Environmental Tax Reform and Heterogenous Labor Markets: Can the Trade-Off between Environmental Quality, Efficiency and Income Distribution been Avoided?

Diane AUBERT*and Mireille CHIROLEU-ASSOULINE†

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Abstract

This paper investigates the distributional and efficiency consequences of an environmental tax reform, when the revenue of the green tax is recycled by a variation of labor tax rates. We build a general equilibrium model with heterogeneous imperfect labor markets, pollution consumption externalities, and where poor households spend relatively more on polluting goods than rich households (Stone-Geary preferences). We characterize the necessary conditions for the obtainment of the environmental and welfare dividends and we analyze the distributional properties of the green tax. We show that even in the case where the reform appears to be regressive, the gains from the double dividend can be made Pareto improving by using a redistributive non-linear income tax if redistribution is initially not too large. Moreover, the use of a non-linear income tax acts on unemployment and can moderate the trade-off between equity and efficiency.

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*Université Paris 1 - Panthéon Sorbonne

†Paris School of Economics, Université Paris 1 - Panthéon Sorbonne and INRA

1 Introduction

Despite the failures of the international negotiations aiming at defining an international successor agreement to the Kyoto protocol, there is a growing awareness of the need to reduce the emissions of greenhouse gas in order to limit the ongoing climate change. Among the different policy instruments at display, the market-based instruments are promoted by the economists as the most efficient in many cases to achieve a given environmental objectives. While cap-and-trade has been preferred by the EU to regulate the industrial emissions, the debate about the use of environmental taxes, and specifically carbon taxes, is still vivid around the world. In the United States, they are advocated to address climate change, for example by some grassroots advocacy organizations like the Citizens' Climate Lobby, who proposes a carbon tax mechanism named Carbon Fee and Dividend. In France, a new carbon tax was introduced in 2014 with a very low initial tax rate that is announced to be due to increase. Economists argue that environmental taxes are an efficient tool to achieve environmental quality objective, especially when emissions due to consumption, transport and heating are at stake. But the opponents underline their macroeconomic gross cost measured as the welfare loss due to lower growth, consumption and employment. Moreover green taxes are usually said to be strongly regressive and governments are most often reluctant to implement significant green tax shifts for fear of strong opposition from public opinion.

Indeed, as any indirect taxation, a green tax causes a loss of purchasing power for the consumers, which is somehow alleviated by the substitution effect that leads them to alter their consumption basket. This substitution effect is greater as the price elasticity of the demand of the polluting good is higher. As a consequence, the more efficient the green tax is for the environmental quality and the less the purchasing power is lowered *ex post*. Nevertheless, the combined effect on growth and employment is unambiguously negative when the green tax is implemented without any recycling of its tax revenues.

However, Terkla [1984], Poterba [1993] and Parry [1995] showed that redistributing the revenues raised by the green taxes enables to reduce their global macroeconomic cost by lowering the consumers' purchasing power loss and/or the firms' production costs. The distribution channel depends on the targeted objective.

As in Sweden in the nineties, a green tax shift can be implemented, as a budget-neutral environmental tax reform. According Baumol and Oates [1988], Pearce [1991] or Poterba [1993], such a reform aims at increasing the economic efficiency by reducing the distortions caused by some taxes. Pearce [1991] was thus the first one to suggest that recycling the green tax revenues by reducing the rates of other distortionary taxes could yield a double dividend, composed of a first, environmental, dividend due to the improvement of the environmental quality, and of a second, economic, dividend, due to a welfare increase (Goulder [1995]). This welfare dividend may correspond to a growth increase, to an improvement of the purchasing power, to a decrease of unemployment, etc (Ekins [1997]). Parry [1995] establishes the general condition, which guarantees the existencesome numerical illustrations of our results for the French case of the second dividend: the *revenue-recycling effect* that reduces the existing tax distortions has to be greater that the *tax-interaction effect*, which increases the welfare gross cost of the green tax, through the mutual tax base erosion. But there is usually a trade-off between the first and the second dividend because the increase of output yields an increase in energy consumption, that conteracts the substitution effect induced by the green tax. Since Bovenberg and De Mooij [1994], a huge theoretical and empirical literature has already emphasized the conditions favorable for the double dividend: when there are several productive factors and/or several consumer groups, the double dividend can be obtained (Bovenberg and van der Ploeg [1996], Proost and van Regemorter [1995]). In particular, Goulder [1995] has shown that the existence of the double dividend essentially depends on the possibility of transferring the overall tax burden from the wage earners to some fixed production factors or to other consumers, thus emphasizing the role of heterogeneity. Heterogeneity of agents is above all a necessary (but not sufficient) condition for the obtainment of a double dividend, which highlights the existence of a trade-off between economic efficiency and equity.

Moreover the environmental taxes by themselves are usually considered as regressive taxes since they hurt relatively harder the poorest households, who are constrained to devote a larger part of their income to the consumption of polluting goods, which are often necessary goods, like energy products used for transportation or heating (Poterba [1991] ; Metcalf [1999] ; Wier et al. [2005] ; Ruiz et Trannoy [2008]). As these expenditures are constrai(revenue effect)ned, and because poor households are not able to invest in less polluting vehicles or boilers, their substitution behavior is limited and they are unable to attenuate their loss of purchasing power. Nevertheless, the standard analysis in partial equilibrium is questioned by some recent works, that prove that the environmental taxes may be less regressive and even progressive when taking account of the whole agents' life-cycle (Sterner [2012]) or of the general equilibrium effects on the factors prices (Dissou et Siddiqui [2014]).

The essential issue faced thus by governments is that of finding a way for designing an environmental fiscal reform with a distributive objective, without loosing the efficiency advantage of environmental taxes. This paper intends to analyse this issue by investigating the distributional and efficiency consequences of an environmental tax reform, when the revenue of the green tax is recycled by a variation of labor tax rates.

This question was already addressed by Chiroleu-Assouline and Fodha [2011] and [2014], who are the first ones to take into account the intra-generational heterogeneity of agents, which previously had never been considered in depth in the double dividend literature. They use an overlapping-generations framework, that allows them to consider the inter-generational heterogeneity between workers and retired agents and they take into account different skills for workers, implying different levels for wage rates among households. Pollution is generated as a by-product of capital used in production (instead of being emitted by the consumption of a specific good or by the output, like in Bovenberg and De Mooij [1994]). They show that, even in very unfavorable circumstances, an adequately designed environmental tax reform can simultaneously lead to a decrease of pollution, an increase of the global welfare and a non-decreasing welfare for each class of households: 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. They propose to increase progressivity of the labor tax together with a decrease of the lowest rate (and a lump-sum compensation to everybody who pays no income tax). However, they note that their results stem from the assumption of inelastic labor supply and full employment.

In an optimal taxation framework, Jacobs and van der Ploeg [2010] acknowledge also the need to focus on the income distributional consequences of environmental policies. They analyze jointly the optimal carbon tax and optimal CO2 abatement and climate adaptation policies with the optimal redistributive income tax and optimal redistribution between non-overlapping generations. To account for inequalities introduced by the environmental policies, they introduce non-homothetic (Stone-Geary) preferences that is compatible with the subsistence need for poor households to consume polluting goods, like energy products. They assume labour market equilibrium, with an endogenous iso-elastic labor supply. One of their concluding remarks apparently corroborates the limit underlined by Chiroleu-Assouline and Fodha to their results: "*a more elastic labour supply makes it more costly to have a high labour income tax rate and therefore it will be more difficult to pursue intra-and inter- generational income distribution leading to a shift from the green to the inequality-corrected private part of social welfare.*" As expected, with Stone-Geary preferences, "*the optimal carbon tax is driven below the modified Pigouvian level and environmental quality is sacrificed for income redistribution".*

We intend to complement this short stream of literature to get a larger picture of the distributional and efficiency consequences of a revenue-neutral environmental tax reform (the revenue of the green tax is recycled by a variation of labor tax rates), in order to assess the usefulness of increasing the progressivity of labor taxes, in cases where the intuition raises doubts about the compatibility betweeen environmental effectiveness, economic efficiency and intra-generational equity. To do so, we focus on the policy recommended by Chiroleu-Assouline and Fodha [2014], in a static framework to which we incorporate two so-called detrimental (for equity) assumptions: firstly, heterogenous households have a subsistence level of polluting goods and an elastic labor supply (like Jacobs and van der Ploeg [2010]) and secondly, there is unemployment.

Our paper incorporates some features borrowed from the literature on labor market performance with progressivity tax, that uses either unions-bargaining models (Koskela and Schöb [2009]) or search generated unemployment (Pissarides [1998] and Lehmann et al. [2013]). As typically argued in public finance, tax progressivity may be detrimental to incentives on work-effort and lead to an inevitable trade-off between equality and efficiency. On the other side, in a framework with non competitive labor market, the literature argues that a more progressive tax schedule remains beneficial for employment (Pissarides [1998], Lehmann et al. [2013], Sørensen [1999], Strand [2002]).

Lehmann et al. [2013], in a search and matching framework, support the unemployment-reducing effect of tax progressivity with two theoretical arguments. The first effect is a *wage moderation effect*, due to the bargaining between employers and workers and the local progressivity of the tax schedule. The second mechanism is a *composition effect* that occurs if the labor demand or the extensive margin of low-skilled is more sensitive to taxation as compared to high-skilled workers. In the latter case progressive taxes contribute to more efficient allocation of the total tax burden. The empirical literature suggest that the *composition effect* is key: the extensive margin elasticity is empirically higher for low-skilled (Røed et al. [1999] and Heckman [1993]) and the idea that low-paid employment is more responsive than high-paid workers is quite common in the literature (Kramarz and Phillipon [2001], Immervoll and al [2007]).

One of our key contributions here, is to combine unemployment and thus, discrete labor supply, with intensive supply of high-skilled workers (Keuschnigg and Ribi [2008], Saez [2002]). This links our paper to the income tax literature with discrete labor supply, without neglecting the detrimental impact of progressivity to incentives on work-effort. Saez [2002] has shown that the relative strength of the intensive and extensive responses is important in the design of optimal tax transfers schedules. If the extensive margin dominates at the low end of the income distribution, it can rationalize an earned income tax credit or wage subsidy.

