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From Regressive Pollution Taxes to Progressive Environmental Tax Reforms

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Abstract

European countries have increased their use of environmental tax instruments by designing new tax bases. But, many countries have to face the opposition of the public opinion, for fear of the distributive consequences of these environmental tax reforms. This paper sheds light on the distributive consequences of environmental tax policies when households are heterogeneous. The objective is to assess whether an environmental tax reform could be Pareto improving, when the revenue of the pollution tax is recycled by a change in the labor tax properties. We show that, whatever the degree of regressivity of the environmental tax alone, it is possible to design a recycling mechanism that renders the tax reform Pareto improving, by simultaneously decreasing the average rate of the wage tax and increasing its progressivity.

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1 Introduction

European countries have increased their use of environmental tax instruments by designing new tax bases, like sulfur dioxide, plastic bags, solid waste and batteries. Even in the United States are there now warm advocates of the tax against the cap and trade approach, like James Hansen an American scientist, who claims "A rising price on carbon emissions is the essential underlying support needed to make all other climate policies work. [...] A rising carbon price is essential to "decarbonize" the economy, i.e., to move the nation toward the era beyond fossil fuels. The most effective way to achieve this is a carbon tax (on oil, gas, and coal) at the well-head or port of entry. [...] The public will support the tax if it is returned to them [...]". This quite surprising attitude corresponds to a larger movement in favour of the price instrument. France, following Sweden and other Scandinavian countries, considered to implement during 2010 a carbon tax at a rate equal to 17€/ton CO2. Finally, in front of the opposition of the public opinion and the practical and legal difficulties, the government decided to postpone the project until a European policy would be put in place. The Swedish presidency of the European Union (second semester of 2009) encouraged the other member countries to implement carbon taxes bearing on all sectors of activity which are not regulated by the emission quotas system. But many countries have to face the opposition of the public opinion, for fear of the distributive consequences of these environmental tax reforms.

What would thus be the inequality consequences of a European Carbon Tax Project or of the Carbon Contribution planned by the French government as from 2010? As Hansen suggests it, an environmental tax can hardly be considered without adequate revenue recycling in order to enhance the acceptance of the environmental policy. But the aim of such a recycling can therefore be twofold: to reduce, or even annihilate the gross cost of the policy, as measured by the global welfare loss, or to compensate the generated inequities. The objective of this paper is to contribute to this debate by designing an environmental tax reform that could be unanimously accepted.

As well as the cap and trade mechanism, the tax allows to achieve the environmental objectives while minimizing the global cost. One of the advantages of an environmental tax is that it provides public revenues which can be recycled. This is a reason why it can be preferred to subsidies or emission quotas. It has been argued that, as governments use these revenues to decrease other distortionary taxes, an environmental tax may simultaneously improve the environmental quality and achieve a less distortionary tax system, i.e. it may lead to a double dividend, according to Goulder [18]. This can be a strong argument in favour of an increasingly green tax system. After Bovenberg and de Mooij [5] who initially provided a refutation of the double dividend hypothesis, a large body of literature has deeply analyzed this issue. In particular, Goulder [18] and Ligthart [23] 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. Following in behind this stream of literature, Chiroleu-Assouline and Fodha [9] and [10] studied the existence conditions of a long term double dividend, taking into account the distinction between wage earners and retired consumers, by means of overlapping generations models.

But one of the disadvantages of the environmental taxes is that, like any consumption tax, they often appear to be regressive, i.e. more harmful for the welfare of the poorest households than for the richest ones. In particular, in the French case, a tax on energy or transport consumption harms the lowest wage households three times more than the highest wage households (Ruiz and Trannoy [33]). Bureau [7] also shows that the distributional effects of a carbon tax on car fuels in France are likely to be regressive before revenue recycling.[1] Moreover, the usual recycling of the environmental tax revenues through a decrease in the labor tax rate could also be regressive (Metcalf [24]). Somewhat surprisingly, the analyses of the double dividend issue have until recently neglected the distribution issue of the welfare gain, although it is usually obtained at the expense of some groups of agents.

This article analyzes the distributional effects between different categories of households and puts forward an appropriate policy mix to ensure a non-decreasing welfare for each class of workers. We show that whatever the degree of regressivity of the environmental tax alone, it is possible to re-design a recycling mechanism that renders the tax reform Pareto-improving,[2] by modifying the progressivity characteristics of the tax system, instead of lump-sum transfers or any other way of homogeneous compensation.

We assume that the production technology is a function of capital and heterogeneous labor. Heterogeneous households live two periods (young and old) and earn wages cor-

[1] See also Wier et al. [37] for the Danish case.

[2] In line with the double dividend literature, we are not seeking for the optimal tax system, which would require to use several instruments in order to internalize the externalities. Nevertheless, according to our Pareto-improving criterion, our results give conditions such that the economy gets closer to its Pareto optimal equilibrium.

responding to their skill. The labor tax is a very general one that could be either a progressive or proportional tax. Our demographic assumptions allow us to take into account several income classes; indeed, we consider (i) the heterogeneity characteristics of the labor market, (ii) the heterogeneity of the individual income sources. The environmental policy consists of increasing the tax on polluting capital, in a second-rank framework. We then characterize the necessary conditions for the obtaining of a double dividend, i.e. an improvement of the environmental quality and an improvement of the welfare when the revenue of the pollution tax is recycled by a change in the labor tax rates. Previous studies show that the obtaining of a double dividend requires economic conditions such that the double dividend hypothesis seems unrealistic, unless it is obtained through the worsening of inequalities. Conversely, we show that the conditions for the obtaining of a double dividend lie in the distributive properties of the labor taxes. The results are dependent on the initial tax system. In a more general framework than Chiroleu-Assouline and Fodha [11], we show that such a Pareto-improving policy can be obtained even in the worst cases of regressivity of the environmental tax alone.

The paper is organized as follows. Section 2 presents the model and Section 3 presents the specification of the balanced tax reform. Section 4 gives the welfare analysis of a tax policy. In Section 5 we present the environmental effects of the tax reform and Section 6 examines the welfare effects of such a combined reform. The last section concludes.

2 The model

We consider an overlapping generations economy with heterogeneous households. We assume that population remains constant, so we normalize it to unity. Agents live two periods (young and old) and earn wages corresponding to their skill. Each class of household is characterized by its skill i. There are I classes of agents, and the size of each class i is q_i (with $\sum_{i=1}^{I} q_i = 1$). q_i and I are supposed to be exogenous. Each agent supplies inelastically one unit of labor[3] when young and earns a wage w_t^i, the labor tax rate is $\tau^i \in [0, 1[$. He divides his labor net income between consumption and savings s_t^i. In the second period the household consumes his savings and the interest he earns. The welfare

[3] Our long term view allows us to assume full employment. Moreover, we focus on the efficiency double dividend (according to Goulder [18]) and not on the employment double dividend.

of an individual born at t is measured with the intertemporal separable utility function:[4]

$$U\left(c_t^{iy}, c_{t+1}^{io}\right) = u(c_t^{iy}) + \beta^i v(c_{t+1}^{io}) \tag{1}$$

with c_t^y denoting the first-period consumption of the agent born at t, c_{t+1}^o his second-period consumption.

