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of Environmental Tax
Reform**

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Summary

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Keywords: Tax reform, Endogenous Growth, Human Capital, Environmental Externality, Transitional Dynamics, Welfare cost

JEL Classification: E62, I21, H22, Q28, O41, D62

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Short and long-term effects of environmental tax reform

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Abstract

This paper examines the macroeconomic effects of an environmental tax reform in a growing economy. A model of endogenous growth based on human capital accumulation is used to numerically simulate the growth effects of different environmental tax reforms and compute their impact on welfare in the short and the long-term. Our results suggest that the magnitude of these effects depends on the type of tax reform. Thus, only environmental tax reform that aims to use the revenue from environmental tax to reduce wage tax and increase the proportion of public spending within GDP, enhance both growth and welfare in the long-term. However, the short-term effect remain negative.

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1 Introduction

There is a recurring question in relation to the recycling of green tax revenues: how can environmental tax reform be undertaken without reducing growth and social welfare? This question is central to public debate, not only in countries where environmental tax reform has been introduced, but also in countries where such reform is still under consideration (Heine *et al.*, 2012). Numerous OECD countries such as Sweden, Norway, Finland, Denmark, the Netherlands, Germany, Italy and the United Kingdom have implemented explicit environmental tax reforms. The stakes in the fiscal debate is substantial. Revenues raised from green taxes average about 2% of GDP and have exceed 9% of total tax revenues in some OECD countries. There are several ways in which green tax revenues are utilised. The macroeconomic effects differ from one tax reform to another. The objective of this paper is to examine the short and long-term effects of different environmental tax reform in a growing economy.

Many prior studies examine the relationship between tighter environmental policy and economic growth. Endogenous growth models were used to analyse the effects of green taxes on the long-term growth rate¹. A tighter environmental policy can potentially operate through different mechanisms such as investment, education and R&D. Overall, to generate a positive growth effect, many studies incorporate environmental quality into firm's production function as an externality by considering that a clean environment would improve the productivity of inputs or the efficiency of the education system (Ligthart and van der Ploeg, 1994; Bovenberg and Smulders, 1995; Hart, 2004; Nakada, 2004, Grimaud, 1999; Chen, 2009; among others). Furthermore, it was highlighted that the labour-leisure choice played a role in the transmission of the environmental tax effect in a two-sector model of endogenous growth (Hettich, 1998). In response to an increase in the environment tax firms increase their abatement, which reduces final output and households substitute education time for leisure time so as to counteract reduced consumption, and finally improve long-term growth rate.

In addition, the environmental tax reform issue has been extensively investigated in endogenous growth structure (Bovenberg and Smulders, 1995, 2000; Bovenberg and de Mooij, 1997; Fullerton and Kim, 2007; Greiner, 2005; Nakada, 2010; Fernandez et al., 2011; among others). These papers consider many combination of tax structure and externalities and give different conditions to achieve a double dividend. The double dividend hypothesis is nicely exposed in Goulder (1998) and Bovenberg (1999) : the first dividend is an improvement in the environmental quality, and the second is an increase in welfare from private commodities as the result of a less distortionary tax system.

In a seminal paper, Lucas (1990) finds that shifting capital income taxation completely to labor income taxation has negligible effects on long-run economic growth in a model of endogenous growth which is calibrated to the US economy. According to this Lucas's positive approach, Jorgenson and Wilcoxon (1993) estimate a model for the US economy using post war data. Their simulations suggest that a carbon tax would have qualitatively different impacts on long-run GDP depending on the preexisting taxes that are reduced. In the same vein, a similar models was mentioned by Koskela and Schob (1999) and Bayindir-Upmann and Raith (2003), who showed that, in a distorted labor market, substituting green taxes for labor taxes would increase employment and out-

¹See Ricci (2007) for a comprehensive survey on impacts of environmental policy on growth.

put and eventually produce a detrimental effect on the environment. Using a dynamic general equilibrium model calibrated to the US economy, Glomm *et al* (2008) find that increasing gasoline taxes and using the revenue to reduce capital income taxes deliver both types of welfare gains: from higher consumption of market goods and from a better environmental quality, even though in the new steady state environmental quality may worsen.

Our goal in this paper is to highlight the short and long-term effects of environmental tax reform within an endogenous growth model. We build our approach on previous work by Gradus and Smulders (1993), who use a Uzawa-Lucas structure augmented with an environmental externality and distortionary taxes. Following Hettich (1998), we assume that labour supply is elastic. This leads us to identify a link between environmental tax and the long-term growth rate even without assuming direct productivity effects of a cleaner environment.