Moreover, the specification of our labor market gives insight of the difference between high and low-skilled wage formations, that is crucial in the distributional properties of the green tax analysis. This distinction allows us to take into account a new channel through which, under conditions on the subsistence level of dirty good, environmental taxes can be progressive. This result is similar to that of Dissou and Siddiqui [2013], who characterize the progressivity of the environmental tax through the substitution of input. Yet here the channel is different: it acts through the wage formation and the difference of sensitivity between both employments.

We build a general equilibrium model with heterogeneous imperfect labor markets, pollution consumption externalities, and where poor households spend relatively more on polluting goods than rich households (Stone-Geary preferences). We assume that the production technology is a function of heterogeneous labor. Heterogeneous households only differ via their labor skill and earn wages corresponding to their skills. We assume structural unemployment in equilibrium caused by hiring costs, and we use a search and matching model to formulate frictions on the labor market with individual worker-firm bargaining. By assumption, the risk of unemployment falls only on low-wage workers, whose labor supply is inelastic, whereas the high-skilled labor supply is endogenous. The tax system is initially composed of progressive labor tax (tax on wages). As in Bovenberg and De Mooij [1994], pollution is due to consumption of a polluting ("dirty") good. We characterize the necessary conditions for the obtainment of the environmental and welfare dividends when the revenue of the pollution tax is recycled by a change in the labor tax rates. The model is fully solved analytically as we have specified, in the simplest way, preferences and technologies. Contrary to previous studies, which argue that the double dividend hypothesis seems unrealistic, unless it is obtained through the worsening of inequalities, we confirm the results of Chiroleu-Assouline and Fodha [2011] and [2014] by showing that even in the case where the reform appears to be regressive, the gains from the double dividend can be made Pareto improving by using a redistributive non-linear income tax if redistribution is initially not too large. Moreover, the use of a non-linear income tax acts on unemployment and can moderate the trade-off between equity and efficiency. We finally provide simulations highlighting the room for manoeuvre for environmental tax reforms for the French case.

The remainder of the paper is set out as follows. In the next section we present our model. In Section 3 we establish the conditions of regressivity of an uncompensated green tax, through some comparative statics, while in Section 4 we study two types of revenue-neutral environmental tax reforms and prove that it is possible to achieve simultaneously environmental, efficiency and distributional objectives. Section 5 provides some numerical illustrations of our results for the French case and Section 6 concludes.

2 The Model

2.1 Overview

The model assumes a small open economy consisting of firms, the government, and two different types of households, which differ with respect to their labor skill. There are a mass 1 of unskilled households (indexed with $i = L$) and a mass N of high-skilled households ($i = H$). The economy contains three types of commodities: the so-called "polluting" consumption commodity (D), that harms the environment when consumed, the "clean" consumption commodity C and a fixed amount of clean public goods G. We assume their prices (before taxes) are fixed and normalized to unity because the rates of transformation is assumed to be constant.[1] Labor

[1]As noticed by Bovenberg and De Mooij [1994], an alternative explanation of the fixed producer prices is possible: some commodities (for example the clean consumption commodity and the public consumption good) can be produced domestically while other goods (the dirty goods as fossil fuels) are imported at exogenous world-market prices.

in contrast is immobile internationally. Hence, wages are the only prices determined endogenously in the economy. We assume structural unemployment in equilibrium caused by hiring costs, and we use a search and matching model to formulate frictions on the labor market with individual worker-firm bargaining. In order to make the analysis as simple as possible, we adopt a static framework. [2] The government finances public goods G, provides fixed unemployment benefit payments to unemployed workers and imposes a tax t_i on the labor income of households of type i. Moreover we assume the government fights pollution externalities by imposing a green tax t_d on the consumption of the dirty good.

2.2 Households behavior

Our households modelling is based on three main assumptions inspired by stylized facts: (i) low-skilled workers supply one unit of labor, whereas high-skilled labor supply is endogeneous (Roed et al. [1999]); (ii) the risk of unemployment falls on low-wage workers only (Keuschnigg and Ribi [2008], Koskela and Schöb [2009]); (iii) we assume a subsistence level of consumption for the dirty good (like Jacobs and Van der Ploeg [2010]). In this subsection, we describe and explain our specification choices.

Consumption preferences

Although households differ with respect to their income and leisure time (that corresponds to their skill abilities and to their labor market activity), we assume that they are all identical in their consumption commodities tastes. Agents are all risk neutral[3] and leisure is supposed to be weakly separable from consumption utility. This enables us to solve the model analytically. Moreover there is no strong empirical evidence suggesting that separability does not hold if we associated dirty consumption with energy used by households (Bovenberg and de Mooij [1994]).

Clean goods and dirty goods are assumed imperfect substitutes in a composite commodity of quantity $Q = q(C, D)$. In contrast to the literature, we do not allow $q(C, D)$ to be linearly homogeneous in C and D. In fact, usual quasi linear and homothetic preferences imply that the wage elasticity of labor supply and the elasticity of substitution between clean and dirty goods are constant and thus independent on individual skill abilities. It results in constant expenditures shares of polluting goods. Hence, in most of the models, the income tax rate does not affect the allocation between clean and dirty goods, and the green tax on the dirty good is superfluous as a distributional device (Jacobs and Van der Ploeg [2010]). However, poor people seem to devote a larger fraction of their consumption to the dirty goods than rich

[2] As Diamond [1982] showed, we can describe the essence of job search and recruiting externalities using a static model. For examples of static search and matching models, see Snower [1996], Sato [2004], Keuschnigg and Ribi [2008]

[3] This assumption places us in the worst case for the introduction of progressivity.

households (Ruiz and Trannoy [2008], Metcalf [1999]). They are therefore the ones most likely to be hurt by an increase in carbon tax. To make the trade-off between redistribution and the efficiency of green tax reforms more realistic and thus more relevant from a policy point of view, we assume Stone-Geary preferences captured by the following consumption utility function Q:

$$Q_i = q(C_i, D_i) = (C_i)^{1-\sigma}(D_i - \bar{D})^{\sigma} \tag{1}$$

where $\bar{D}$ denotes the subsistence level for the dirty good, that is the same for all households.

The Stone-Geary utility function makes it possible to model a share of consumption that is not responsive to price changes ($\bar{D}$) and another share that can adapt instantaneously to price variations ($D_i - \bar{D}$). This specification allows us to represent dirty goods as necessities (their income elasticity is less than unity). Moreover, these elasticities now depend on skills, which captures that the least able and poorest members of society are hurt most by a green tax (Deaton and Muellbauer [1980], Chung [1994], Jacobs and van der Ploeg [2010]).
As the environmental degradation acts as an externality, we assume households ignore the adverse effect of their demand for polluting goods on the quality of the environment. Consequently, households i choose C_i and D_i in order to maximize utility subject to their budget constraint: $C_i + (1 + t_d)D_i = I_i$ (with I_i denoting the income of households i). From the first-order conditions of the maximization of (1), we obtain the uncompensated demand for good D and that for good C, and the indirect utility of consumption.

$$D_i^* = \frac{\sigma}{1+t_d}\left[I_i - (1+t_d)\bar{D}\right] + \bar{D}$$

$$C_i^* = (1-\sigma)\left[I_i - (1+t_d)\bar{D}\right]$$

$$Q_i^* = \frac{\left[I_i - (1+t_d)\bar{D}\right]}{P_q}$$

where P_q represents the price index defined as $(\frac{1}{1-\sigma})\left[(1+t_D) * \frac{1-\sigma}{\sigma}\right]^{\sigma}$.

The consumer first purchases a subsistence level of the polluting good and then allocates the leftover income ($I_i - (1+t_d)\bar{D}$), in fixed proportions to each good according to their respective preference parameter (σ, $1-\sigma$). The assumption of households' risk neutrality implies that their indirect consumption utility is defined as the purchasing power of their leftover income of households.

Income and welfare

Low-skilled workers supply one unit of labor at wage $w_L\,(1-t_L)$ net of tax, if employed. If unemployed, they receive a benefit B, given by some fixed payment[4] and enjoy a utility of leisure Z. Because we consider a static framework of matching, the *ex ante* probability of being unemployment u, is equal to the *ex post* unemployment rate. Assume further that the environmental externality enters the utility function linearly, the indirect utility of the low-skilled workers can be represented by:

$$V_L = u * [Q^*(B) + Z] + (1-u) * Q^*(w_L\,(1-t_L)) - \psi\,[D_{tot}] \tag{2}$$

where $\psi\,[D_{tot}]$ denotes the disutility due to the environmental degradation, $D_{tot} = D_L + D_H$, the aggregated consumption of the polluting good.

Given an hourly wage net of tax $w_H\,(1-t_H)$, skilled workers supply variable labor H. High skilled workers' welfare V_H is a linear increasing function of income I_H minus a given convex increasing effort costs $\varphi\,(H)$ and the disutility due to the environmental degradation:

$$V_H = \left(\max_H \left[Q^*(I_H) - \varphi(H)\right]\right) - \psi\,[D_{tot}] \qquad s.t.\ I_h = w_H(1-t_H) * H \tag{3}$$

Assuming an effort costs function of the form $\frac{H^{1+\frac{1}{\eta_H}}}{1+\frac{1}{\eta_H}}$ (where η_H reflects the elasticity of labor supply to wage), we get a skilled labor supply of:

$$H^* = \left(\frac{w_H\,(1-t_H)}{P_q}\right)^{\eta_H} \tag{4}$$

2.3 Firm's behavior

Technology

The production process applies to the production of the dirty good, and of the clean goods including the public one. As all commodities goods are produced at constant and identical unit costs, we can normalize producer prices to unity. We assume a mass one of firms that produce output y with labor as the only variable input.