The individual preference rate for the future is denoted by $\beta^i \in]0,1[$.[5] We assume that this rate depends on the class i, *i.e.* the wage level, of each agent, respecting the following scheme: $\beta^i \geqslant \beta^{i-1}$, $\forall i \in I$. This assumption encompasses one side of the Keynesian fundamental psychological law that establishes that the average propensity to save, i.e. the savings rate, decreases when the income increases. As emphasized by Saez [34], *"However, propensities to save vary widely across the population and empirical studies have shown that savings rates are correlated with education even controlling for income. Therefore, there is a strong presumption that higher income individuals save more not only because they have more income to save but also because they might have a better financial education and be more aware of the need to save for retirement."* For example, Lawrance [22] showed that subjective rates of time preference, identified from estimation of consumption Euler equations, are three to five percentage points higher for households with low permanent incomes than for those with high permanent incomes.

The two instantaneous components of the utility function exhibit the usual properties: they are increasing in their argument, strictly concave and satisfy the Inada conditions. We also impose homotheticity. The real interest rate is r_{t+1}. The household's budget constraints write:

$$\begin{cases} \left(1-\tau_t^i\right) w_t^i = c_t^{iy} + s_t^i \\ c_{t+1}^{io} = \left(1+r_{t+1}\right) s_t^i = R_{t+1} s_t^i \end{cases} \tag{2}$$

The household's problem is to maximize his lifetime utility (1) with respect to his intertemporal budget constraint given by (2). The First Order Conditions give

$$\frac{v'(c_{t+1}^{io})}{u'(c_t^{iy})} = R_{t+1}\beta^i \tag{3}$$

[4] We do not introduce any direct effect of pollution on the household's welfare, but only the indirect one through the consequences on productivity of the degradation of environmental quality (see below). Indeed the direct effect would have no impact on the welfare distribution among heterogenous agents while the indirect one affects the wage gaps, because agents do not differ here by their preferences regarding the environmental quality.

[5] The assumption of intertemporal separability is not necessary and we could obtain the same results with a very general utility function such that $\beta^i = \frac{\partial U(.)/\partial c_{t+1}^{io}}{\partial U(.)/\partial c_t^{iy}}$.

This yields the optimal consumption and savings path of the representative household, within the Diamond framework (Diamond [14]) with a homothetic utility function:

$$\begin{cases} c_t^{iy} = c^y(R_{t+1}, w_t^i, \tau_t^i, \beta^i) \\ c_{t+1}^{io} = c^o(R_{t+1}, w_t^i, \tau_t^i, \beta^i) \\ s_t^i = s^i(R_{t+1}, w_t^i, \tau_t^i, \beta^i) \end{cases} \tag{4}$$

Usual results of comparative static for w_t^i, τ_t^i and β^i hold. We also assume that the degree of intertemporal substitution between consumption when young and consumption when old (σ) should not be too small, so that the substitution effect will not be dominated too much by the income effect due to changes in the rate of return R_{t+1} (de la Croix and Michel [13]).

The production sector consists of many firms, each of them being characterized by the same production function $F(\cdot)$ with constant returns to scale. They use different kinds of labor (high wages - skilled workers, middle wages, low wages - non skilled workers). Our model shares the mean features of Chiroleu-Assouline and Fodha [9] and [10]. As in Chao and Peck [8] or Williams [38] or [39], we assume that the degradation of environmental quality has a negative impact on the total productivity of factors. This assumption is justified by the results of an increasing number of empirical studies measuring the health effects of pollution (OECD [26]) and the impact of the health of workers on labor productivity (Bloom et al. [3], in a sample consisting of both developing and industrial countries, found that good health, proxied by life expectancy, has a sizable, positive effect on economic growth). Since Ostro [27], many papers have emphasized the loss of productivity caused by the health effects of pollution, e.g. Samakovlis et al. [35], or Pervin et al. [30] for air-pollution, and also Bosello et al. [4] or Hübler et al. [20] for the health effects of climate change. For example, according to Bosello et al. [4] strong heat stress causes a productivity loss of 3% and extreme heat a loss of 12%. Another source of productivity loss originates in the impact of pollution on the quality of natural resources (Gollop and Swinand [17] for the agricultural sector).[6] As a result, the total productivity of fac-

[6] Our model adresses the specific issue of pollutions due to industrial, highly capital-intensive sectors, that emit fine particles, NOx or SOx. These pollutants are harmful for the health of all agents, and especially of the workers employed by these sectors. This stylized model can not describe the GHG case, since the dioxyde emissions have no direct effect on the health and productivity of workers and they are due to the use of fossil energies which can be susbsituted by carbon free inputs, such as capital or knowledge.

tors $A(P_t)$ is negatively affected by pollution P_t because pollution degrades the health of workers or the quality of natural resources ($\partial A(P)/\partial P \leqslant 0$):

$$Y_t = A(P_t)\, F(K_t, \{L_{i,t}\})$$

The maximization problem of the representative firm is (taking the output price as *numeraire*):

$$\underset{K,\{L_i\}}{Max} \quad \pi_t = A(P_t)\, F(K_t, \{L_{i,t}\}) - \sum_{i=1}^{I} w_t^i L_{i,t} - (1 + r_t + \tau_t^e) K_t$$

with π_t the current net revenue and w_t^i the real wage rate of class i of workers. The depreciation rate of capital is equal to unity. We assume that pollution is due to capital stock in order to integrate in a very simple framework the fact that energy use is more likely a complement to capital than a substitute. The firm pays a tax $\tau^e \in [0, 1[$ proportional to the use of this factor. We hence suppose that there exists a constant technical relationship between capital stock employed and emission of pollutants.

Since markets are competitive, capital and labor earn their marginal products:

$$\begin{cases} A(P_t)F'_K - \tau_t^e = 1 + r_t \equiv R(K_t, \{L_{i,t}\}, A(P_t), \tau_t^e) \\ A(P_t)F'_{L^i} = w_t^i \equiv W^i(K_t, \{L_{i,t}\}, A(P_t)) \end{cases} \tag{5}$$

Let ε_L^i be the elasticity of output to labor, we have $\varepsilon_L^i = F'_{L^i} \frac{L_{i,t}}{F(K_t, \{L_{i,t}\})} > 0 \ \forall i, \forall t$. We can then write $w_t^i = \frac{Y_t}{L_{i,t}} \varepsilon_L^i$. Likewise, let ε_F be the elasticity of output to capital $\varepsilon_F = F'_K \frac{K_t}{F(K_t, \{L_{i,t}\})} > 0$. We obtain $R(K_t, \{L_{i,t}\}, A(P_t), \tau_t^e) = \frac{Y_t}{K_t} \varepsilon_F - \tau_t^e$.