Whereas most endogenous growth models dealing with environmental concerns restrict their analysis to the steady state, little has been said so far on the short-term effects of environmental tax reform. Bovenberg and Smulders (1996), Vellinga (1999), Hofkes (2001), Oueslati (2002) are the few exceptions in the literature. However, these studies are limited to the effect of a tighter environmental policy and do not explicitly consider the transitional effects of environmental fiscal reforms. In this paper, we compute the entire dynamic adjustment path towards a balanced growth path. Furthermore, the analysis of the dynamic adjustment path enables us to perform welfare calculations. In particular, we make explicit the trade-off between the short and long-term welfare costs of environmental tax reform.

We consider five scenarios of tax reform associated with the implementation of pollution tax. Firstly, we examine the cases in which the government uses the environmental tax revenue to decrease the distorting tax rates keeping the share of public spending in the final product constant. We next study the case where environmental tax reform involves the use of environmental tax revenue as an additional resource for the government budget.

Our main results can be summarised as follows. Firstly, green tax reform which aims to use the revenue from environmental tax to reduce physical capital tax is growth-reducing in the long-term. However, tax reform which aims to reduce wage tax had a positive effect on the long-term growth. Secondly, tax reforms accompanied by increased public spending that promotes depollution present the best results in terms of long-term growth. Our results show also that tax reform which aims to reduce wage tax and increase the proportion of public spending within GDP, is the most welfare-enhancing in the short and long-term.

The remainder of the paper is organised as follows. In section 2 the general model is presented and market solution is derived. Section 3 proposes a numerical simulation of different tax reforms. We then simulate the transitional dynamics. Section 4 computes welfare costs for each reform in the short and long-term. Section 5, summarises the main findings.

2 The model

We consider a discrete time economy populated with a continuum of identical, infinitely-lived households. Each household owns the stock of physical capital in the economy, K_t , and is endowed with a (normalised) unit time. The time endowment can be allocated between work (remunerated at the current competitive wage rate), leisure and schooling. A proportion of the final product produces a flow of pollution that can be reduced by a public effort towards depollution. The net pollution flow is assumed to affect individuals' utility.

2.1 Households

The behaviour of the rational household is guided by the maximisation of the discounted lifetime utility

$$\mathcal{W}_0 = \sum_{t=0}^{\infty} \beta^t (\log C_t + \phi_l \log l_t - \phi_P \log P_t) \quad (1)$$

where C_t is consumption, l_t represents hours spent away from leisure, $0 < \beta < 1$ is the discount factor and P_t is the net pollution flow. The parameters ϕ_l and ϕ_P represent the weights of leisure and pollution in utility. The consumer budget constraint can be written as follows :

$$K_t = [1 + (1 - \tau_t^K) r_t - \delta_K] K_{t-1} + (1 - \tau_t^H) w_t u_t H_{t-1} + T_t - C_t \quad (2)$$

where r_t is the return to physical capital and w_t is the gross wage rate per effective unit of human capital $u_t H_{t-1}$. u_t is the supply of working time. δ_K denotes the rate of depreciation for physical capital. τ_t^K and τ_t^H are respectively a tax on capital income, and wage tax. T_t is a lump-sum transfer from the government. The representative household can increase their human capital stock H_t , by devoting time to schooling. We assume that this activity takes place outside the market, and new human capital can only be acquired by spending time. Thus, the law of motion for human capital is given by the constraint

$$H_t = [1 + Bv_t - \delta_H] H_{t-1} \quad (3)$$

where B is the marginal productivity of schooling time v_t , δ_H denotes the rate of human capital depreciation. The household is endowed with a (normalised) time unit which can be allocated either to work, leisure or schooling

$$1 = u_t + v_t + l_t \quad (4)$$

2.2 Firms

The economy comprises a large number of identical and competitive firms. They rent capital and hire effective labour from the households at the interest rate r and the wage rate w respectively. They use the following constant-returns Cobb-Douglas technology

$$Y_t = AK_{t-1}^\alpha (u_t H_{t-1})^{1-\alpha} \quad (5)$$

where $A > 0$ and $0 < \alpha < 1$. We suppose that pollution is taxed at the rate $\tau^P > 0$ and firms take into account that one unit of output creates $\mu > 0$ units of pollution for which

they have to pay $\tau^p \mu$ per unit of output. Firms are assumed to maximise their market value, which is equal to the appropriately discounted sum of profit flows, the latter is given by

$$\pi_t = (1 - \tau^p \mu) Y_t - r_t K_{t-1} - w_t u_t H_{t-1} \quad (6)$$

Profit maximisation implies that in equilibrium, firms pay each production factor at its marginal productivity.

$$r_t = (1 - \tau^p \mu) \frac{\alpha Y_t}{K_{t-1}} \quad (7)$$

$$w_t = (1 - \tau^p \mu) \frac{(1 - \alpha) Y_t}{u_t H_{t-1}} \quad (8)$$

We assume that the pollution flow is a by-product of aggregate production (Y_t). Moreover, the pollution flow can be reduced by means of public abatement activities (D_t) which in turn consume a proportion of output, in line with the flow resource constraint. Thus, the effective pollution flow (P_t) can take the following form :

$$P_t = \mu Y_t / D_t \quad (9)$$

This form is inspired by Gradus and Smulders (1993), Ligthart and van der Ploeg (1994), Hettich (1998) among others.