The total technology is homothetic: a firm acquires labor services by high-skilled workers and low-skilled workers $l = L$ and $h = NH$, to produce raw value added:

$$y = f(l,h) = l^{\alpha} h^{1-\alpha} \quad with\ 0 < \alpha < 1. \tag{5}$$

[4]Since Koskela and Schöb [1999] already emphasized the impact of indexation of unemployment benefits, we assume here that they are only exogenous.

Since f is linear homogeneous, the cost per unit of value added $C(p_L, p_H)$ depends on prices but no on scale. Profit maximization $\pi(C) = \underset{l,h}{max}\ [y - (lp_L + hp_H)]$ s.t. $y = f(l,h)$ gives $p_L l = \alpha y$ and $p_H h = (1-\alpha)y$: the Cobb-Douglas technology implies constant cost shares. Whereas for high skilled workers $p_H = w_H$, the factor price of low-skilled labor p_L includes not only the wage but also some recruitment costs due to frictions.

We use a simple static search and matching model of labor market to model unemployment among low-skilled workers. There are heterogeneities (or mismatches) in the labor market that make it costly for a low-skilled worker or a firm to find a partner with whom they can produce sufficiently high returns (Pissarides [1998]). Labor market heterogeneities are summarized in the matching function that gives the rate at which good matches are formed in the labor market. Given a mass 1 of job searchers, and the number of vacant jobs v, in its simplest form, the matching function is defined as: $M = m(v, 1)$, with positive first partial derivatives, negative second derivatives and constant returns to scale. The matching function implies that a firm looking for a low skilled worker finds one with probability less than one, equal to $\frac{M}{v}$, even if there are enough jobs to satisfy all workers. Denoting $\theta = \frac{v}{1}$, the tightness ratio of the labor market, we can rewrite this probability as: $q(\theta) = \frac{M}{v} = m(1, 1/\theta)$. It represents the Poisson matching probability of a vacant job *i-e* the rate at which vacant jobs are filled. Symmetrically, the rate at which an unemployed finds a job is given by $\theta q(\theta) = l = M$. As usual in the search and matching models, we assume that $0 < \xi = -\frac{\partial q(\theta)}{q(\theta)} * \frac{\theta}{\partial \theta} < 1$. Then, for low-skilled workers, $\theta q(\theta)$ of workers are employed and $[1 - \theta q(\theta)]$ are unemployed. Thus the classical Beveridge curve is defined as:

$$u = [1 - \theta q(\theta)] = 1 - l \tag{6}$$

Maintaining a vacancy costs c units of output. For simplicity, we assume one shot matching so that no other search opportunity is available. The firm needs h units of skilled labor and l units of unskilled labor. Anticipating the result of wage bargaining generates profits of:

$$\pi = \underset{h,v}{max}\ [y - p_H h - w_L l - cv] \qquad s.t. \qquad l = v * q((\theta));\ y = f(l,h)$$

The firm's hiring results in the following job creation and labor demand conditions:

$$(f_L - w_L) * m = c \quad \Leftrightarrow \quad f_L = p_L = w_L + \frac{c}{m} \tag{7}$$

$$f_H = p_H = w_H \tag{8}$$

The market for skilled labor is competitive. Firms hire until marginal productivity is equal to the wage. With unskilled workers, the total cost of an unskilled worker, exceeds the wage by a recruitment cost equal to the search cost time the number of vacancies needed for a successful hire. Equation (6) represents the traditional job creation condition: the marginal cost of investing in a job vacancy must correspond to the expected job rent.

Low-skilled wage determination

Once a suitably qualified worker is found, a job rent appears that has to be shared through Nash bargaining. This rent corresponds to the sum of the expected search costs for the firm and the worker. We assume a decentralized Nash bargain, which imposes a particular splitting of the matching surplus between the two parties involved according to the relative bargaining power between them. For a low-skilled worker the matching surplus is the difference between its expected utility when employed and that when unemployed: $Q^*((w_L(1-t_L)) - [Q^*(B) + Z]$. For a firm, the matching surplus is the difference between the profit when it fills a vacancy and when it remains with vacancy: $(f_L - w_L - c) - (c) = f_L - w_L$.
w_L is determined as: $w_L = argmax\left\{\left(Q^*\left(I_L^E\right) - \left[Q^*(I_L^U) + Z\right]\right)^{\beta}\left(f_L - w_L\right)^{1-\beta}\right\}$ with β the union's bargaining power.

Appendix A.I shows that the first-order condition for the maximization of the Nash product implies the following expression of the wage mark-up M:

$$M = \frac{P_q\left(Q_L^{E*} - Q_L^{U*} - Z\right)}{(1-t_L)} = \frac{\beta}{1-\beta} * \left[\frac{c}{q(\theta)}\right]$$

Remember that M is defined as the difference between the wage w and the reservation wage (denoted by w_R), for which a household is indifferent between being employed or unemployed $\left(Q^E = Q^U + Z\right)$. If hiring costs are zero ($c = 0$), in equilibrium, $M = 0$. Thus, positive hiring costs drive a wedge between the utility of unemployment and that of unemployment. A tighter labor market increases the expected value of the firm's hiring costs ($\frac{y_i c_i}{q(\theta_i)}$). This raises the rents from the job match and thus increases the wage mark-up. Another formulation of equation (4) (see in appendix) can be given as:

$$w_L = w_R + \beta(p_L - w_R) \tag{9}$$

Workers receive their reservation wage w_R and a fraction β (union' s bargaining power) of the net surplus that they create by accepting the job. In this model, $w_R = \frac{B+P_q Z}{1-t_L}$.

2.4 The government budget constraint

To finance the unemployment benefit payment and a fixed amount of some public goods G, the government levies a tax t_i on wages i and a green tax t_d on the consumption of the dirty good D. The burden of the labor income tax depends on the nominal wage rate w_i, and the rates t_i of the income tax, that is assumed to be progressive: $t_H > t_L$. Government budget constraint can then be written as:

$$G + (1 - l)\, B = l w_L t_L + N H w_H t_H + t_d D_{tot} \tag{10}$$

3 Uncompensated Green Tax: Comparative statics

We define the equilibrium of the model as a tuple (l^*, H^*, θ^*, w_L^*, w_H^*, f_l^*, y^*) that satisfies the following conditions: the job creation condition (7), the wage mark up equation (9), the Beveridge curve (6), the high skilled labor supply (4) and demand (8) equations and the production function (5). Due to the properties of the matching function, it is not possible here to solve explicitly the equilibrium of this economy in levels. We thus examine in this paper, the local behavior of a small open economy around the initial equilibrium: the model is log-linearized around the initial equilibrium.

In the following section, we analyze how wages, employment and finally welfare react to an exogenous infinitesimal increase of taxes dt_d, dt_L and dt_H. For the moment, we do not constrain the government to balance its spending with its revenues. In fact, in this section everything is considered as if the additional revenue raised by the increase of green/labor taxes were saved, or sterilized, *i-e* we do not take the government budget constraint (10) into account (partial equilibrium).

3.1 Revenue and employment effects

Table 1 contains the log-linearized model. The tilde ($\sim$) denotes percentage changes relative to initial values, i-e $\tilde{l} \equiv \frac{dl}{l}$. Exceptions to this definition are separately indicated.

Low-skilled labor	$\tilde{l} = (1-\xi) * \tilde{\theta} = \tilde{y} - \tilde{p_L}$	(6-7)
Job creation condition	$\tilde{p_L} = \frac{w_L}{p_L} * \tilde{w_L} + \frac{c}{q(\theta)} \frac{\xi}{p_L} * \widetilde{\theta}$	(7)
Wage mark-up equation	$\widetilde{w_L} w_L = \beta \tilde{p_L} p_L + [1-\beta]\, \tilde{w_R} w_R$	(9)
High-skilled labor demand	$\tilde{H} = \xi * [\tilde{p_H} - \frac{\sigma}{1+t_d} * dt_d - \frac{1}{1+t_H} * dt_H] = \tilde{y} - \tilde{p_H}$	(4-8)
Production	$\tilde{y} = \alpha \tilde{l} + (1-\alpha)\tilde{h} \quad \Leftrightarrow \quad \tilde{p_H} = -\frac{\alpha}{1-\alpha} \tilde{p_L}$	(5)

where we denote $\tilde{w_R} = \left[\frac{1}{1-t_L}\frac{dt_L}{1-t_L} + \frac{ZP_q}{w_R(1-t_L)}\frac{\sigma}{1+t_d}dt_d\right]$, the variation of the reservation wage with the tax rate variations dt_d and dt_L.

Solutions of the system are given in the following table. Notations are explained at the end of the table. Details of computation are reported in Appendix A.II.

Low-skilled labor	$\tilde{l} = -\mu_L \left[\tilde{w_R}\frac{w_R}{p_L} + \eta_H \left(\alpha\tilde{w_R}\frac{w_R}{p_L} + (1-\alpha)dR_L\right)\right]$	(I)
High-skilled labor	$\tilde{h} = \tilde{H} = -\mu_H \left[dR_L + \eta_L \left(\alpha\tilde{w_R}\frac{w_R}{p_L} + (1-\alpha)dR_L\right)\right]$	(II)
Production	$\tilde{y} = -\left[\alpha\mu_L\tilde{w_R}\frac{w_R}{p_L}(1+\eta_H) + (1-\alpha)\mu_H dR_L (1+\eta_L)\right]$	(III)
Low-skilled productivity	$\tilde{p_l} = (1-\alpha)\frac{\mu_L}{\eta_L}\left[\eta_L\tilde{w_R}\frac{w_R}{p_L} - \eta_H dR_L\right]$	(IV)
High-skilled productivity	$\tilde{p_H} = -(\alpha)\frac{\mu_H}{\eta_H}\left[\eta_L\tilde{w_R}\frac{w_R}{p_L} - \eta_H dR_L\right]$	(V)
Low-skilled wage	$\widetilde{w_L} = \frac{p_L}{w_L}\left[((1-\beta) + (1-\alpha)\beta\mu_L)\tilde{w_R}\frac{w_R}{p_L} + -\beta((1-\alpha)\mu_H) dR_L\right]$	(VI)

where $0 < \mu_H = \frac{\eta_H}{1+(1-\alpha)\eta_L+\alpha\eta_H} = \frac{\eta_H}{\eta_L}\mu_L < 1$, $\eta_L = \frac{1-\xi}{\xi}\left[\frac{p_L}{p_L - w_R}\right]$ is the elasticity of the low-skilled labor to productivity p_L, and $dR_L = \frac{\sigma}{1+t_d} * dt_d + \frac{1}{1+t_H} * dt_H$.