This yields, at the equilibrium of the labor markets (i.e. $L_{i,t} = q_i, \forall i \in I, \forall t$):

$$Y_t = A(P_t)\, F(K_t)$$

The ratio of wages is (using 5), $\forall i \in I$:

$$\frac{w_t^i}{w_t^1} = \frac{F'_{L^i}}{F'_{L^1}} = \frac{\varepsilon_L^i}{\varepsilon_L^1} \frac{q^1}{q^i}$$

The different labor classes are conventionally ranked by growing skills, i.e. by growing wages:

$$w_t^i > w_t^{i-1} \Leftrightarrow \frac{\varepsilon_L^i}{q_i} > \frac{\varepsilon_L^{i-1}}{q_{i-1}}$$

We assume that government spending (G) is entirely financed by current taxes. The government's budget constraint states that its purchases must be equal to, at each period, its tax revenues generated by the pollution tax and the labor tax:

$$\sum_{i=1}^{I} q_i \tau_t^i w_t^i + \tau_t^e K_t = G_t \tag{6}$$

We define a progressivity index of the labor tax, such as:

$$\tau^i = \tau^1 + ab\,(i)$$

where τ^1 is the flat component of the tax rate and a is a positive parameter called from now on the progressivity multiplier of the labor tax. Assume $b(i+1) > b(i) \quad \forall i > 1$. We consider the general case for the characteristics of the tax progressivity. For example, the design of progressivity fits well the characteristics of the French tax system when $b(i+2) - b(i+1) < b(i+1) - b(i)$.

This yields, regarding the labor tax revenue:

$$\sum_{i=1}^{I} q_i \tau^i w^i = \sum_{i=1}^{I} \tau^i \varepsilon_L^i Y = Y \left(\tau^1 \sum_{i=1}^{I} \varepsilon_L^i + a \sum_{i=1}^{I} b(i) \varepsilon_L^i \right) \tag{7}$$

Let us define $\varepsilon_L = \sum_{i=1}^{I} \varepsilon_L^i > 0$ and B as the sum $\sum_{i=1}^{I} b\,(i)\,\varepsilon_L^i$. $B > 0$, which is constant for any given I and progressivity characteristics $\{b(i)\}_{1 \leq i \leq I}$.

Like in our companion paper[7] (Chiroleu-Assouline and Fodha [11]), we assume capital-intensive sectors to be polluting sectors. To keep things simple, as we deal only with a one sector aggregate output, we assume that capital input is the main source of pollution (even if it is only a proxy) either because capital and energy are more complement than substitutes or, in a broader view, because capital accumulation favors the production of pollution-intensive goods. For industrial pollution, this is consistent with evidence (Brown et al. [6], Gale and Mendez [16], Antweiller et al. [1]). Antweiller et al.[1] find that a 1% increase in a nation's capital-to-labor ratio, holding scale, income, and other determinants constant, leads to perhaps a one percentage point increase in pollution.

[7] In Chiroleu-Assouline and Fodha [**?**], we assume weak heterogeneity among households, who only differ via their labor skill. Moreover, the environmental tax bears on savings. The model is fully solved analytically as we have specified, in the simpliest way, preferences and technologies. In contrast, in the present article, households' heterogeneity concerns their preferences too. The environmental tax bears on the polluting capital, which is closer to a polluter-payer principle. And finally, since we do not specify any functions, the results are more general.

The dynamics of pollution is described by the following law of motion:

$$P_t = (1-h) P_{t-1} + \phi K_{t-1} \equiv P(P_{t-1}, K_{t-1}) \tag{8}$$

where h is the constant rate of natural absorption of pollution ($0 < h < 1$) and $\phi > 0$ stands for the emission rate of pollutants.

The equilibrium condition of the capital market, meaning that the capital stock in period $t+1$ is the amount saved by young individuals in period t, is obtained by substituting the zero-profit condition, the government's budget constraint (eq. 6) and the household's budget constraints (eq. 2) into the equilibrium of the output good market. It writes:

$$K_t = \sum_{i=1}^{I} q_i s_{t-1}^i$$

By substituting eq. 4 and using eq. 5, we finally obtain:

$$K_t = \sum_{i=1}^{I} q_i s^i \left(W^i \left[K_{t-1}, \{q_i\}, A(P(P_{t-2}, K_{t-2})) \right], R\left[K_t, A(P(P_{t-1}, K_{t-1})), \tau_t^e \right], \tau_{t-1}^i, \beta^i \right) \tag{9}$$

The competitive equilibrium is thus described by the set $\left\{ \left\{ \hat{c}_t^{iy}, \hat{c}_t^{io}, \hat{s}_t^i \right\}_{i=1}^{i=I}, \hat{K}_t, \hat{Y}_t, \hat{P}, \hat{G}_t, \hat{w}_t, \hat{r}_t \right\}_{t=0}^{t=+\infty}$ satisfying equations $\{(4), (5), (6), (8), (9)\}_{t=0}^{t=+\infty}$. A steady state equilibrium is an allocation where capital and pollution are stationary, *i.e.* $\hat{K}$ and $\hat{P}$ are such that (using (8) and by substitution of (4) and (5) in (9)):

$$\hat{K} = \sum_{i=1}^{I} q_i \hat{s}^i \tag{10}$$

$$\hat{P} = \frac{\phi}{h} \hat{K} \tag{11}$$

For some given initial conditions $\{K_0, K_{-1}, P_{-1}\}$ and for a given triplet of tax policy instruments, $\left\{\tau^e, \tau^1, a\right\}$, we assume that there exists a long-term locally stable steady-state defined by $\left(\hat{K}, \hat{P}\right)$ such that:

$$\begin{aligned} \hat{K} &= K\left(\tau^e, \tau^1, a, \{b(i)\}, \left\{\beta^i\right\}\right) \\ \hat{P} &= P\left(\tau^e, \tau^1, a, \{b(i)\}, \left\{\beta^i\right\}\right) \end{aligned} \tag{12}$$

Using eq. (5) and (10), one obtains the output value at the steady-state equilibrium:

$$\hat{Y} = Y\left(\tau^e, \tau^1, a, \{b(i)\}, \left\{\beta^i\right\}\right) \tag{13}$$

3 The specification of the balanced tax reform

We assume an exogenous increase of the environmental tax rate, imposed by the government in order to control pollution. The amount of government spending is assumed *ex post* invariant, and the tax policy has to maintain the amount of the tax revenues constant. This increase $d\tau^e$ of the environmental tax rate can be accompanied by a variation of the labor tax rates $d\tau^i$ by two potential means: a homogenous variation of all labor tax rates through the flat rate component ($d\tau^1$) or a variation in the progressivity of the labor tax (through a variation of the progressivity multiplier da). At the steady-state equilibrium, the government's budget constraint is (using (6) and (7)):

$$\left(\tau^1 \varepsilon_L + aB\right) \hat{Y} + \tau^e \hat{K} = \hat{G} \tag{14}$$

Let us first define the following elasticities (in absolute values) computed at the steady-state equilibrium: $\varepsilon_A = \left| \hat{K} \hat{A}'_K / \hat{A} \right| > 0$ the elasticity of the total factor productivity w.r.t. the stock of capital (through pollution); $\varepsilon_{\tau^1} = \left| \tau^1 \hat{K}'_{\tau^1} / \hat{K} \right| > 0$, $\varepsilon_{\tau^e} = \left| \tau^e \hat{K}'_{\tau^e} / \hat{K} \right| > 0$ and $\varepsilon_a = \left| a \hat{K}'_a / \hat{K} \right| > 0$ measure respectively the elasticity of the steady-state equilibrium stock of capital w.r.t. A, τ^1, τ^e and a.