2.3 Government budget constraint

The government revenue comes from taxes on capital income (τ_t^K), wage (τ_t^H) and pollution (τ_t^P). All government tax revenues (Z_t) are used to cover expenditure abatement activity (D_t) and lump-sum transfer (T_t). The government budget constraint implies that in each period, we have:

$$Z_t = \tau_t^K r_t K_{t-1} + \tau_t^H w_t u_t H_{t-1} + \tau_t^P \mu Y_t = D_t + T_t \quad (10)$$

Let $\theta > 0$, such as $D_t = \theta Z_t$ and $T_t = (1 - \theta) Z_t$. The market clearing condition for the goods market is

$$Y_t = C_t + K_t - (1 - \delta_K) K_{t-1} + Z_t \quad (11)$$

2.4 The market solution

Definition 1 A competitive equilibrium for this economy consists of the consequences $\{C_t, Y_t, K_t, H_t, u_t, l_t, Z_t, r_t, w_t, \tau^P, \tau_t^K, \tau_t^H, P_t\}$ for $t = 1, 2, 3, \dots$ and for $0 \leq \theta \leq 1$, that satisfy the following conditions.

(i) Household utility maximisation : Maximise (1) subject (2), (3), (4) and (9) $\lim_{t \rightarrow \infty} \beta^t \lambda_t K_t = \lim_{t \rightarrow \infty} \beta^t q_t H_t = 0$, H_0 and K_0 are given. The variables λ_t and q_t represent respectively the shadow prices of physical and human capital. (ii) Profit maximisation (6). (iii) Government budget constraint (10) (iv) Market clearing : $C_t + Z_t + K_t - K_{t-1} (1 - \delta_K) = Y_t$

So as to characterise the competitive equilibrium, let us focus on the different trade-offs faced by the household. After eliminating the shadow prices for physical and human capital, the first order conditions for the household problem are written

$$\frac{\phi_l}{l_t} \frac{C_t}{H_{t-1}} = (1 - \tau_t^H) w_t \quad (12)$$

$$\frac{C_{t+1}}{C_t} = \beta [1 + (1 - \tau_{t+1}^K) r_{t+1} - \delta_K] \quad (13)$$

$$\frac{C_{t+1}}{C_t} = \beta \frac{1 - \tau_{t+1}^H}{1 - \tau_t^H} \frac{w_{t+1}}{w_t} \{1 + B(1 - l_{t+1}) - \delta_H\} \quad (14)$$

Equation (12) equates the marginal rate of substitution between consumption and leisure to the real wage. Equations (13) and (14) are Euler conditions determining the optimal accumulation of physical and human capital. These conditions, along with equations (1), (2), (3), (4), (9), (7), (8) and (10) constitute a dynamic system in C , D , E , u , l , K and H which, together with the transversality conditions² and initial $K(0)$ and $H(0)$, fully describe the dynamic behaviour of the economy along an interior equilibrium.

2.5 The balanced growth path

Definition 2 *A balanced growth path (or steady state) is an allocation $\{C_t, Z_t, u_t, l_t, K_t, H_t, P_t, T_t\}$, a price system $\{r_t, w_t\}$ and taxes τ^K , τ^H and τ^p satisfying Definition 1, and such that for some initial conditions $K(0) = K_0$ and $H(0) = H_0$, the paths $\{C_t, Z_t, K_t, H_t\}$ grow at the constant rate g , and u_t, v_t, l_t and P_t remain constant.*

For analytical convenience we use the following transformed variables: $h_t = H_t/K_t$, $c_t = C_t/K_{t-1}$, $y_t = Y_t/K_{t-1}$, $z_t = Z_t/K_{t-1}$ and $g_t = K_t/K_{t-1}$. Using this change of variables, we obtain the following dynamic system:

$$r_t = \alpha (1 - \tau_t^p \mu) y_t \quad (15)$$

$$w_t = (1 - \alpha) (1 - \tau^p \mu) \frac{y_t}{u_t h_{t-1}} \quad (16)$$

$$P_t = \frac{\mu y_t}{\theta z_t} \quad (17)$$

$$\frac{l_t}{u_t} = \frac{\phi_l}{(1 - \tau_t^H) (1 - \tau_t^p \mu) (1 - \alpha) y_t} \quad (18)$$

$$g_t = 1 + y_t - z_t - c_t - \delta_K \quad (19)$$

$$g_t \frac{h_t}{h_{t-1}} = 1 + B(1 - u_t - l_t) - \delta_H \quad (20)$$

$$g_t \frac{c_{t+1}}{c_t} = \beta [1 + (1 - \tau_{t+1}^K) r_{t+1} - \delta_K] \quad (21)$$