Proposition 1: *A higher uncompensated green tax raises unemployment and decreases production if and only if utilities depend on leisure. If it is not the case, green taxes let employment unaffected.*

This is what we can call a *price effect,* which impacts labor. Due to the increase of the environmental tax, P_q is higher. Through the utility of leisure Z, the outside option becomes more attractive for unemployed workers. The reservation wage ($w_R = \frac{B+P_qZ}{1-t_L}$) increases. Consequently, the tightness of market decreases (unions are more powerful), and labor of low-skilled decreases. In the other side, the increase of P_q decreases the real after tax wage: $\frac{w_H(1-t_H)}{P_q}$. High skilled workers supply less labor.

Proposition 2: *An uncompensated green tax has an ambiguous effect on wages, which depends on the amplitude of the elasticity of labor supply of high skilled η_H compared to the sensibility of labor demand of low-skilled*

- *If* $\eta_H < \frac{\eta_L}{1-t_L}\frac{P_q Z}{f_l}$, *a higher uncompensated green tax increases* p_L, *and decreases* w_H
- *If* $\eta_H \Gamma > \frac{\eta_L}{1-t_1}\frac{P_q Z}{f_l}$, *a higher uncompensated green tax decreases* w_L
- *If* $\eta_H \Gamma < \frac{\eta_L}{1-t_1}\frac{P_q Z}{f_l} < \eta_H$, *a higher uncompensated green tax decreases* p_L, *and increases* w_H *and* w_L.

where: $0 < \Gamma = \frac{\mu_L(1-\beta)}{\mu_L(1-\beta)+\beta(1-\alpha)} < 1$

If labor supply and outside reactions to the environmental tax were the same, productivities would have been unchanged and labor would have decreased in the same proportion for high and low skilled workers. We would have seen only a *price effect*. But there is also a substitution effect here, which impacts on labor productivities, and then on labor and wages. If labor supply of high skilled is more elastic than the sensitivity to outside option, production will become more intensive in low skilled worker, and productivities of high skilled will increase compared to low skilled.

3.2 Welfare analysis

One can measure the welfare effects of small tax changes with 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 by dR. It stands for the excess welfare loss of the consumers over and above the tax revenues collected by the government and it 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 welfare unchanged (dV_H, $dV_L = 0$).

$$dV_H = 0 \Leftrightarrow \frac{\partial V_H}{\partial C_H}dC_H + \frac{\partial V_H}{\partial D_H}dD_H + \frac{\partial V_H}{\partial H}dH + \frac{\partial V_H}{\partial D_{tot}}dD_{tot} = 0$$

Using the first order conditions of consumer's program, this leads to:

$$dV_H = 0 \Leftrightarrow \frac{dC_H}{P_q} + \frac{(1+t_d)}{P_q}dD_H + \frac{w_H(1-t_H)}{P_q}dH + \frac{\partial V_H}{\partial D_{tot}}dD_{tot} = 0$$

By differentiating the budget constraint of high skilled households and using the definition of the compensatory income variation we obtain:

$$dC_H + (1+t_d)dD_H + D_H dt_d = (1-t_H)w_H dH + H(1-t_H)dw_H - Hw_H dt_H + dR_H$$

Combining the last two equations gives us:

$$dR_H = -\left[\underbrace{I_H\left(\widetilde{w_H} + \frac{dt_H}{1-t_H}\right)}_{WE_H} - \underbrace{D_H dt_d}_{CE_H} - \underbrace{\frac{\partial V_H}{\partial D_{tot}} P_q dD_{tot}}_{dR^e}\right] \tag{11}$$

The compensatory variation is the variation of the revenue needed to overcome the variation of the after tax wage WE_H, the increase of price of the polluting good CE_H, and the deterioration of environmental quality dR^e.
Similarly, we derive in Appendix A.III the compensatory variation for the low-skilled workers:

$$dR_L = -\left[\underbrace{\underbrace{l\, I_L^E\left(\widetilde{w_L} + \frac{dt_L}{1-t_L}\right)}_{WE_L} + \underbrace{P_q\left(V_L^E - V_L^U\right) dl}_{EmpE}}_{RE_L} - \underbrace{D_L dt_d}_{CE_L} - \underbrace{\frac{\partial V_L}{\partial D_{tot}} P_q dD_{tot}}_{dR^e}\right] \tag{12}$$

where V_L^E and V_L^U represent the indirect utility of an unskilled worker when she is employed and unemployed respectively. $I_L^E = w_L\left(1-t_L\right)$, the revenue of the unskilled worker when employed. Due to imperfections on the labor market of low-skilled workers, another term is added in the compensatory variation of the unskilled worker: the employment effect $EmpE$, that is proportional to the difference between utility of employed and unemployed worker.

As in Bovenberg and de Mooij [1994], it is here possible to distinguish an environmental component and a non-environmental one. By rearranging the terms in expression (11) and (12), one can alternatively display the marginal excess burden as the sum of an effect on the tax base dR^t (the revenue effect RE and the consumption effect *CE)* and an environmental effect dR^e. The tax base effect is nothing else than the loss of purchasing power. Because, in this paper, we do not allow for heterogeneous valuations of damages from pollution, the regressivity of environmental taxes only appears through the loss of purchasing power, proportionally to the income of the agents.

Proposition 3: *An uncompensated green tax may be regressive or progressive, depending on the amplitude of the elasticity of labor supply of high skilled η_H, and of the subsistence level of polluting consumption $\bar{D}$.*

In fact, we can show that environmental taxes are regressive if and only if:

$$\frac{dR_H^t}{I_H dt_d} = -\left[\underbrace{\frac{dw_H}{w_H dt_d}}_{WE_H} - \underbrace{\frac{D_H}{I_H}}_{CE_H}\right] < \frac{dR_L^t}{I_L dt_d} = -\left[\underbrace{\underbrace{\frac{lI_L^E}{I_L}\left(\frac{dw_L}{w_L dt_d}\right)}_{WE_L} + \underbrace{\frac{P_q\left(V_L^E - V_L^U\right)\frac{dl}{dt_d}}{I_L}}_{EmpE}}_{RE_L} - \underbrace{\frac{D_L}{I_L}}_{CE_L}\right]$$

In appendix A.IV, we show that it is always true if: $\eta_H \Gamma > \frac{\eta_L}{1-t_1}\frac{P_q Z}{f_l}$,, that is in the situation where an uncompensated green tax increase implies a decrease of the wage of the low-skilled-workers. If $\eta_H < \frac{\beta \eta_L}{1-t_L}\frac{P_q Z}{F_l}\left[1 + \frac{1-\beta}{\beta}\frac{\alpha}{1-\alpha}\right]$, situation is ambiguous. The reaction of unions to environmental taxes is high compared to labor supply of high skilled worker and leads to an increase of unskilled wages. Remember that due to the properties of the utility function (that is non homothetic), we have $\frac{D_L}{I_L} - \frac{D_H}{I_H} = (1-\sigma)\bar{D}\left(\frac{1}{I_L} - \frac{1}{I_H}\right) > 0$. If the difference between the two consumption effects of class worker is not so high, that is if $\bar{D}$ is not too high, uncompensated green taxes can be progressive.

4 The revenue-neutral environmental tax reform

We can now analyze a revenue-neutral green tax reform, that increases the tax on the dirty good and reduces the income tax correspondingly. In this section, we first characterize a uniform revenue-neutral reform and the necessary conditions for the obtainment of the environmental and welfare dividends. Distributional properties of the reform are then analyzed. We finally discuss the implication of a reform taking redistributive objective into account, using the progressivity of labor tax tools.

4.1 The specification of a uniform revenue-neutral tax reform

We focus on balanced tax reforms: the government keeps the amount of government spending ex post invariant, and the tax policy has to maintain the amount of the tax revenues constant. We can describe a revenue-neutral green tax reform by the following expression:

$$\frac{dG}{GY} = G_{t_H}^* dt_H + G_{t_L}^* dt_L + G_{t_d}^* dt_d = 0$$

where $G_{t_H}^*$ and $G_{t_L}^*$ denote the marginal tax revenues from the low and high skilled income taxes t_L, t_H, and $G_{t_d}^*$ from the tax on dirty good.