The link between the variations of the pollution tax and of the characteristics of the labor tax is obtained through the differentiation of constraint (14), which is quite direct (using eq. 10 and 13).

Any balanced tax reform is then characterized by the following relationship between $d\tau^e$, $d\tau^1$ and da (with $dG = dq_i = d\alpha_i = 0$):

$$\left(\varepsilon_L \frac{\widehat{Y}}{\widehat{K}} - \frac{\varepsilon_{\tau^1}}{\tau^1} C \right) d\tau^1 + \left(B \frac{\widehat{Y}}{\widehat{K}} - \frac{\varepsilon_a}{a} C \right) da + \left(1 - \frac{\varepsilon_{\tau^e}}{\tau^e} C \right) d\tau^e = 0 \tag{15}$$

where $C = \left(1 - \frac{\varepsilon_A}{\varepsilon_F}\right) (R + \tau^e) \left(\tau^1 \varepsilon_L + aB\right) + \tau^e$, constant.

Assumption 1: *We assume that* $1 \geqslant \varepsilon_F - \varepsilon_A > 0$.

$\varepsilon_F - \varepsilon_A$ is the total measure of the sensitivity of output to capital stock through the direct effect ε_F of capital stock as an input, and the indirect effect ε_A, which corresponds to the impact of capital stock on total productivity of factor, *via* the evolution of pollution. The direct contribution of capital to output is therefore assumed to be greater than the indirect one. The reverse ($\varepsilon_F < \varepsilon_A$) would be of negligible economic interest because any rise in τ^e would result in a decrease of K allowing an increase of Y. Under Assumption 1, we can easily show that $C \geqslant \tau^e \geqslant 0$.

We will study two polar cases for balancing this environmental tax reform:

- uniform variation of all labor tax rates, with invariant progressivity ($da = 0$):

$$d\tau^1 = -\frac{1 - \dfrac{\varepsilon_{\tau^e}}{\tau^e} C}{\varepsilon_L \frac{\widehat{Y}}{\widehat{K}} - \frac{\varepsilon_{\tau^1}}{\tau^1} C} \; d\tau^e = - \; \Lambda \; d\tau^e \tag{16}$$

- variation of the progressivity, with invariant flat rate component of the tax rate ($d\tau^1 = 0$):

$$da = -\frac{1 - \dfrac{\varepsilon_{\tau^e}}{\tau^e} C}{B \frac{\widehat{Y}}{\widehat{K}} - \dfrac{\varepsilon_a}{a} C} \; d\tau^e = - \; \Omega \; d\tau^e \tag{17}$$

Proposition 1 *The sign of the balanced tax reform multipliers Λ and Ω is a priori undetermined and depends on the initial tax rates and on the values of the various elasticities.*

Proof. (i) The numerator measures the effect of the change in pollution tax rate on its revenue. There are both a *value effect* (the tax revenue increases with the tax rate, for unchanged stock of capital) and a *tax base effect* (the stock of capital decreases, and so does the output; as the tax rate increases, so the tax base erodes), which work in opposite ways. As a result, this term might be positive or negative.

(ii) The denominator measures the effect of the change in labor tax rate on its revenue. There are also both a *value effect* (the tax revenue increases with the tax rate, for unchanged wages) and a *tax base effect* (the wages decrease as the tax rate increases, thus the tax base erodes) which work in opposite ways. As a result, this term too might be positive or negative.
As the signs of the numerator and of the denominator are undetermined, the sign of the necessary change in the labor tax components is also undetermined. ■

Assumption 2: *We only consider the Laffer-efficiency case, where the sign of the balanced tax reform multipliers Λ and Ω is positive.*

Using eq. 15, Assumption 2 implies $sign \left[1 - \dfrac{\varepsilon_{\tau^e}}{\tau^e} C\right] = sign \left[\varepsilon_L \frac{\widehat{Y}}{\widehat{K}} - \frac{\varepsilon_{\tau^1}}{\tau^1} C\right] = sign \left[B \frac{\widehat{Y}}{\widehat{K}} - \dfrac{\varepsilon_a}{a} C\right]$.
The case of tax inefficiencies is of minor interest in our model since it corresponds to weak

pollution externality, inducing very low environmental tax revenue, or to a very strong sensitivity of capital stock to the environmental tax variation. Under Assumption 2, we do not consider those very specific and extreme cases. Nevertheless, considering the latter cases would not change our results, it would only put in light some particular results.

4 Welfare analysis

Like Chiroleu-Assouline and Fodha [10] and [11], we examine here the welfare effects of the tax change for a generation during its life-cycle, once the final steady-state equilibrium is reached. In this section, the welfare issue is thus a long term one.

One can measure the welfare effects of small tax changes by the marginal *excess burden*. It corresponds to the additional income that needs to be provided to the representative household to keep her utility at its initial level: this is the *compensatory income variation*, denoted dR_c. It stands for the excess welfare loss of the consumers over and above the tax revenues collected by the government and can be interpreted as the hidden costs of financing public spending: a positive value for the marginal excess burden indicates a loss in welfare after the tax reform.

Let us determine the compensatory income variation which, after the tax reform, would leave the level of life-cycle utility unchanged ($dU = 0$):

$$\frac{\partial U}{\partial c^{iy}}\ dc^{iy} + \ \frac{\partial U}{\partial c^{io}}\ dc^{io} = 0$$

We use the first-order condition of the representative household's program, which gives, using 2 and 3:

$$\iff R\ dc^{iy} + \ dc^{io} = 0$$

The intertemporal budget constraint of household i writes:

$$\left(1 - \tau^i\right) w^i = c^{iy} + \frac{1}{R} c^{io}$$

Applying the definition of the compensatory income variation dR_c^i:

$$\left(1 - \tau^i\right) dw^i - w^i \left(d\tau^1 + b(i)da\right) + dR_c^i = -\frac{1}{R^2} c^{io}\ dR$$

this leads to:

$$dR_c^i = -\left(1 - \tau^i\right) dw^i + w^i \left(d\tau^1 + b(i)da\right) - \frac{1}{R^2} c^{io}\ dR \tag{18}$$

Unlike Bovenberg and de Moiij [5] and the greatest part of the literature on this subject, it is here impossible to distinguish an environmental component and a non-environmental one, because pollution and production affect each other. In this paper, we are thus constrained to depart from the usual definition of the double dividend (Goulder [18]) because of this non-separability: a double dividend will be characterized by the simultaneous decrease of pollution (which stands for the usual first dividend) and increase of economic welfare (which depends here also on the pollution level).