$$g_t \frac{c_{t+1}}{c_t} = \beta \left\{ \frac{1 - \tau_{t+1}^H}{1 - \tau_t^H} \frac{w_{t+1}}{w_t} [1 + B(1 - l_{t+1}) - \delta_H] \right\} \quad (22)$$

$$z_t = y_t \{ [\tau_t^K \alpha + \tau_t^H (1 - \alpha)] (1 - \tau_t^p \mu) + \tau_t^p \mu \} \quad (23)$$

$$y_t = A u_t^{1-\alpha} h_t^{1-\alpha} \quad (24)$$

From the linearisation of the system (15)-(24) one can show that, independently of the size of taxes, the model displays a saddle path dynamic structure. The steady-state values y , h , c , z , u , l and g are obtained by eliminating the index t from the system (15)-(24). Taxes are fixed by the government and do not have a transitional dynamics.

²The transversality conditions are standard and entail that the present discounted value of both human and physical capital stocks tends to zero at infinity.

3 Numerical simulations

3.1 Data and calibration

The purpose of this calibration is to calculate the values of initial steady state SS0 (benchmark case, BC). We determine the values of certain parameters in accordance with macroeconomic stylised facts. The data are obtained from the OECD database, which includes: (i) Main economic indicators (MEI), (ii) Economic Outlook (EO); (iii) International Sectoral Database (ISDB).

To calibrate the model, we consider that the economy is initially on the equilibrium growth path where pollution is not taxed ($\tau^P = 0$) and there is a low share of public abatement in public spending ($\theta = 0.1$). To compute the steady state variable values SS0, we resort to the common parameter values already used in two-sector endogenous growth models. Additionally, the calibration is carried out so as to capture the public spending share of GDP at 44%, which corresponds to the average of public spending in OECD countries. The environment-related expenditure is estimated to be approximately 2.3 – 5.8% of GDP in the OECD countries (MEI). We then set an average rate $\theta z/y = 4.4\%$. Unfortunately there are no data on the share of polluting activities in GDP (μ). We set $\mu = 0.7$ to get a plausible values for the calibrated variables and parameters of the model. In accordance with the ISBD dataset, we set the value of α equal to capital's share in income (i.e. 0.399). The discount rate, $1/\beta$ is equal to 1 plus the ex-post real interest rate. We use the ex-post real interest from MEI. This implies a value 0.976 for β . Following Barro and Sala-i-Martin (1995), we set the depreciation rates the same across sectors and equal $\delta_H = \delta_K = 0.05$.

Regarding the allocation of time, there are no data that decompose total time in work, leisure and education. However, we use survey data on hours worked from EO, which indicate that agents who work, allocate about 65% of their time to leisure. The breakdown of non-leisure time to work and education effort is roughly two thirds to work and one third to education. For tax parameters, we use the effective average tax rates from Martinez-Mongay (2000) to retain $\tau^K = 0.47$. The value of the scale factor $A = 0.234$ was chosen to get z/y and τ^H close to the values observed in OECD countries. The calibration is carried out in order to capture an equilibrium growth rate of 1 % . Benchmark case (BC) values are summarised in the table 1 for the chosen parameters and variables and in the table 2 for the calibration results.

Table 1: Chosen parameters and variables

Parameter or variable	Value	Description
A	0.234	Total productivity
β	0.976	discount factor
g	1.01	growth rate
$\delta_K = \delta_H$	0.05	depreciation rate
α	0.399	physical capital share in product
l	0.65	leisure time
τ^K	0.47	tax on capital income
μ	0.7	part of pollution in the product
θ	0.1	abatement share in public spending

Values for the remaining parameters and variables are given in table 2.

Table 2: Calibration Results

Parameter or variable	Value	Description
y	0.235	Final output per unit of physical capital
h	5.192	Human capital per unit of physical capital
u	0193	working time
c	0.111	Consumption per unit of physical capital
z	0.103	Public spending per unit of physical capital
B	0.128	Human capital productivity
ϕ_l	2.606	Weight of leisure in utility
τ^H	0.423	Wage tax

We deduce also steady state values of $w = 0.149$, $r = 0.084$ and $P = 15.909$. Furthermore, we obtain the following ratios: the proportion of public spending in the final output $z/y = 0.44$. The proportion of abatement in the final output is $d/y = 0.044$ and the proportion of consumption in the final output $c/y = 0.474$. These values are close to those observed, on average, in OECD countries.