Although we will relax this assumption latter, we first assume that $dt_H = dt_L = dt$, that means that the increase of the environmental tax rate is accompanied by a homogeneous variation of all labor tax rates, proportionally to their labor income. In other words, we do not allow for the moment the government to recycle the revenue with a distributive objective. Moreover, we assume that we are on the Laffer-efficient side of the three tax revenues, i-e $G^*_{t_H} > 0, \quad G^*_{t_L} > 0 \quad G^*_{t_d} > 0$. In this case, we can express dt by: $dt = -\frac{G^*_{t_d}}{G^*_{t_H}+G^*_{t_L}} dt_d < 0$ Computation in the appendix A.V shows that a uniform revenue-neutral tax reform is defined as follows:

$$-\frac{dt}{dt_d} = \left[\frac{\overbrace{D_{tot}}^{value\, effect} + \overbrace{B\frac{\partial L}{\partial t_d}}^{benefit\, effect} + \overbrace{\frac{t_d}{1+t_d}E_s}^{substitution\, effect} + \overbrace{\frac{\sigma t_d}{1+t_d}\frac{\partial I_{tot}}{\partial t_d} + \sum_{i=l}^{H} i w_i t_i \left(\frac{\partial w_i}{w_i \partial t_d} + \frac{\partial i}{i \partial t_d}\right)}^{revenue\, effect}}{\underbrace{(w_L L + w_H H)}_{value\, effect} + \underbrace{B\left(\frac{\partial L}{\partial t_L} + \frac{\partial L}{\partial t_H}\right)}_{benefit\, effect} + \underbrace{\sum_{j=l}^{H}\left(\frac{\sigma t_d}{1+t_d}\frac{\partial I_{tot}}{\partial t_j} + \sum_{i=l}^{H} i w_i t_i \left(\frac{\partial w_i}{w_i \partial t_j} + \frac{\partial i}{i \partial t_j}\right)\right)}_{revenue\, effect}} \right]$$

The numerator measures the effect of the change in pollution tax rate on the part of its revenue that can be recycled (after the unemployment benefits have been paid). We can distinguish both *a value effect* (the tax revenue increases with the pollution tax rate, for unchanged consumption D_{tot}) and a *tax base effect*. The latter one represents the possible erosion of the tax base: the increase of the pollution tax induces agents to substitute between clean and polluting goods (*substitution effect*), and impacts also on wages and labors. Labor of low skilled decreases (Proposition 1) which leads to an increase of the amount of unemployment benefits provided by the government (*benefit effect*). Changes in wages and labors do not leave the total income of agents ($I_{tot} = I_L + NI_H$) unaffected. It generates a decrease of the total consumption, and of D_{tot} according to its proportion into the total unconstrained consumption ($\frac{\sigma t_d}{1+t_d}$) (*revenue effect*).

The denominator measures the effect of the change in labor tax rates on its revenue. The *value effect* is proportional to labor revenues: the tax revenues increase with the tax rates, for unchanged labor incomes. The *tax base effect* works in opposite way. The total revenue decreases (*revenue effect*) and the decrease of low-skilled labor imply an increase of unemployment benefice (*benefit effect*).

Note: the absolute variation of labor tax rate $\mid dt \mid$ is an increasing function with respect to the subsistence level of polluting good $\bar{D}$. It acts through the numerator. Augmenting $\bar{D}$

increases the value effect by increasing D_{tot}, but also minimize the substitution effect and so the erosion of the tax base.

4.2 Efficiency issue: The environmental and welfare dividend

We refer in this paper to Goulder's definition of the double dividend: an environmental dividend (*i-e* a decrease of the consumption of the polluting good, here) together with a non environmental welfare dividend measured by the purchasing power effect of the marginal excess burden. From equations of the marginal excess burden (11 and 12), and by considering an egalitarian criteria where the marginal excess burden of the economy is $dR_{tot} = dR_L + NdR_H$, conditions for the obtainment of the double dividend are given by:

- $dR^t_{tot} = -\left[\overbrace{\sum_{i=L}^{H}\left(I_i[\tilde{w}_i + \frac{\frac{dt}{dt_d}}{1-t_i}]\right)}^{after-tax-wage-effect} + \overbrace{P_q\left(V^e_L - V^u_L\right)\tilde{L}}^{employment\, effect} - \overbrace{D_{tot}}^{consumption}\right] < 0$
- $dR^e_{tot} = \left(-\frac{\partial\psi(D_{tot})}{\partial D_{tot}}\frac{dD_{tot}}{dt_d}\right) < 0$

Proposition 4: *A uniform revenue-neutral tax reform that increases the green tax rate t_d and decreases equally both labor tax rates dt_i, can lead to a double dividend if and only if:*

$$D_{tot}dt_d + P_q ZdL + \varphi'(H^*)NdH < dI_{tot} < (\frac{I_{tot}}{1+t_d})dt_d$$

where dI_{tot} is the variation of total revenue of the agents. (*see proof in appendix A.VI*)

Proposition 4 is very intuitive: on one hand, the positive impact on the total revenue of the agents has to be not too high in order to leave the polluting consumption D_i decreasing (right hand side of the inequality). On the other hand, the reform has to compensate agents for their loss on their consumption D_{tot} and their disutility of work (left hand side of the inequality).

Our results here do not change from those of the traditional literature on the double dividend conditions, except with the subsistence level in the dirty good. The introduction of $\bar{D}$ exacerbates the trade-off between the green and the non-environmental dividend. On one side, by decreasing the facility to substitute between clean and dirty technology, $\bar{D}$ makes the reform less efficient to achieve a better environmental quality. In the other side, because of the low level of the substitution effect, the erosion of the tax base of the green tax is also low. Demand for dirty goods being less elastic, the Ramsey logic dictates that the optimal carbon tax must be set relatively high (Jacobs and Van der Ploeg [2010]). The tax system is then more efficient.

4.3 Equity issue: the distributive properties of the tax reform and the trade-off between efficiency and equity

Proposition 5: *A uniform revenue-neutral environmental reform has an ambiguous effect on wages, which depends on the amplitude of the sensitivity of employments to the labor tax and of the reform's efficiency.*

For $\left[\frac{\sigma}{(1+t_{d})} - \frac{1}{(1-t_H)} \mid \frac{dt}{dt_d} \mid\right] > 0$

- *If* $\eta_H < \frac{\eta_L\left[\frac{\sigma}{(1+t_{d})}\frac{P_qZ}{(1-t_L)f_L} - \frac{w_R}{(1-t_L)^2 f_L}\mid\frac{dt}{dt_d}\mid\right]}{\left[\frac{\sigma}{(1+t_{d})} - \frac{1}{(1-t_H)}\mid\frac{dt}{dt_d}\mid\right]}$*, a uniform revenue-neutral green shift decreases* w_H *and increases* p_L*,*
- *If* $\eta_H\Gamma < \frac{\eta_L\left[\frac{\sigma}{(1+t_{d})}\frac{P_qZ}{(1-t_L)f_L} - \frac{w_R}{(1-t_L)^2 f_L}\mid\frac{dt}{dt_d}\mid\right]}{\left[\frac{\sigma}{(1+t_{d})} - \frac{1}{(1-t_H)}\mid\frac{dt}{dt_d}\mid\right]}$*, a uniform revenue-neutral green shift increases* w_L*,*
- *If* $\eta_H\Gamma < \frac{\eta_L\left[\frac{\sigma}{(1+t_{d})}\frac{P_qZ}{(1-t_L)f_L} - \frac{w_R}{(1-t_L)^2 f_L}\mid\frac{dt}{dt_d}\mid\right]}{\left[\frac{\sigma}{(1+t_{d})} - \frac{1}{(1-t_H)}\mid\frac{dt}{dt_d}\mid\right]} < \eta_H$*, a uniform revenue-neutral green shift increases* w_H *and* w_L *and decreases* p_L*.*

The signs of inequalities must be changed if $\left[\frac{\sigma}{(1+t_{d})} - \frac{1}{(1-t_H)} \mid \frac{dt}{dt_d} \mid\right] < 0.$

Notice that for the double dividend can only been obtained if at least the denominator or the numerator of the ratio $\frac{\left[\frac{\sigma}{(1+t_{d})}\frac{P_qZ}{(1-t_L)f_L} - \frac{w_R}{(1-t_L)^2 f_L}\mid\frac{dt}{dt_d}\mid\right]}{\left[\frac{\sigma}{(1+t_{d})} - \frac{1}{(1-t_H)}\mid\frac{dt}{dt_d}\mid\right]}$ is negative. It means for a very low $\eta_H\Gamma$ whereas the uncompensated environmental tax leads to an increase of w_L (see Proposition 2), the reform may lead to a decrease of w_L. If $\mid \frac{dt}{dt_d} \mid$is sufficiently large, the welfare improvement may reverse the distributive properties of the environmental tax reform through the *revenue effect.*

Corollary: *If the reform succeed to provide a double dividend, the welfare improvement may reverse the distributive properties of the environmental tax reform, depending on the amplitude of the elasticity of labor to taxes, the initial progressivity of the tax system and the level of* $\bar{D}$

Unions and households react not only to the increase of environmental taxes but also to the decrease of labor taxes. This latter effect dominate in the case where the reform is efficient. If n_H is relatively low, *i.e.* in the case of a progressive uncompensated green tax (Proposition 4), the union's reaction would be high compared to labor supply of high skilled worker. This will lead to a decrease of low-skilled wages and an increase of high-skilled wage, and will be in favor of the regressivity.

How to compensate the low-skilled workers?

In the cases where the environmental tax reform appears to be regressive, how is it possible to combine a redistributive objective with the double dividend conditions? As in Chiroleu-Assouline and Fodha [2014], we argue that the distributive properties of the labor tax policy could be one of the instruments of fair internalization of the environmental externalities. We propose in this paper a solution to increase the progressivity of labor taxes inside the environmental tax reform. Consequently, we allow dt_L to differ from dt_H in the following way:

$$dt_L = -(1+\gamma)da = -(1+\gamma)\left(\frac{G^*_{t_d}}{(1-\gamma)G^*_{t_H} + (1+\gamma)G^*_{t_L}}\right) dt_d$$

$$dt_H = -(1-\gamma)da = -(1-\gamma)\left(\frac{G^*_{t_d}}{(1-\gamma)G^*_{t_H} + (1+\gamma)G^*_{t_L}}\right) dt_d$$

Where γ represents the progressivity index. If $\gamma = 0$, we redistribute proportionally to revenue of agents $dt_L = dt_H = dt$. If $\gamma = 1 (\gamma = -1)$ we redistribute everything to low-skilled workers (to high-skilled workers).

Proposition 6: *It is efficient to redistribute through $\gamma > 0$ if and only if:*

$$\triangle = \frac{dR_{tot}}{dt_d}(\gamma) - \frac{dR_{tot}}{dt_d}(\gamma = 0) > 0 \iff \left| \frac{\partial R_{tot}/\partial t_L}{\partial R_{tot}/\partial t_H} \right| > \frac{G^*_{t_l}}{G^*_{t_H}}$$

(see proof in appendix A.VII)

There is no trade-off between efficiency of the reform and the use of progressivity if and only if the ratio of the marginal indirect utilities in respect to labor taxes is larger than the ratio of marginal revenues from labor taxes. If the elasticity of labour supply of high-skilled is really high, it is not possible to avoid the trade-off between efficiency and equality of the reform, but the reform may probably be progressive (if $\bar{D}$ is not really high).