The increase of welfare is verified for any variations of consumptions such that $\partial U/\partial c^{iy}\, dc^{iy} + \partial U/\partial c^{io}\, dc^{io} > 0$. This property plays an important role in our results. The first dividend requires a decrease of the capital stock inducing a decrease of the output, but this does not prevent the obtaining of the economic dividend. This originates from the opposite impacts of K on W and R: $dW/dK > 0$ and $dR/dK < 0$. Such a decrease in the capital stock has a negative impact on both consumptions through the wage rate effect but it can be compensated by the positive influence on consumption when old through the interest rate effect.

We now compute these two impacts of the capital stock on the input prices. Concerning the wage rate, we have (from 5):

$$d\hat{w}^i = -\left(\varepsilon_F - \varepsilon_A\right)\hat{w}^i \left[\frac{\varepsilon_{\tau^1}}{\tau^1} d\tau^1 + \frac{\varepsilon_{\tau^e}}{\tau^e} d\tau^e + \frac{\varepsilon_a}{a} da\right] < 0$$

The impact of any tax increase on wage is unambiguously negative. This effect harms all households welfare through two channels. It first decreases the wage rate, which is a base effect that increases the compensatory income variation. Secondly, this policy also reduces the net income as the tax rate increases, the latter plays as a rate effect that also increases the compensatory income variation.

We now turn to the impact of the policy on the interest rate.

$$d\hat{R} = \left[\hat{R} + \tau^e\right]\left[1 - \left(\varepsilon_F - \varepsilon_A\right)\right]\left(\varepsilon_{\tau^1}\frac{d\tau^1}{\tau^1} + \varepsilon_{\tau^e}\frac{d\tau^e}{\tau^e} + \varepsilon_a \frac{da}{a}\right) - d\tau^e \gtreqless 0$$

The final effect on the interest rate is *a priori* undetermined. Indeed, any tax rate increase lowers the equilibrium level of the capital stock. This drop induces a higher marginal productivity of capital that increases the interest rate. But, the drop in capital stock reduces pollution stock as well, and therefore rises global productivity of factors which in turn pulls the interest rate down.

We finally obtain:

$$dR_c^i = Z^i \left(\varepsilon_{\tau^1} \frac{d\tau^1}{\tau^1} + \varepsilon_{\tau^e} \frac{d\tau^e}{\tau^e} + \varepsilon_a \frac{da}{a} \right) + \hat{w}^i \left(d\tau^1 + b(i) \cdot da \right) + \frac{\hat{s}^i}{\hat{R}} d\tau^e$$

with $Z^i = \left(1 - \tau^i\right) \hat{w}^i \left(\varepsilon_F - \varepsilon_A\right) - \left(\hat{R} + \tau^e\right) \left(1 - \left[\varepsilon_F - \varepsilon_A\right]\right) \frac{\hat{s}^i}{\hat{R}}$. Although the compensatory income variation dR_c^i measures the monetary effect of the gross welfare variation, we also need to compute this variation relatively to the initial wage rate in order to assess the regressivity properties of the tax reform.

Definition 1 A tax is welfare regressive if and only if an increase of its rate implies a relative compensatory income variation $dR_c^i/\hat{w}^i$ decreasing with i.

Obviously, the ratio $\hat{s}^i/\hat{w}^i$ is positively and directly determined[8] by the value of β^i which is increasing with i.

Proposition 2 *Any non-compensated increase of the environmental tax is harmful for household i:*

(i) $\forall \frac{\hat{s}^i}{\hat{w}^i}$ *when* $1 - \left[\hat{R} + \tau^e\right] \left[1 - \left(\varepsilon_F - \varepsilon_A\right)\right] \geq 0$*;*

(ii) for $\frac{\hat{s}^i}{\hat{w}^i} \leq \left| \frac{\hat{R}\left(1-\tau^i\right)\left(\varepsilon_F - \varepsilon_A\right)}{1-\left[\hat{R}+\tau^e\right]\left[1-\left(\varepsilon_F-\varepsilon_A\right)\right]} \right|$ *when* $1 - \left[\hat{R} + \tau^e\right] \left[1 - \left(\varepsilon_F - \varepsilon_A\right)\right] < 0$.

Corollary 3 *When* $1-\left[\hat{R} + \tau^e\right] \left[1 - \left(\varepsilon_F - \varepsilon_A\right)\right] < 0$, *household i such that* $\frac{\hat{s}^i}{\hat{w}^i} > \left| \frac{\hat{R}\left(1-\tau^i\right)\left(\varepsilon_F - \varepsilon_A\right)}{1-\left[\hat{R}+\tau^e\right]\left[1-\left(\varepsilon_F-\varepsilon_A\right)\right]} \right|$ *benefits from the environmental tax.*

Proof. Let us compute this effect for agent i:

$$\begin{aligned} \frac{dR_c^i}{\hat{w}^i d\tau^e} &= \frac{Z^i}{\hat{w}^i} + \frac{1}{\hat{w}^i} \frac{\hat{s}^i}{\hat{R}} \\ &= \left(1 - \tau^i\right) \left(\varepsilon_F - \varepsilon_A\right) + \frac{1}{\hat{R}} \frac{\hat{s}^i}{\hat{w}^i} \left(1 - \left[\hat{R} + \tau^e\right] \left[1 - \left(\varepsilon_F - \varepsilon_A\right)\right]\right) \end{aligned}$$

Regarding the harmfulness properties of the environmental tax, we need to have $dR_c^i \geq 0$. ■

[8]For several specifications of the preferences of the households, $\frac{\hat{s}^i}{\left(1-\tau^i\right)\hat{w}^i}$ is equal to β^i. More generally, $\frac{\hat{s}^i}{\hat{w}^i}$ is positively correlated to β^i. Notice that $\frac{1}{\left(1-\tau^i\right)}$ is also increasing with i. As we have $\hat{w}^{i+1} \geqslant \hat{w}^i$ and $\beta^{i+1} \geqslant \beta^i$, we then have $\frac{\hat{s}^{i+1}}{\left(1-\tau^{i+1}\right)\hat{w}^{i+1}} \geqslant \frac{\hat{s}^i}{\left(1-\tau^i\right)\hat{w}^i}$ and $\frac{\hat{s}^{i+1}}{\hat{w}^{i+1}} \geqslant \frac{\hat{s}^i}{\hat{w}^i}$.