3.2 Long-term effects

We now study successively the long term effects of different tax reforms. We consider five scenarios of tax reform associated with the implementation of pollution tax ($\tau^P = 0.05$). Firstly, we examine the cases in which the government uses the environmental tax revenue to decrease the distorting tax rates τ^K and τ^H keeping the share of public spending in the final product constant, $z/y = 0.44$. These two reforms are respectively called reform 1 and reform 2. We next study the case where environmental tax reform involves the use of environmental tax revenue as an additional resource for the government budget. Reform 3 consists to keep distortionary tax rates unchanged and use entirely the revenue from environmental tax for public spending. However, reform 4 and reform 5 indicate that the government reduces respectively τ^K and τ^H and increases the proportion of public expenditure in GDP. Table 3 summarizes the various reform scenarios.

Table 3 : tax reform scenarios

	Revenue-neutral tax reforms			Increased public spending		
	BC	Reform 1	Reform 2	Reform 3	Reform 4	Reform 5
τ^P	0	0.05		0.05		
z/y	0.44	0.44		0.47	0.46	0.46
τ^K	0.47	0.41	0.47	0.47	0.44	0.47
τ^H	0.42	0.42	0.39	0.42	0.42	0.40

3.2.1 Revenue-neutral tax reform

Reforms 1 and 2 are revenue-neutral tax reforms. The government keeps constant the proportion of public spending in the final output ($z/y = 0.44$) and reduces distortionary taxes τ^K and/or τ^H . Under reform 1, the government uses the revenue from environmental tax to reduce only tax on physical capital income (τ^K). This implies that the

economy leaves its initial steady state (SS0) and converges to a new steady state (SS1) (see Table 4). We observe a slight decrease in growth rate ($g = 1.006$). Under the reform 2, the government uses the revenue from environmental tax to reduce only tax on human capital income (τ^H). We observe a slight increase in growth ($g = 1.011$).

Table 4 : Revenue-neutral tax reforms

	g	h	l	u	c/y
BC : (SS0)	1.01	5.192	0.650	0.140	0.474
Reform 1 : (SS1)	1.006	4.184	0.675	0.193	0.475
Reform 2 : (SS2)	1.011	5.742	0.639	0.194	0.475

The results of these two reforms show opposite long-term effects on the growth rate. In both reforms, the introduction of an environmental tax can be seen as a levy on available resources within the economy, which induces a decline in productive capacity. The decrease of τ^K makes investment in physical capital more attractive and generates the decrease of h . This reflects the transformation of the production function, which becomes more intensive in terms of physical capital. This change in τ^K also reduces the time allocated to education and therefore lowers long-term growth. In contrast, the reform 2 produces a positive effect on growth in the long-term. The new steady state values SS2 indicate that h increases significantly. Thus, the decrease in τ^H has encouraged the substitution of physical capital by human capital. Additionally, households spend less time in their leisure activities and devote more time to human capital development, which finally improves human capital stock and boosts the long-term growth rate. As the share of public abatement in the final product remains constant ($d/y = 0.044$), in both reforms 1 and 2 the pollution flow does not change ($P = 15.909$).

3.2.2 Tax reform with increased public spending

Another possible reform is to keep distortionary tax rates unchanged and use the revenue from environmental tax for public spending (reform 3). In this case the economy converges to a new steady state SS3 (see Table 5), where we get $z/y = 0.47$. As we can see there is a positive effect on the growth rate ($g = 1.013$). The values of u and h increase. However the values l and c/y decrease. Increasing the share of public spending in GDP generates an increase in d/y and therefore reduces the flow of pollution ($P = 14.736$). Tax reform with increased z/y affects the allocation of time within the economy. Thus, the introduction of an environmental tax increases schooling time and improves human capital stock, which improves long term growth.

Reforms 4 and 5 show the same trends with different magnitudes (see Table 5). Overall, we find the same mechanisms as those described in the case of revenue-neutral tax reforms. However, the rise in public spending leads to an improvement in both long-term growth and pollution.

Table 5 : Tax reform with increased public spending

	g	h	l	u	c/y	d/y	P
BC : (SS0)	1.010	5.192	0.650	0.140	0.474	0.044	15.909
Reform 3: (SS3)	1.013	6.234	0.619	0.194	0.435	0.047	14.736
Reform 4 : (SS4)	1.012	5.622	0.628	0.194	0.441	0.0467	15.004
Reform 5 : (SS5)	1.014	6.344	0.6150	0.1947	0.447	0.0461	15.169

The fact that a part of the environmental tax revenues is re-injected into the economy, as a public expenditure, allows to maintain partially the productive capacities and enhances growth. This effect is more apparent in the reform 5.