5 A numerical illustration

In order to illustrate the economic and welfare consequences of the environmental reform, we calibrate and choose some realistic parameters of our theoretical model. Our purpose here, is to yield some insight of the regressivity of the reform, depending on a range of key parameters. In more detail, we compute the values of $dR_i^t(\gamma)$ for different values of $\bar{D}$, η_H, and γ. The parameters of the model are chosen to match the French data.[5]

To close the numerical model, we specify the functional form of the matching function. Empirically, a reasonable approximation to the matching function in equation M, is a Cobb-Douglas function, where the index on each variable lies between 0 and 1. Following Pissarides [1986] and [1998], we specify the matching function as $M = \omega v^{1-\xi} 1^{\xi}$, with $\xi = 0.5$ and $\omega > 0$. It gives $q(\theta) = \frac{M}{v} = \omega\theta^{-\xi}$. The bargaining power of low-skilled workers is also taken equal to 0.5 as assumed by the symmetric Nash bargaining solution. The unemployment benefit payment B and the total recruitment costs c are calibrated to represent respectively 30% and 4% of the initial low-skilled wage. The constant ω is free and chosen to yield a plausible value for unemployment (here 12%).

As in Chiroleu-Assouline and Fodha [2014], we assume the initial tax system defined by the following values: $t_d = 0.01$, $t_L = 0.25$, and $t_H = 0.45$. The environmental tax rate corresponds closely to the budget of the French Environmental and Energy Management Agency (ADEME), which is entirely financed by environmental tax revenues. The labor taxes rates are chosen according the initial progressivity in the French tax system.
We assume a non equi-distribution of the workers among classes such that the high-skilled workers represent 35% of the mass of total workers, and 75% of the total labor income. Thus N=0.58. We calibrate the share in total output for low-skilled workers α, such that the ratio of wages $w_H/w_L = 2.1$ fits the French data.

Following the empirical taxation and double dividend literature[6], we assume a share of polluting good in total output of 0.35 that gives $\sigma = 0.3$ if we assume $\bar{D} = 0.05$.
The choice of an Irving-Fisher form for the disutility of hours of work imposes a range of plausible value for the consumption-leisure substitution elasticity η_H between 0.5 and 1, the Irving-Fisher parameter being between 1 and 2. These are typical estimates from the literature, and are meant to represent the effects of changes in the real wage on average hours worked.

[5]Some sensitivity analysis will be provided in a next draft of this paper.
[6]See Cremer and al [2003], Chiroleu-Assouline and Fodha [2014].

In Figures 1 and 2, we illustrate the relevance of the Propositions 5 and 6.

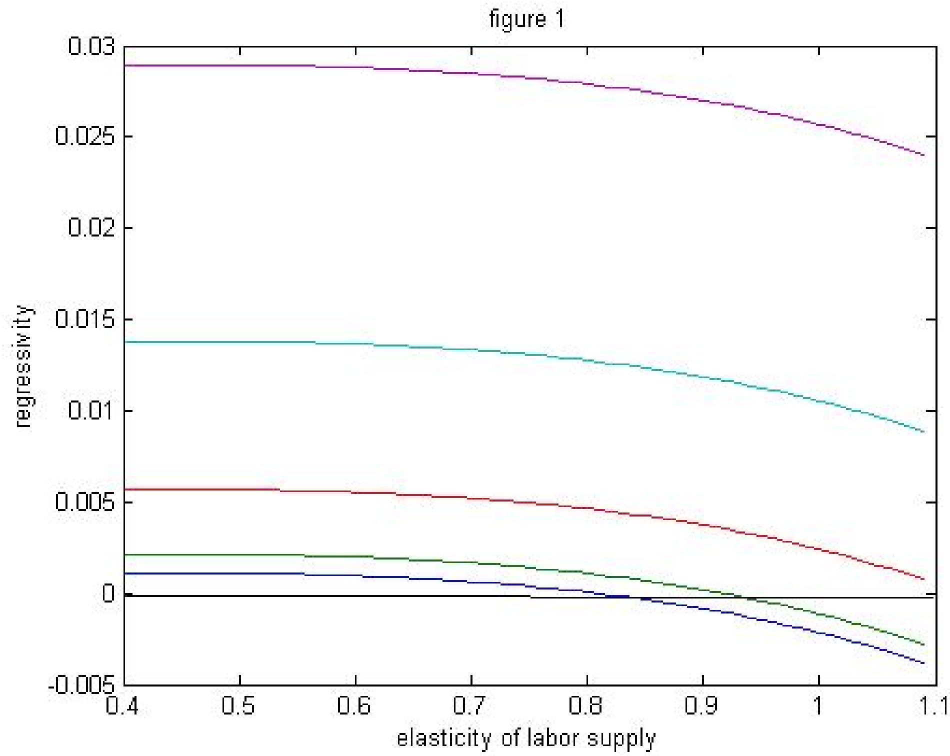
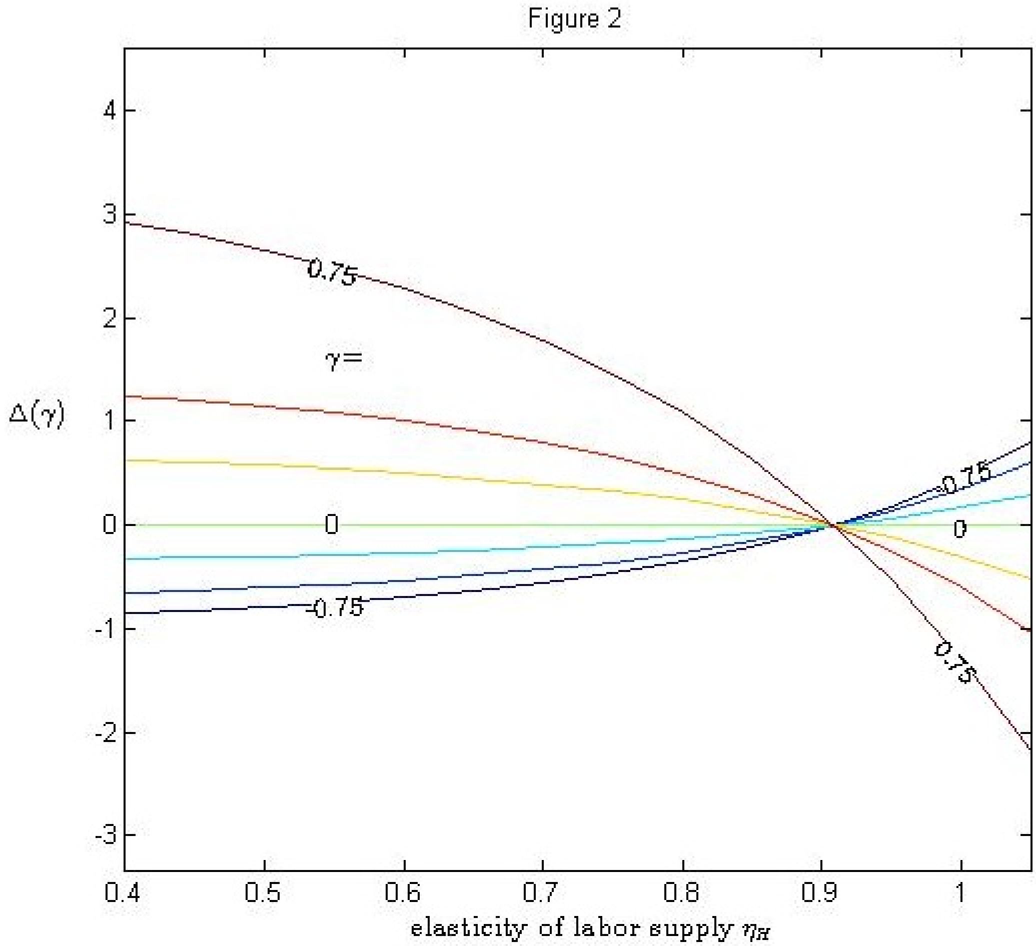


Figure 1 represents the difference between the tax burden of the reform for both households (variable *regressivity* on the y axis). If this difference is positive (negative), the reform appears regressive (progressive). This graph illustrates the Proposition 4: because we are under the condition where a double dividend occurs, the higher η_H is, the more progressive the reform is. Differences between the curve stands for the differences level of $\bar{D}$, that changes the amplitude of progressivity. One can read on this graph the limit value of η_H for which the reform is regressive. This limit value varies with the subsistence level of consumption of polluting commodities: for high values of $\bar{D}$, the revenue-neutral environmental tax reform cannot be progressive whatever reasonable values of η_H. And if $\bar{D}$ equals 10% of the ex ante dirty consumption, the reform is progressive as soon as $\eta_H > 0.84$.



In Figure 2, the range of (γ, η_H) combinations for which the progressive reform leads to a higher efficiency is shaded. The curves stand for differents level of $\gamma \in]0;1[$. On the y axis, we represent $\triangle$, the difference between $\frac{dR_{tot}}{dt_d}(\gamma)$ and $\frac{dR_{tot}}{dt_d}(\gamma = 0)$. We can see that, for $\eta_H < 0.5$, redistributing the whole revenue of the environmental tax to low-skilled households $(\gamma = 1)$ can be the best option. In contrast, when $\eta_H > 0.94$, progressivity leads in any case to inefficiency. Hence the range of critical elasticity of labor supply widens as the progressivity index increases. But the boundary is really high (0.92). Regarding the two previous graphs, a conclusion can appear. If the elasticity of high-skilled labor supply is really high, it is not possible to avoid the trade-off between efficiency and equality of the reform. But the reform may probably initially be progressive for $\gamma = 0$ (here $\bar{D} = 0.05$ is not so high).