The conditions defined in Proposition 2 ensure harmfulness despite a specific effect due to life-cycle assumption. As the propensity to save of the richest households is higher, their consumption when old is also relatively higher. Indeed the increase of the environmental tax lowers the capital stock increasing hence the rate of return of savings. The benefit of this effect is greater when the share of savings is high. Therefore, the environmental tax is harmful if the savings rate is lower than the threshold defined by $\left|\frac{\hat{R}\left(1-\tau^i\right)(\varepsilon_F-\varepsilon_A)}{1-\left[\hat{R}+\tau^e\right][1-(\varepsilon_F-\varepsilon_A)]}\right|$.

Corollary 4 *If the environmental tax is harmful, it is also welfare regressive when*

(i) $1-\left[\hat{R}+\tau^e\right][1-(\varepsilon_F-\varepsilon_A)] \geq 0$ *if and only if* $\frac{\Delta\left(\frac{\hat{s}^i}{\hat{w}^i}\right)}{\Delta\tau^i} \leq \frac{\hat{R}(\varepsilon_F-\varepsilon_A)}{1-\left[\hat{R}+\tau^e\right][1-(\varepsilon_F-\varepsilon_A)]}$*;*

(ii) $1-\left[\hat{R}+\tau^e\right][1-(\varepsilon_F-\varepsilon_A)] < 0$.

Proof. The environmental tax is welfare regressive if and only if the poorest households bear the heaviest burden of the increase of the environmental tax, i.e. $\Delta\left(dR_c^i\right) = dR_c^{i+1} - dR_c^i \leq 0$ i.e. $-\Delta\tau^i\left(\varepsilon_F-\varepsilon_A\right) + \Delta\left(\frac{\hat{s}^i}{\hat{w}^i}\right)\frac{1-\left[\hat{R}+\tau^e\right][1-(\varepsilon_F-\varepsilon_A)]}{\hat{R}} \leq 0$
As β^i and τ^i increase with i, according to Assumption 1, the sign of $\Delta\left(dR_c^i\right)$ depends on the sign of $1-\left[\hat{R}+\tau^e\right][1-(\varepsilon_F-\varepsilon_A)]$. ■

Combining the sufficient conditions for harmfulness and welfare regressivity, we obtain that there exists a threshold for the savings rate and the initial environmental tax rate given by

$$\left(\varepsilon_F-\varepsilon_A\right)\hat{R} \geqslant \frac{\varepsilon_F-\varepsilon_A}{1-(\varepsilon_F-\varepsilon_A)}\frac{\hat{R}}{\hat{R}+\tau^e} \geqslant \frac{1}{(1-\tau^i)}\frac{\hat{s}^i}{\hat{w}^i}$$

Under this sufficient condition, any increase of the environmental tax rate is harmful and regressive.

Proposition 5 *(i) The increase of the wage flat tax is harmful if and only if* $\frac{\hat{s}^i}{\hat{w}^i} \leq \frac{\hat{R}\left[1+\left(1-\tau^i\right)(\varepsilon_F-\varepsilon_A)\right]}{\left[\hat{R}+\tau^e\right][1-(\varepsilon_F-\varepsilon_A)]}$*. (ii) It is welfare regressive i.e. it more heavily penalizes the lowest wage-earners.*

Proof. Let us compute this effect for agent i:

$$\frac{dR_c^i}{\hat{w}^i d\tau^1} = \frac{Z^i}{\hat{w}^i} + 1 = \left(1-\tau^i\right)\left(\varepsilon_F-\varepsilon_A\right) - \left(\hat{R}+\tau^e\right)\left(1-[\varepsilon_F-\varepsilon_A]\right)\frac{\hat{s}^i}{\hat{w}^i\hat{R}} + 1$$

The condition $dR_c^i \geq 0$ gives the threshold for harmfulness and, as τ^i and $\frac{\hat{s}^i}{\hat{w}^i}$ are both increasing with i, this tax is always welfare regressive. ■

Proposition 6 *The effect of an increase of the progressivity multiplier of the wage tax on welfare of agents i is harmful if and only if* $\dfrac{\hat{s}^i}{\hat{w}^i} \leq \frac{\hat{R}\left[b(i)/\frac{\varepsilon_a}{a}+\left(1-\tau^i\right)(\varepsilon_F-\varepsilon_A)\right]}{\left[\hat{R}+\tau^e\right][1-(\varepsilon_F-\varepsilon_A)]}$.

Proof. Let us compute this effect for agent i:

$$\frac{dR_c^i}{\hat{w}^i da} = \frac{Z^i}{\hat{w}^i}\frac{\varepsilon_a}{a} + b(i) = \left[\left(1-\tau^i\right)(\varepsilon_F - \varepsilon_A) - \left(\hat{R}+\tau^e\right)(1-[\varepsilon_F-\varepsilon_A])\frac{\hat{s}^i}{\hat{w}^i\hat{R}}\right]\frac{\varepsilon_a}{a} + b(i)$$

The condition $dR_c^i \geq 0$ gives the threshold for harmfulness. ■

Obviously, the total effect of such an increase in the progressivity multiplier a can be either progressive or regressive, depending on the relative strengths of the regressivity of $Z^i/\hat{w}^i$ and the progressivity characteristics of $b(i)$.

5 The environmental effects of the tax reform

As steady-state pollution depends only on steady-state capital, we find straightforward that the first dividend (*i.e.* a decrease of pollution) is reached if $d\hat{P} = \dfrac{\phi}{h}d\hat{K} < 0$. This condition rewrites (see equation 12):

$$\begin{aligned} d\hat{K} &= -\left[\varepsilon_{\tau^1}\frac{\hat{K}}{\tau^1}d\tau^1 + \varepsilon_{\tau^e}\frac{\hat{K}}{\tau^e}d\tau^e + \varepsilon_a\frac{\hat{K}}{a}da\right] < 0 \\ &\Leftrightarrow \frac{\varepsilon_{\tau^1}}{\tau^1}\Lambda + \frac{\varepsilon_a}{a}\Omega < \frac{\varepsilon_{\tau^e}}{\tau^e} \end{aligned}$$

$$\Leftrightarrow \left(1-\frac{\varepsilon_{\tau^e}}{\tau^e}C\right)\left[\frac{\frac{\varepsilon_{\tau^1}}{\tau^1}}{\varepsilon_L\frac{\hat{Y}}{\hat{K}} - \frac{\varepsilon_{\tau^1}}{\tau^1}C} + \frac{\frac{\varepsilon_a}{a}}{B\frac{\hat{Y}}{\hat{K}} - \frac{\varepsilon_a}{a}C}\right] < \frac{\varepsilon_{\tau^e}}{\tau^e}$$

The Laffer-efficiency assumption does not guarantee that the environmental dividend occurs. It would need a low positive impact on capital, because of the decrease of the wage tax, compared to the negative impact of the environmental tax.