3.3 Transitional effects

In order to compute the transitional dynamics we log-linearise the dynamic system (15)-(24) to make the equations approximately linear in the log-deviations from the steady state. After doing this, we solve the recursive equilibrium law of motion via the method of undetermined coefficients method. Starting from this solution, the time series can easily be reconstituted from SS0. We summarise all transitional dynamics using two sets of figures. Figures 1-2 show the different transitional dynamics generated by the five scenarios of tax reforms presented above. In each figure we plot the trajectory of some key variables (g , h , c/y , u , l and P) to highlight the economic mechanisms that come into effect after the implementation of environmental reforms. The simulation of the transitional dynamics starts in period $t = 0$, where the government, without forewarning, implements an environmental tax reform. This policy shocks the initial steady state (SS0) and induces an instantaneous reaction for all economic variables. These reactions show the short-run dynamics within the economy before reaching a new steady state.

In the first set of figures (fig. 1), we simulate the transitional dynamics induced by revenue-neutral tax reforms reducing τ^K and τ^L without change in public spending share. The second set of figures (fig. 2) concerns tax reforms with increased public spending. We note several differences in transitional dynamics, which lead us to study the transitional effects of tax reforms. The pace at which the economy reaches the new steady state is the result of the interaction between many economic trade-offs. Clearly, transitional dynamics reflect three main mechanisms. Firstly, there is a crowding out effect caused by the implementation of the environmental tax. The later can be considered as a levy on the resources available within the economy. Thus, with government spending remaining constant, the consumption proportion of in GDP must decline. Secondly, a factorial reallocation effect occurs, which changes the intensity of physical capital and/or human capital in the final product. This mechanism is enhanced by reducing one of the two distortionary taxes. Thirdly, a reallocation of available time take place leading to an increase schooling time. When the government uses environmental tax revenue to reduce the tax on income from physical capital, the economy gains an immediate sharp increase in growth, but it converges in the long term to a lower growth rate (see fig 1.a). In contrast, within reforms 2, 3 and 4, the growth rate immediately drops before increasing to reach its new steady state value (see figs 1b, 2a). The difference between the short-term effects of tax reforms, with or without changes to the public spending share is evident in the trajectory of pollution. An increase of public spending share (z/y) leads to a significant decrease in pollution (see fig. 1f, 2f)

Figure 1: Revenue-neutral tax reforms

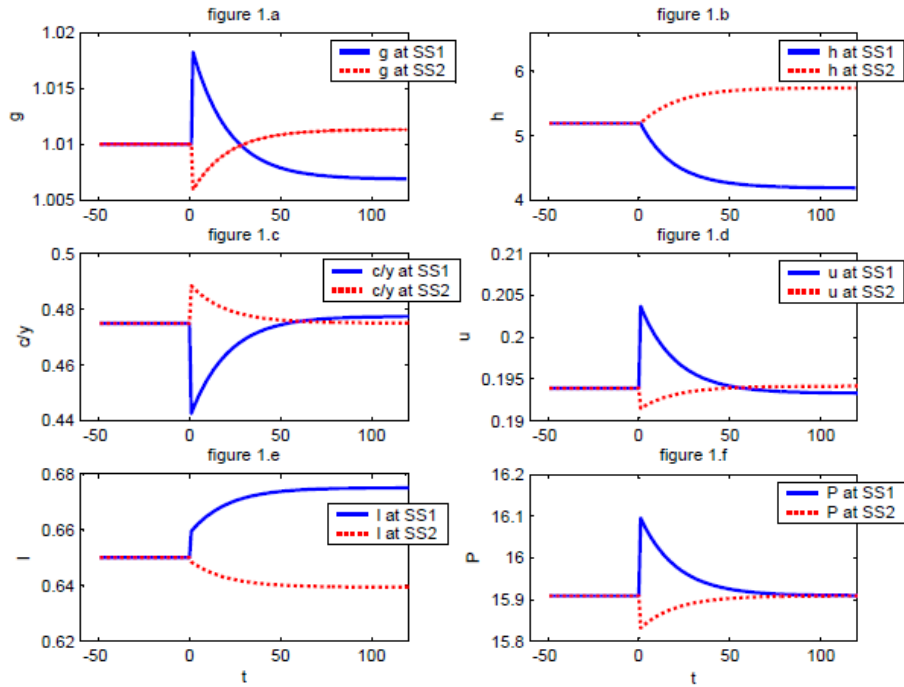
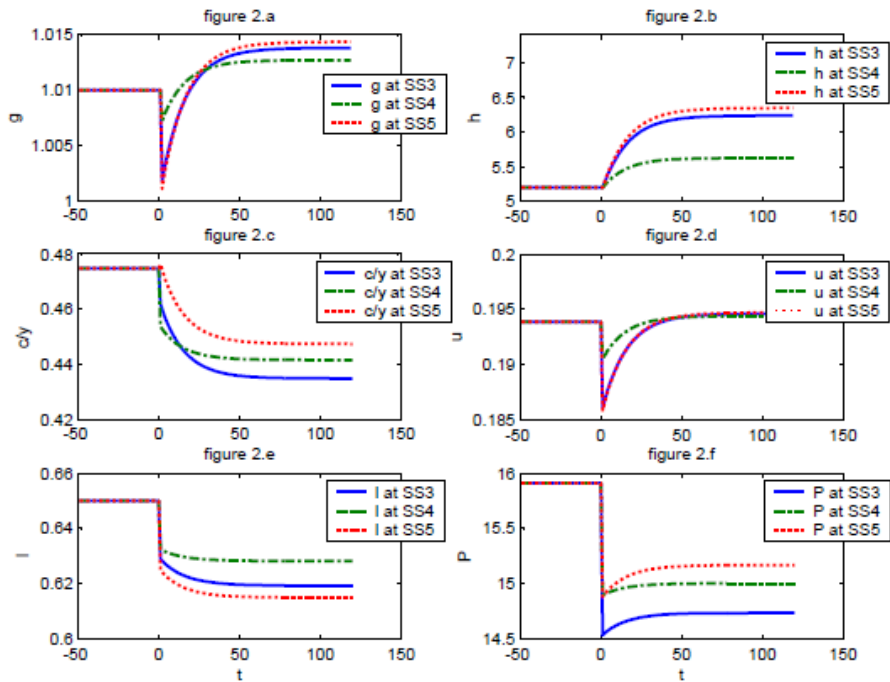


