 1$, there exists $\widehat{\delta} \in (0, \overline{\delta})$ such that $\psi(\delta) < 1$ for all $\delta < \widehat{\delta}$. Using Proposition 3, we deduce the proposition.[7] ■

[7] Note that to ensure under-accumulation, the conditions obtained in this proposition should be in accordance with Proposition 4. Case (*ii*) of Proposition 4 may not be satisfied, but case (*i*) may be if $1-(1-g)\beta/\alpha < 1-\frac{1-g}{\alpha\beta}[\beta-\alpha(1+\beta)]$. This requires $\alpha > \beta(1-\beta)/(1+\beta)$, which is satisfied for β sufficiently close to 1.

Under Proposition 3, the positive environmental and macroeconomic effects occur if the fiscal reform raises z (or k). Here, a larger environmental tax rate implies a variation of the debt-output ratio, the income tax rate staying constant. We show that when a larger τ^e implies a lower debt-output ratio δ, capital accumulation raises. Since the income tax rate is constant, the debt-output ratio modifies k or z through the level of the crowding-out effect only. This configuration is especially interesting because the fiscal policy allows to improve aggregate consumption and environmental quality by reducing the debt-output ratio. Regarding the debt sustainability constraints faced by many countries today, this fiscal reform induces a third dividend.

7 Conclusion

This paper examines the effects of environmental tax reform in an overlapping generations model by integrating debt and public emission abatement into the traditional model. Using this model, it is found that, when the personal income tax is cut, environmental tax reform increases the steady state investment factor. This fact implies an increase in pollution emission and that the environmental dividend cannot be obtained in the absence of public emission abatement. On the other hand, the non-environmental dividend is obtained only when there should be under-accumulation of per capita capital stock at steady state. Then, debt plays an important role because a feasible set of debt-output ratios determines the range of steady state investment factors.

Moreover, the literature on the environmental tax issue gives some clear results: when the economy is made of one productive sector, using only one productive factor (labor), and one representative consumer, the strong version of the double dividend is rejected. When there are several productive factors and/or several consumer groups, the double dividend can be obtained but at the expense of equity (Bovenberg and van der Ploeg [1995], Proost and van Regemorter [1995], Bovenberg and Heijdra [1998]). This property might question the relevance of the fiscal reform if it harms some generations. Nevertheless, any environmental tax is based on the equity and intergenerational solidarity principle: it aims to give to the future generations the same environmental amenities as to the present generations. But such a tax reform will only be acceptable if it improves the global welfare of all generations, the present like the future ones. We show that this objective can be achieved in some cases but it needs the implementation of some transfers either from the older to the younger or, contrary to intuition, from the younger to the older. Thus the tax change does not always harm the welfare of the older generation and, under certain assumptions about agents' preferences, it is possible to obtain both a double dividend and the respect of intergenerational equity.

Thus, we show that the effects of environmental tax reform are largely affected by several characteristics on government budget. However, by considering alternative packages of using environmental tax revenues under the government revenue neutrality, we reveal different conditions for the double dividend from those in environmental tax reform. Therefore, we show that the double dividend may be obtained by choosing a suitable scheme even when there is over-accumulation of per capita capital or public emission abatement is not so large.

However, the economic growth is not taken into account in this model. This factor must be related to the feasible set of debt-output ratios. This fact surely affects the steady state investment factor and, therefore, should be considered in further works.

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