Proposition 7 *The environmental tax reform ensures the environmental dividend if and only if*

(i) $\Lambda < \dfrac{\varepsilon_{\tau^e}}{\tau^e}/\dfrac{\varepsilon_{\tau^1}}{\tau^1}$ *when the revenues are recycled only through a decrease of the wage flat tax;*

(ii) $\Omega < \frac{\varepsilon_{\tau^e}}{\tau^e} / \frac{\varepsilon_a}{a}$ *when the revenues are recycled only through a decrease of the progressivity multiplier of the wage tax*

(iii) $\frac{\varepsilon_{\tau^1}}{\tau^1}\Lambda + \frac{\varepsilon_a}{a}\Omega < \frac{\varepsilon_{\tau^e}}{\tau^e}$ *when the revenues are recycled through a decrease of both the wage flat tax and the progressivity multiplier of the wage tax.*

With respect to the environmental objective of the policy, the tax reform should not involve a too strong decrease of the labor tax rate in order to limit the economic boost.

6 The welfare effects of the tax reform under regressivity conditions

Since we intend to focus on the worst case, we assume that the environmental dividend id obtained (i.e. conditions *(i)* to *(iii)* of Proposition (7) are verified) and that the environmental tax is both harmful for all households and regressive.[9] As each policy does not affect all classes equally, one can wonder which one would be preferred by each class of worker.

Proposition 8 *When the impact on the steady-state capital stock of a balancing variation of* τ^1 *is greater than the impact of a balancing variation of* a, (i) *the revenue recycling of the environmental tax reform preferred by the workers of the lowest classes consists of a decrease in the flat rate component of the tax rate* τ^1 (ii) *but the one preferred by the workers of the highest classes consists of a decrease in the progressivity of the wage tax rate.*

Proof. Let us compare the compensatory income variations associated with each policy.

- First case ($dR^i_{(\tau^1)}$): uniform variation of all labor tax rates (with invariant progressivity): $da = 0$ and $d\tau^1 = -\,\Lambda\; d\tau^e$

$$\begin{aligned} \frac{dR^i_c(\tau^1)}{d\tau^e} &= -Z^i\left[\frac{\varepsilon_{\tau^1}}{\tau^1}\Lambda - \frac{\varepsilon_{\tau^e}}{\tau^e}\right] - \hat{w}^i\Lambda + \frac{\hat{s}^i}{\hat{R}} \\ \iff \quad \frac{dR^i_c(\tau^1)}{\hat{w}^i d\tau^e} &= -\underbrace{\frac{Z^i}{\hat{w}^i}}_{+}\underbrace{\left[\frac{\varepsilon_{\tau^1}}{\tau^1}\Lambda - \frac{\varepsilon_{\tau^e}}{\tau^e}\right]}_{-} - \underbrace{\Lambda}_{+} + \frac{1}{\hat{R}}\frac{\hat{s}^i}{\hat{w}^i} \end{aligned}$$

[9] This is the case when $\forall i \in [1, I]$ $(\varepsilon_F - \varepsilon_A)\,\hat{R} \geqslant \frac{\varepsilon_F - \varepsilon_A}{1-(\varepsilon_F - \varepsilon_A)}\frac{\hat{R}}{\hat{R}+\tau^e} \geqslant \frac{1}{\left(1-\tau^i\right)}\frac{\hat{s}^i}{\hat{w}^i}$ $\left(\approx \beta^i\right)$, i.e. when the preference rate for the future (or the propensity to save) is not too high. Hence, a sufficient condition is $\frac{\varepsilon_F - \varepsilon_A}{1-(\varepsilon_F - \varepsilon_A)}\frac{\hat{R}}{\hat{R}+\tau^e} \geqslant \frac{1}{\left(1-\tau^i\right)}\frac{\hat{s}^I}{\hat{w}^I}$.

The sign of this compensatory income variation is not the same whatever the class of households. By substituting the value of Z^i into the latter condition, we show that this recycling option induces a relatively higher welfare loss for the richest households than for the poorest ones:

$$\frac{dR_c^i(\tau^1)}{\hat{w}^i d\tau^e} > 0 \Longleftrightarrow \frac{\hat{s}^i}{\hat{w}^i} \leq \frac{\hat{R}\left[\Lambda + \left(1-\tau^i\right)\left(\varepsilon_F - \varepsilon_A\right)\left(\frac{\varepsilon_{\tau^1}}{\tau^1}\Lambda - \frac{\varepsilon_{\tau^e}}{\tau^e}\right)\right]}{1 + \left[\hat{R} + \tau^e\right]\left[1 - \left(\varepsilon_F - \varepsilon_A\right)\right]\left(\frac{\varepsilon_{\tau^1}}{\tau^1}\Lambda - \frac{\varepsilon_{\tau^e}}{\tau^e}\right)}$$

- Second case ($dR^i_{(a)}$): variation of the progressivity (with invariant flat rate component): $d\tau^1 = 0$, $da_i = b\,(i)\,da$ and $da = -\ \Omega\ d\tau^e$

$$\begin{aligned} \frac{dR_c^i(a)}{d\tau^e} &= -\underbrace{Z^i}_{+}\underbrace{\left[\frac{\varepsilon_a}{a}\Omega - \frac{\varepsilon_{\tau^e}}{\tau^e}\right]}_{-} - \underbrace{\hat{w}^i b(i)\Omega}_{+} + \frac{\hat{s}^i}{\hat{R}} \\ \Longleftrightarrow \quad \frac{dR_c^i(a)}{\hat{w}^i d\tau^e} &= -\underbrace{\frac{Z^i}{\hat{w}^i}}_{+}\underbrace{\left[\frac{\varepsilon_a}{a}\Omega - \frac{\varepsilon_{\tau^e}}{\tau^e}\right]}_{-} - \underbrace{b(i)\Omega}_{+} + \frac{1}{\hat{R}}\frac{\hat{s}^i}{\hat{w}^i} \end{aligned}$$

A similar reasoning applies here: since $Z^i/\hat{w}^i$ decreases with i, conversely $\frac{\hat{s}^i}{\hat{w}^i}$ and $b(i)$ increase when i increases unlike Ω that is constant, this recycling option induces a relatively higher welfare loss (that may turn into a welfare gain) for the poorest households than for the richest ones. ■

The signs of these compensatory income variations depend on the values of the characteristics of the economy $(b(i), \varepsilon_F, \varepsilon_A, \varepsilon_a, \varepsilon_{\tau^e})$ and of the initial tax rates (τ^e, τ^i, a). The result above suggests that, in the case where some workers' classes would be suffering from a deterioration of their welfare after the above tax reforms, an appropriate policy mix could be designed in order to leave each workers' class unharmed by the environmental tax reform : it would consist in an increase of the progressivity index together with a decrease of the flat rate component of the wage tax rate.

Assume that the balanced tax reform is defined by $d\tau^1 < 0$ and $da = -\mu d\tau^1$ with $\mu > 0$ hence $da > 0$. Such a compensation for the increase in the environmental tax rate will imply a greater decrease of τ^1 than above because the degree of progressivity is raised.