Figure 2: Tax reform with increased public spending



4 Welfare analysis

4.1 Welfare decomposition

We differentiate welfare as transitional welfare (also referred to as the short-term welfare) $\mathcal{W}_{1 \rightarrow 2}$ corresponding to the economy's transition from (SS0) to a new steady state (NSS), and \mathcal{W}_2 welfare related to the NSS. In order to obtain a numerical result, we assume that the transition from a steady state to another state is achieved within a finite number of periods, and we simply denote T as the date at which we consider that the economy has numerically reached its new rest point. The total welfare associated with the environmental policy change \mathcal{W}^{Tot} is equal to the sum of utility flows, from $t = 0$ to $+\infty$, which can be written as the sum of $\mathcal{W}_{1 \rightarrow 2}$ and \mathcal{W}_2 : $\mathcal{W}^{Tot} = \mathcal{W}_{1 \rightarrow 2} + \mathcal{W}_2$. Note that the economy converges only asymptotically to the steady state, and we therefore truncate the transitional dynamics in the effective computation at the horizon T . This horizon is chosen so that for all $t > T$, the difference between the value of physical capital stock at T (k_T) and its value at NSS (k_2) is numerically very small³. Formally, the transitional welfare can be written⁴:

$$\mathcal{W}_{1 \rightarrow 2} = \sum_{t=0}^T \beta^t \left[\log c_t + \sum_{i=0}^{t-1} \log(g_i) + \phi_l \log l_t - \phi_P \log P_t \right] \quad (25)$$

the welfare related to the new steady state (NSS) is given by:

$$\mathcal{W}_2 = \frac{\beta^{T+1}}{1-\beta} \left[\log c_2 + \sum_{i=0}^T \log(g_i) + \phi_l \log l_2 - \phi_p \log P_2 + \frac{\beta \log g_2}{1-\beta} \right] \quad (26)$$

and the welfare related to the BC steady state is given by⁵

$$\mathcal{W}_1 = \frac{\log c_1 + \phi_l \log l_1 - \phi_P \log P_1}{1-\beta} + \frac{\beta \log g_1}{(1-\beta)^2} \quad (27)$$

4.1.1 Total welfare cost

To obtain a meaningful evaluation of the welfare cost associated with our tax reform policies, we express all welfare measures as percentage point of the permanent consumption that generates an equivalent welfare in the benchmark case. Thus, our welfare cost measures the compensation in consumption terms that leaves the consumer indifferent between the SS0 consumption path and the NSS consumption path corresponding to a change in fiscal policy. Let us define \tilde{c}_2 as the constant flow of consumption that gives a welfare \mathcal{W}^{Tot} when the pollution disutility and the growth rate are constant.

$$\tilde{c}_2 = \exp \left[(1-\beta) \mathcal{W}^{Tot} - \frac{\beta}{1-\beta} \log g_1 - \phi_l \log l_1 + \phi_P \log P_1 \right] \quad (28)$$

³We tolerate a difference between k_T and k_2 smaller than 10^{-10} .

⁴The detailed calculation is available from the author upon request.