6 Conclusions

In this paper, we investigate the distributional and efficiency consequences of an environmental tax reform. Our model contains several features that contribute to identify the key components of the regressivity/ progressivity of the environmental tax. Our specification of utility, as a Stone-Geary function, allows us to represent dirty goods as necessities and emphasizes the importance of the magnitude of the subsistence level of consumption of polluting goods, like energy products. An increase of this subsistence level always plays for regressivity of the environmental tax through a *consumption effect*: the share of dirty good in total consumption is higher for low skilled, as compared to high-skilled, and the tax burden also.
Moreover, the asymmetry between low and high skilled labor markets sheds light on the difference between high and low-skilled wage formations, that is crucial in the distributional properties of the green tax analysis. We show that if the low-paid employment is more responsive than high-paid employment, *i.e.* if the labor supply of high-skilled is relatively low compared to low-skilled labor demand sensitivity, an uncompensated environmental tax can be progressive. This acts through a *revenue effect.* However, the *revenue effect* of the revenue-neutral environmental reform, when the green tax is recycled by a variation of labor tax rates, is more ambiguous and depends clearly of the magnitude of the efficiency of the reform. We show that in the case where the reform appears to be regressive, the gains from the double dividend can be made Pareto improving by using a redistributive non-linear income tax if redistribution is initially not too large, and if the subsistence level of polluting consumption is not too high. Moreover, the use of a non-linear income tax acts on unemployment and can moderate the trade-off between equity and efficiency.

Appendix

A.I Wage Bargaining

Wage of low skilled worker is determined as: $w_L = argmax \left\{ \left(Q^* \left(I_L^E \right) - \left[Q^*(I_L^U) + Z \right] \right)^{\beta} \left(f_L - w_L \right)^{1-\beta} \right\}$

where $Q^* \left(I_L^E \right) = \left(\frac{w_L(1-t_L)-(1+t_d)\bar{D}}{P_Q} \right)$ and $\left[Q^*(I_L^U) + Z \right] = \left(\frac{B-(1+t_d)\bar{D}}{P_Q} \right) + Z$

This is equivalent to $w_L = argmax \left\{ \beta \left(lnQ^* \left(I_L^E \right) - \left[Q^*(I_L^U) + Z \right] \right) + (1-\beta) ln \left(f_L - w_L \right) \right\}$.
First order condition gives: $\beta \left[\frac{(1-t_L)}{P_Q \left[Q_L^{E*} - Q_L^{U*} - Z \right]} \right] - (1-\beta) \left[\frac{1}{f_L - w_L} \right] = 0$. And with equation (7) we obtain:

$$\frac{P_Q \left[Q_L^{E*} - Q_L^{U*} - Z \right]}{(1-t_L)} = \frac{\beta}{1-\beta} * \left[f_L - w_L \right] = \frac{\beta}{1-\beta} * \left[\frac{c}{q(\theta)} \right] \text{ (A.1)}$$

Remember that w_R is defined as w_L such that $Q^*\left(I_L^E\right) = \left[Q^*(I_L^U) + Z\right]$, it gives:

$w_R = \frac{B+P_q Z}{1-t_L} = \frac{P_Q\left[Q_L^{U*}+Z+(1+t_d)\bar{D}\right]}{1-t_L}$. Then we can rewrite (A.1) as:

$\frac{P_Q\left[Q_L^{E*}-Q_L^{U*}-Z\right]}{(1-t_L)} = \frac{P_Q\left[Q_L^{E*}\right]+(1+t_d)\bar{D}}{(1-t_L)} - w_R = w_L - w_R = M$ (A.2)

Equation A.1 and A.2 finally lead to: $w_L = w_R + \beta(f_L - w_R)$

A.II Comparative statics

Combining the wage-mark up equation and the job creation condition, we obtain:
$\xi\widetilde{\theta} = \frac{p_L \tilde{p_L} - w_R \tilde{w_R}}{p_L - w_R} = \frac{w_L \tilde{w_L} - w_R \tilde{w_R}}{w_L - w_R}$

Replacing $\widetilde{\theta}$ in the low-skilled labor equation, we found:
$\tilde{l} = (1-\xi) * \tilde{\theta} = \tilde{y} - \tilde{p_L} = \frac{1-\xi}{\xi}\left[\frac{p_L \tilde{p_L} - w_R \tilde{w_R}}{p_L - w_R}\right] = \eta_L\left(\tilde{p_L} - \frac{w_R}{p_L}\tilde{w_R}\right)$

with $\eta_L = \frac{1-\xi}{\xi}\left[\frac{p_L}{p_{L-w_R}}\right]$, the elasticity of the low-skilled labor to productivity p_L
We can rewrite the previous equation in the following way:
$\tilde{p_L}\left(1+\eta_L\right) = \tilde{y} + \left(\eta_L \frac{w_R}{p_L}\right)\tilde{w_R}$ (A.3)

Similarly, we can write: $\tilde{p_H}\left(1+\eta_H\right) - \left(\eta_H\right) dR_H = \tilde{y}$ (A. 4)

Replacing $\tilde{y}$ by (A.4) and $\tilde{p_H} = -\frac{\alpha}{1-\alpha}\tilde{p_L}$ in (A.3), we finally obtain:

$\frac{\tilde{p_L}}{(1-\alpha)}\left(1 + (1-\alpha)\eta_L + \eta_H\right) = \left(\eta_L \frac{w_R}{p_L}\right)\tilde{w_R} - \left(\eta_H\right) dR_H$. That gives:

$\tilde{p_L} = \frac{(1-\alpha)}{1+(1-\alpha)\eta_L+\alpha\eta_H}\left[\left(\eta_L \frac{w_R}{p_L}\right)\tilde{w_R} - \left(\eta_H\right) dR_H\right] = (1-\alpha)\frac{\mu_L}{\eta_L}\left[\left(\eta_L \frac{w_R}{p_L}\right)\tilde{w_R} - \left(\eta_H\right) dR_H\right]$ (IV)

with $0 < \mu_L = \frac{\eta_L}{1+(1-\alpha)\eta_L+\alpha\eta_H} < 1$. Replacing (IV) in the log-linearized model, gives to us the solutions I, II, III, V, and VI.

A.III The compensatory variation

Let us determine the compensatory income variation of low-skilled workers:
$dV_L = 0 \Leftrightarrow (1-l)\, dV_L^U + l dV_L^E = 0 \Leftrightarrow$

$$(1-l)\frac{\partial V_L^U}{\partial C_L} dC_L^U + l\frac{\partial V_L^E}{\partial C_L} dC_L^E + (1-l)\frac{\partial V_L^U}{\partial D_L} dD_L^U + l\frac{\partial V_L^E}{\partial D_L} dD_L^E + \left(V_L^E - V_L^U\right) dl + \frac{\partial V_L}{\partial D_{tot}} dD_{tot} = 0$$

Using first order conditions of consumer's program, this leads to:

$$dV_L = 0 \Leftrightarrow \frac{1}{P_q}\left[(1-l)\,dC_L^U + ldC_L^E\right] + \frac{(1+t_d)}{P_q}\left[(1-l)\,dD_L^U + ldD_L^E\right] + \frac{\partial V_L}{\partial D_{tot}}dD_{tot} = 0$$

By differentiating the budget constraint of low-skilled households and using the definition of the compensatory income variation we obtain:

$$\left[C_L^E + (1+t_d)D_L^E - C_L^U - (1+t_d)D_L^U\right] dl + \left[(1+t_d)\left((1-l)\,dD_L^U + ldD_L^E\right) + (1-l)\,dC_L^U + ldC_L^E\right] = \left[w_L(1-t_L) - B\right] dl + I_L^E l\left(\widetilde{w_L} + \frac{dt_L}{1-t_L}\right) + dR_L$$

Because we have $C_L^E + (1+t_d)D_L^E = I_L^E$ and $C_L^U + (1+t_d)D_L^U = B$, terms in dl can be eliminated. The combination of the last two equations gives:

$$dR_L = -\left[I_L^E\left(\widetilde{w_L} + \frac{dt_L}{1-t_L}\right) + P_q\left(V_L^E - V_L^U\right) dl - D_L dt_d - \frac{\partial V_L}{\partial D_{tot}} P_q dD_{tot}\right]$$

A.IV Proposition 3: The regressivity of an uncompensated green tax

An increase of an uncompensated green tax appears regressive if and only if:

$$\left[\frac{dw_H}{w_H dt_d} - \frac{D_H}{I_H}\right] > \left[\frac{lI_L^E}{I_L}\left(\frac{dw_L}{w_L dt_d}\right) + \frac{P_q\left(V_L^E - V_L^U\right)\frac{dl}{dt_d}}{I_L} - \frac{D_L}{I_L}\right]$$

Because of the functional form of the consumption utility, we have:
$\frac{D_H}{I_H} - \frac{D_L}{I_L} = (1-\sigma)\bar{D}\left[\frac{1}{I_H} - \frac{1}{I_L}\right] < 0, \forall \bar{D} > 0$

According to Proposition 1, a higher uncompensated green tax raises unemployment $\frac{dl}{dt_d} < 0$. If $\frac{dw_L}{w_L dt_d} < 0$, (which implies necessarily $\frac{dw_H}{w_H dt_d} > 0$, see Proposition 2), we have:

$$\left[\underbrace{\frac{dw_H}{w_H dt_d}}_{>0}\right] > \left[\underbrace{\frac{lI_L^E}{I_L}\left(\frac{dw_L}{w_L dt_d}\right)}_{<0} + \underbrace{\frac{P_q\left(V_L^E - V_L^U\right)\frac{dl}{dt_d}}{I_L}}_{<0} + \underbrace{\frac{D_H}{I_H} - \frac{D_L}{I_L}}_{<0}\right]$$

A higher uncompensated green tax is then unambiguous regressive. In fact we can show that a higher uncompensated green tax is regressive if η_H satisfies the following condition:

$$\eta_H > \frac{\left[(1+(1-\alpha)\eta_L)\,A + \eta_L\right]}{\left[\left(\frac{p_L(1-t_L)}{P_q Z}\right) - \alpha A\right]} > 0 \quad where \quad 0 < A = \frac{\left[lI_L^E\,(1-\beta)\,\frac{p_L}{w_L} - P_q\left(V_L^E - V_L^U\right)\eta_L\right]}{\left[I_L + \beta\frac{1-\alpha}{\alpha}\left(lI_L^E\,(1-\beta)\,\frac{p_L}{w_L} - P_q\left(V_L^E - V_L^U\right)\eta_L\right)\right]} < 1$$

If $\eta_H < \frac{[(1+(1-\alpha)\eta_L)A+\eta_L]}{\left[\left(\frac{p_L(1-t_L)}{P_q Z}\right)-\alpha A\right]}$, there is a trade-off between the revenue effect of the tax (that is progressive), and the consumption effect $\frac{D_H}{I_H} - \frac{D_L}{I_L}$.