Proposition 9 *For economies where a decrease in the minimal wage rate does not suffice to re-establish the welfare of some class of worker, one can choose* $\bar{\mu}$ *in order to ensure that all classes will be better off with the environmental tax reform.*

Proof. Let us specify the link implied by such a policy between the increase in the environmental tax rate and the decrease in the flat component of the wage tax.

$$d\tau_e = -\frac{1}{\Lambda}d\tau^1 - \frac{1}{\Omega}da = -\frac{1}{\Omega}\left(\frac{\Omega}{\Lambda} - \mu\right)d\tau^1$$

The compensatory income variation of the balanced mix policy is:

$$dR^i_{(\mu)} = -\left[\left(Z^i\frac{\varepsilon_{\tau^1}}{\tau^1} + \hat{w}^i\right) - \left(Z^i\frac{\varepsilon_a}{a} + \hat{w}^i b(i)\right)\mu\right]\frac{\Lambda}{\left(\frac{\Lambda}{\Omega} - \mu\right)} + \left(Z^i\frac{\varepsilon_{\tau^e}}{\tau^e} + \frac{\hat{s}^i}{\hat{R}}\right)$$

- $dR^i_{(\mu)} \lesseqqgtr 0$, $\forall i = 1, ...I$.

- $dR^i_{(\mu)}$ is not monotonous in $b(i)$, nor in μ, $\forall i$.

- If $dR^i_{(\tau^1)} < 0$, $\forall i = 1, ...I$, all classes will be better off even with $\mu = 0$.

If $\exists i, dR^i_{(\tau^1)} > 0$, as the function $dR^i_{(\mu)}$ is bound for each μ, there is one $\bar{\imath}$ which maximizes it:

$$\bar{\imath} = \text{INT}\left[\arg\max dR^i_{(\mu)}\right]$$

One can choose $\bar{\mu} > 0$ in order to nullify $dR^{\bar{\imath}}_{(\mu)}$: it ensures that all classes will be better off (their compensatory income variations are all negative or null).

$$\bar{\mu} = \frac{Z^{\bar{\imath}}\frac{\varepsilon_{\tau^1}}{\tau^1} + \hat{w}^{\bar{\imath}} - \frac{1}{\Omega}\left(Z^{\bar{\imath}}\frac{\varepsilon_{\tau^e}}{\tau^e} + \frac{\hat{s}^i}{\hat{R}}\right)}{Z^{\bar{\imath}}\frac{\varepsilon_a}{a} + \hat{w}^{\bar{\imath}}b(\bar{\imath}) - \frac{1}{\Lambda}\left(Z^{\bar{\imath}}\frac{\varepsilon_{\tau^e}}{\tau^e} + \frac{\hat{s}^i}{\hat{R}}\right)}$$

■

This policy mix aims to reduce the pre-existing distortions of the tax system, in a second-best world, but not to reach an optimal outcome. Therefore $\bar{\mu}$ comes from our Pareto-improving criterion but not from any optimality criterion. Figure 1 shows the qualitative impact of such a policy mix on the design of the wage tax.

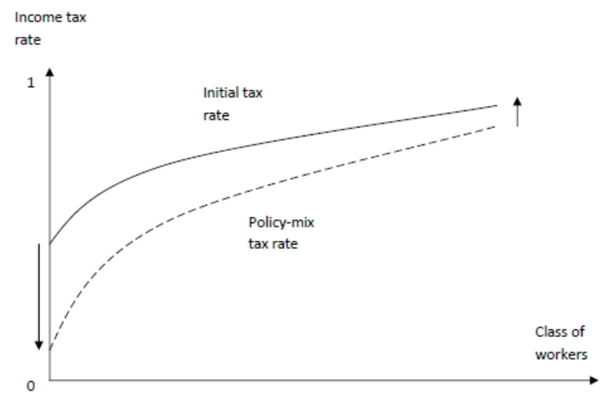

Fig. 1: Profile of the wage tax rates after the tax reform

The government can thus combine variations of the two parts of the wage tax rate and design a policy-mix system: by increasing the tax burden for the upper brackets, it is possible to earn greater tax revenues than through the environmental tax alone, and then to decrease more the income tax of the first rate bracket. Therefore, all classes are less taxed but even the poorest class would benefit from the environmental tax reform. The increase in the welfare of the upper classes will be reduced, but is still high, comparatively to the lower classes.

7 Conclusion

In this paper, we have shown in a very general framework, that a budget-neutral environmental tax reform may result in a double dividend, even when the economy is characterized by heterogenous agents (old and young) and many worker classes (heterogenous labor).

We have analyzed the distributional effects of several tax policies between different categories of households and put forward an appropriate policy mix to compensate them, in order to ensure a non-decreasing welfare for each class of workers.

We have also emphasized that the conditions for the obtaining of a double dividend depend on the distributive properties of the labor taxes. Hence, we have shown that *(i)* an increase of the environmental tax deteriorates the welfare of all and is regressive, *(ii)* the low paid workers prefer an environmental tax reform balanced by a decrease in the flat rate component but the high paid workers prefer a decrease of the progressivity.

We have demonstrated that whatever the degree of regressivity of the environmental tax alone, it is possible to re-design a recycling mechanism to obtain a Pareto-improving tax reform, by modifying the progressivity characteristics of the tax system, instead of lump-sum transfers or any other way of homogeneous compensation. The mechanisms underlying this result can be summarized as follows. The primary consequence of the environmental policy is the decrease of the pollution allowed by the decrease of the capital stock which also implies a reduction of the output. The cost of this environmental benefit consists in a fall in the gross wages of all agents. Nevertheless, for some groups of agents, this decline of the gross wages may be slowed by a decrease of their labor tax rate. The harmful effect of the fall in net wages on the total life-cycle consumption can be somehow counterbalanced by the drop in the capital stock, implying a rise of the interest rate which benefits the second-period consumption.

The heterogeneity characteristics of the economy and the progressivity of the labor tax allow the government to obtain more revenues from the environmental policy. The decrease of the flat rate component can be greater without compromising the environmental benefit. Moreover, it enables the redistribution of welfare between the agents in order to fulfill our Pareto-improvement criterion.

Observe that even if the productivity is insensitive to pollution ($A'_P = 0$) and/or if the pollution would affect the household's welfare in an additive way, our results would still be robust and contribute to the standard literature.

One of the reasons for the failure of the French carbon tax (so-called Carbon Contribution) in 2010 was that the intended revenue-recycling process was hardly understood by the tax-payers and that it did not manage to make the reform acceptable. But in fact, a careful design of a broader tax reform should have reached this goal by alleviating the effect of the carbon tax on the poorest agents and increasing the fairness of such a policy. This kind of revenue recycling should be considered by policy-makers as it allows to eliminate all obstacles to the acceptation of the environmental tax reform.

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