⁵We assume that $K_{-1} = 1$

The total welfare cost is given by λ , which is the fraction of consumption at SS0 that agents are willing to renounce to move to NSS. Let

$$\lambda = \frac{\tilde{c}_1}{\tilde{c}_2} - 1 \quad (29)$$

where $\tilde{c}_1 = \exp \left[(1 - \beta) \mathcal{W}_1 - \frac{\beta}{1 - \beta} \log g_1 - \phi_l \log l_1 + \phi \log P_1 \right]$

4.1.2 Transitional welfare cost

We assume that the economy can instantaneously jump on the new steady state (without transition). Let us define \tilde{c}^{rp} as the constant flow of consumption that gives the same welfare in this hypothetical scenario. We obtain

$$\tilde{c}^{rp} = \exp \left\{ (1 - \beta) \mathcal{W}_2 - \frac{\beta}{1 - \beta} \log g_1 - \phi_l \log l_1 + \phi_P \log P_1 \right\}$$

The welfare cost of transition expressed in consumption terms is then

$$\lambda^{dyn} = \frac{\tilde{c}^{rp} - \tilde{c}_2}{\tilde{c}_1} \quad (30)$$

4.2 Welfare cost simulation

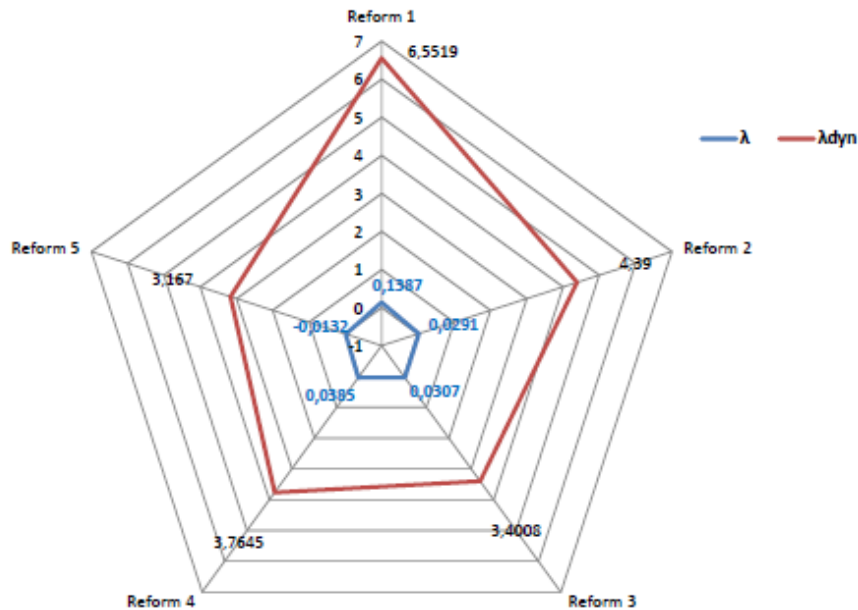
We now compute total and transitional welfare costs for our five scenarios. We consider that the weight of pollution in the preferences (ϕ_P) is equal to 0.1 and all other values of parameters and variables are those defined SS0. Figure 3 summarises the results of welfare costs in the short term (λ^{dyn}) and long term (λ) for the five proposed reforms. It may be noted that all tax reforms have a positive welfare cost in the short term and reform 1 presents the highest welfare cost in the short term. Otherwise, reform 5 presents a negative welfare cost in the long-term, which means that this tax reform induces a welfare benefit in the long-term.

Overall, reforms with increased public spending have the lowest welfare cost in short and long term. The significant decrease in pollution in reforms 3, 4 and 5 may explain the low magnitude of the welfare costs. Tax reform which aims to use the revenue from environmental tax to reduce wage tax and increase the proportion of public spending within GDP, is a relatively more welfare-enhancing in the short and long-term.

5 Conclusion

In this paper, we have demonstrated that different environmental tax reforms may have diverse impacts on growth and welfare in the short and long-term. The magnitude of these effects depends on the type of tax reform and the budgetary policy. Thus, the implementation of environmental tax has been considered under five scenarios of tax reforms and public spending. Based on a numerical approach, we quantified the effect of environmental tax reforms on long-term growth. Tax reform which aims to use the revenue from environmental tax to reduce physical capital tax is growth-reducing in the long-term. However, tax reform which aims to reduce wage tax had a positive effect on

Figure 3: Short and long term welfare costs



the long-term growth. Moreover, tax reforms accompanied by increased public spending that promotes depollution present the best results in terms of long-term growth. The measurement of welfare costs in the short and long term gives a clear idea about the feasibility of certain environmental policies. Tax reform which aims to use the revenue from environmental tax to reduce wage tax and increase the proportion of public spending within GDP, is the most welfare-enhancing in the short and long-term.

The tax system is necessary to fund public spending. But, it can also be a powerful means for influencing individual behaviour. Thus, taxation may be used to discourage activities that lead to environmental damage, such as pollution and excessive resource use. As we highlighted in this article, there is scope to restructure the tax system in ways that promote economic growth and inhibit environmental damage. This basic idea is being extensively discussed, analysed and implemented in Europe and constitutes an important piece of the environmental debate.

Beyond these results, our research highlights a specific approach to distinguish the short and long-term effects. This approach can be extended to study the effects of environmental tax reforms in the context of an indebted economy or in the presence of social disparities. These questions are left for future research.

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