A.V A revenue-neutral tax reform

Remember the government budget constraint:
$G + (1-l)\,B = lw_L t_L + NHw_H t_H + t_d D_{tot}$. With the definition of D_{tot}:

$$G = lw_L t_L + NHw_H t_H + \left(\sigma \frac{t_d}{1+t_d} I_{tot} + (N+1)(1-\sigma)\bar{D}\right) - (1-l)\,B$$

We want to identify $G^*_{t_d}$, $G^*_{t_L}$, and $G^*_{t_H}$.

$$G^*_{t_d} = \frac{dG}{dt_d} = \frac{\partial G}{\partial t_d} + lw_L t_L \left(\frac{\partial w_L}{w_L \partial t_d} + \frac{\partial l}{l \partial t_d}\right) + NHw_H t_H \left(\frac{\partial w_H}{w_H \partial t_d} + \frac{\partial H}{H \partial t_d}\right) + B\frac{\partial l}{\partial t_d} + \sigma \frac{t_d}{1+t_d}\frac{\partial I_{tot}}{\partial t_d}$$

Note that $\frac{\partial G}{\partial t_d} = \left(D_{tot} - \frac{\sigma t_d}{1+t_d}\frac{I_{tot}}{1+t_d}\right) = \left(D_{tot} - \frac{t_d}{1+t_d} \mid E_s \mid\right)$, with E_s, the elasticity of substitution. In the same way:

$$G^*_{t_L} = \frac{dG}{dt_L} = \frac{\partial G}{\partial t_L} + lw_L t_L \left(\frac{\partial w_L}{w_L \partial t_L} + \frac{\partial l}{l \partial t_L}\right) + NHw_H t_H \left(\frac{\partial w_H}{w_H \partial t_L} + \frac{\partial H}{H \partial t_L}\right) + B\frac{\partial l}{\partial t_L} + \sigma \frac{t_d}{1+t_d}\frac{\partial I_{tot}}{\partial t_L}$$

$$G^*_{t_L} = \frac{dG}{dt_L} = w_L L + lw_L t_L \left(\frac{\partial w_L}{w_L \partial t_L} + \frac{\partial l}{l \partial t_L}\right) + NHw_H t_H \left(\frac{\partial w_H}{w_H \partial t_L} + \frac{\partial H}{H \partial t_L}\right) + B\frac{\partial l}{\partial t_L} + \sigma \frac{t_d}{1+t_d}\frac{\partial I_{tot}}{\partial t_L}$$

Finally we find:

$$-\frac{dt}{dt_d} = \left[\frac{\overbrace{D_{tot}}^{value\,effect} + \overbrace{B\frac{\partial L}{\partial t_d}}^{benefice} + \overbrace{\frac{t_d}{1+t_d}E_s}^{substitution\,effect} + \overbrace{\frac{\sigma t_d}{1+t_d}\frac{\partial I_{tot}}{\partial t_d} + \sum_{i=l}^{H} i w_i t_i \left(\frac{\partial w_i}{w_i \partial t_d} + \frac{\partial i}{i \partial t_d}\right)}^{the\,revenue\,effect}}{\underbrace{(w_L L + w_H H)}_{value\,effect} + \underbrace{B\left(\frac{\partial L}{\partial t_L} + \frac{\partial L}{\partial t_H}\right)}_{benefice} + \underbrace{\sum_{j=l}^{H}\left(\frac{\sigma t_d}{1+t_d}\frac{\partial I_{tot}}{\partial t_j} + \sum_{i=l}^{H} i w_i t_i \left(\frac{\partial w_i}{w_i \partial t_j} + \frac{\partial i}{i \partial t_j}\right)\right)}_{the\,revenue\,effect}}\right]$$

A.VI Proposition 4: Double dividend

Condition for the obtainment of the first dividend:
$\tilde{D_{tot}} < 0 \iff \left(-\left[\frac{\sigma}{(1+t_d)^2} * \frac{I_{tot}}{D_{tot}}\right] dt_d + \left[\frac{\sigma}{(1+t_d)} * \frac{dI_{tot}}{D_{tot}}\right]\right)$

Notice that $\mid E_s \mid$,the substitution elasticity between clean and polluting good is equal to

$| E_s |= \frac{\sigma}{(1+t_d)} * \frac{I_{tot}}{D_{tot}}$, we have:

$$\tilde{D_{tot}} < 0 \iff \frac{|E_s|}{(1+t_d)} * \left[(1+t_d)\,\tilde{I_{tot}} - dt_d\right] < 0 \iff \left[\tilde{I_{tot}} < \frac{dt_d}{(1+t_d)}\right]$$

Condition for the obtainment of the second dividend:
$dR^t_{tot} < 0 \iff P_q\,(dV_L + NdV_H) > 0$

And we know that $P_q\,(dV_L) = lI^E_L\left(\widetilde{w_L} + \frac{dt_L}{1-t_L}\right) + P_q\left(V^E_L - V^U_L\right)dl - D_L dt_d$

$$P_q\,(dV_L) = ldI^E_l + \left(I^E_L - B\right)dl - P_q Zdl - D_L dt_d = dI_L - P_q Zdl - D_L dt_d$$

Similarly: $P_q\,(dV_H) = dI_H - \varphi'(H^*)dH - D_H dt_d)$

Combining the last two equations, the condition for the second dividend is given by:
$D_{tot}dt_d + P_q ZdL + \varphi'(H^*)NdH < dItot$

A.VII Proposition 5 (et 2)

$$\tilde{p_H} = -(\alpha)\frac{\mu_H}{\eta_H}\left[\eta_L\tilde{w_R}\frac{w_R}{p_L} - \eta_H dR_L\right]<0$$

$$<=>\eta_L\tilde{w_R}\frac{w_R}{p_L} > \eta_H dR_L$$

$$<=>\eta_L\left(\left[\frac{w_R}{p_L}\frac{1}{1-t_L}\frac{dt_L}{1-t_L}\right] + \frac{ZP_q}{p_L(1-t_L)}\frac{\sigma}{1+t_d}dt_d\right) > \eta_H\left(\frac{\sigma}{1+t_d} * dt_d + \frac{dt_H}{1+t_H}\right)$$

But $dt_H = dt_L = dt$

$$\eta_L\left(\left[\frac{w_R}{p_L}\frac{1}{1-t_L}\frac{|dt/dt_d|}{1-t_L}\right] + \frac{ZP_q}{p_L(1-t_L)}\frac{\sigma}{1+t_d}\right)dt_d > \eta_H\left(\frac{\sigma}{1+t_d} - \frac{|dt/dt_d|}{1+t_H}\right)dt_d$$

Thus $\tilde{p_H} < 0 <=>$

$$\eta_H < \frac{\eta_L\left[\frac{\sigma}{(1+t_d)}\frac{P_q Z}{(1-t_L)f_l} - \frac{w_r}{(1-t_L)^2 f_l}\left|\frac{dt}{dt_d}\right|\right]}{\left[\frac{\sigma}{(1+t_d)} - \frac{1}{(1-t_H)}\left|\frac{dt}{dt_d}\right|\right]}$$

A.VIII Proposition 6

$dR_{tot}(\gamma) - dR_{tot}(\gamma = 0) > 0 \iff \left(\frac{\partial V_{tot}}{\partial t_d} dt_d + \left(\frac{\partial v_{tot}}{\partial t_L} + \frac{\partial V_{tot}}{\partial t_H} \right) dt \right) - \left(\frac{\partial Vtot}{\partial t_d} dt_d + \frac{\partial V_{tot}}{\partial t_L} dt_L + \frac{\partial V_{tot}}{\partial t_H} dt_H \right) < 0$

But $dt = -\frac{G^*_{t_d}}{G^*_{t_H} + G^*_{t_L}} dt_d$, $dt_L = -(1+\gamma)da$, and $dt_H = -(1-\gamma)da$ with:
$da = \left(\frac{G^*_{t_d}}{(1-\gamma)G^*_{t_H} + (1+\gamma)G^*_{t_L}} \right) dt_d$

In the case where $\gamma > 0$, we have: $dt - dt_L = \frac{(1+\gamma)G^*_{t_d}}{(1+\gamma)G^*_{t_H} + (1+\gamma)G^*_{t_L}} - \frac{(1+\gamma)G^*_{t_d}}{(1-\gamma)G^*_{t_H} + (1+\gamma)G^*_{t_L}} < 0$ and then:

$dR_{tot}(\gamma) - dR_{tot}(\gamma = 0) > 0 \iff \left(\frac{\partial R_{tot}}{\partial t_L} < -\frac{\partial R_{tot}}{\partial t_H} \left(\frac{dt - dt_H}{dt - dt_L} \right) \right)$

Using definitions of dt_L and dt_H, we find: $\left(\frac{dt - dt_H}{dt - dt_L} \right) = -\frac{G^*_{t_L}}{G^*_{t_H}}$.

$dR_{tot}(\gamma) - dR_{tot}(\gamma = 0) > 0 \iff \left(\mid \frac{\partial R_{tot}/\partial t_L}{\partial R_{tot}/\partial t_H} \mid > \frac{G^*_{t_l}}{G^*_{t_H}} \right)$
Using the definition of R_{tot} and the solutions of the log-linearized model, we show that:

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