Integrating the Environmental and Fiscal Benefits of Pollution Taxes: the Double Dividend Approach

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Abstract

This paper deals with the welfare effects of pollution taxes beyond the mere environmental sphere. We model a second-best world where the interactions between the environmental and fiscal effects of pollution taxes. The main goal of the paper is to clarify what should be included as profits and costs in the measurement of the first dividend and the second dividend. We also consider the influences of such effects in instrument choice within environmental policy. Finally, we can gauge the dimension of both dividends within a numerical application.

Key words: double dividend, externality, tax reform, green tax
JEL:

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1 Introduction

Green tax reforms are increasingly policy options for governments. They consist on setting a tax on pollution emissions and, then, to devote the tax revenue to decrease other distorting taxes, like income tax and consumption tax. This policy has some profits and costs.[1] The resulting effect depends on the magnitude of the profits and costs. We will study under what circumstances this opposite effects are offset. The excess of gravamen will help us to understand this resulting effect.

The literature has suggested the presence of rather divergent approximations to the various dividends from environmental taxation. There is an "environmental view" that assumes a persisting existence of positive extra dividends, occasionally examining their impacts on optimal environmental tax rates. This view reaffirms the desirability of environmental taxation (see Tullock, 1967, Lee and Misiolek, 1986, and Pearce, 1991).

The "public finance view" constitutes the converse approximation. In general, it is not interested in the first dividend, considered to be vaguely positive. Instead, it tends to focus on the sign of the extra dividends and its impact on optimal environmental tax rates. This view limits the quantitative and qualitative relevance of taxation for environmental policies (see Bovenberg and de Mooij, 1994, and Parry, 1995). This second view was justified by Goulder (1995) because of the uncertainties about the magnitude of the first dividend, which encouraged the avoidance of a cost-benefit analysis of the environmental tax. Thus, if the costs of abatement and the efficiency costs produced by an environmental tax, i.e. its "gross" costs, were negative would the extra dividend claim hold and so policy makers could avoid the difficulties in valuing uncertain benefits.

The paper introduces the double dividend analysis in a general equilibrium framework with an externality. This set-up is richer to study the reciprocal interactions among economic variables. The main goal of the paper is to clarify what should be included as profits and costs in the measurement of the first dividend and the second dividend. In the present paper we look for general equilibrium interactions, that could not be analyzed in the *ad-hoc* models by Labandeira (2000), Lee and Misiolek (1986) and Labandeira and McCoy (1997). The efficient allocation and the second best solution can be computed. Through a numerical application, we can gauge the dimension of both dividends. An empirical calibration is done to assess whether the present allocations are closer or not to the efficiency.

This work develops through the following sections. In Section 2 we present a rational general equilibrium model with heterogeneous agents and an externality. First, the Pareto-optimal allocation and the competitive equilibrium are found. This market equilibrium is inefficient, so two mechanisms are proposed to achieve first-best solutions in Section 3. Section 4 presents a second-best where the tax menu that includes the green tax, allow us to understand the magnitude of the first and

[1] For example a tax on emissions will decrease production but increases clear air and citizens welfare.

second dividend. Finally, Section 5 summarizes conclusions and indicates further research.

2 The social optimum and the market allocation.

We present a static rational general equilibrium model with an externality, and heterogeneous agents in preferences. For the sake of paralleling our results with previous literature, the closest microeconomic foundation version of Labandeira (2000) is constructed. Also, we extend a similar work by Bovenberg and de Mooij (1994) where a homogeneous agent framework is considered.

2.2.- The agents

There are two types of agents in the economy: a finite number of households and firms.

Households consume and supply labor. The model is static, so there are no savings. Households are the owners of the firms. Each individual h is endowed with T units of time (e.g., a year, or any other delimited period) that are allocated between working time at firms n^h and leisure time. We represent by $N = \sum_{h=1}^{H} n^h$ the total number of hours of working time in firms. Each household h derives welfare from the consumption of both the private good c^h produced by firms and the leisure time l^h. In addition, the individual welfare is reduced the more pollution E is emitted by firms when producing. This negative externality affects all households.[2] Let us assume that household h's preferences can be represented by the following utility function:[3] $U^h(c^h, l^h, E)$. In the interest of modeling simplicity we will assume that this is an increasing monotone and strictly concave function, i.e., U_c^h, U_l^h are positive and U_E^h is negative, and U_{cc}^h and U_{ll}^h are negative while U_{EE}^h, U_{cl}^h and U_{lc}^h are positive.

There exists also a number of perfectly price-taker competitive firms. Given that constant returns of scale for technology are assumed, a single aggregate pol-

[2]Bovenberg and de Mooij (1994) assumes additionally that agent's welfare is increased with public expenditure g. We will not consider that this public good affects welfare. In fact, due our goal is to study green taxes, which do not affect public expenditure, we will not consider this additional source of welfare.

[3]The complementarity or substituibility relationship between pollution and consumption or leisure may be crucial on certain results. First, pollution could be thought as a source of agents' diseases, not related with the other variables. In this case, e.g., the quasilinear approach $U^h(c^h, l^h, E) = v^h(c^h, l^h) + g^h(E)$, pollution has no effect on labor supply. Second, the pollution could decrease the "quality" leisure, since agents cannot carry out certain activities (e.g., polluted rivers, etc.). Hence a complementarity relation with leisure could be taken, e.g., $U^h(c^h, l^h, E) = c^h + v^h(l^h, E)$. Finally, the pollution could decrease the "quality" of consumption. In this case a complementarity relation with consumption could be, for example, $U^h(c^h, l^h, E) = v^h(c^h, E) + l^h$. In last two cases, labor supply and its slope is affected by an increase of pollution.

lutionary firm could be considered. The aggregate technology requires labor N as the only input to produce a private good and pollution.[4] Hence, the production function can be considered a homomorphic function Ψ on $\mathcal{R}^2$ such that $\Psi(N) = (Y, E) = (F(N), \Lambda(F(N)))$. This formulation is recognizing the existence of complementarities between the production of the private good and the polluted emissions, E, externality that affects negatively on all households' welfare. We will consider that this relationship represented by a real monotonically increasing function $\Lambda()$.[5] We assume that both F and Λ verifies Inada conditions.

2.1 The social planner Pareto-efficient problem.

The social planner maximizes the agents' weighted welfare function subject to feasible conditions. That is to say, consumption of goods equals private good production, each household time endowment is devote to working activities and leisure, and pollution is a function of private good production.

$$\begin{array}{rrcll}
\max_{\left\{c^h, l^h, n^d\right\}_{h\in H}, E} & \sum_{h=1}^{H} \alpha_h U^h\left(c^h, l^h, E\right) & & & \\
\text{s.t.} & n^h + l^h & = & T & \text{for } h = 1, ...H \\
& \sum_{h=1}^{H} c^h & = & Y & \\
& \Lambda(Y) & = & E & \\
& Y & = & F\left(\sum_{h=1}^{H} n^h\right) &
\end{array}$$

where α_h is the weighting assigned to household h by the planner. The first order conditions are:

$$\begin{aligned}
\alpha_h \frac{\partial U^h\left(c^h, l^h, E\right)}{\partial c} - \lambda &= 0 && \text{for } h = 1, ...H && (1) \\
-\alpha_h \frac{\partial U^h\left(c^h, l^h, E\right)}{\partial l} + \lambda F'(N) &= \mu \Lambda'(F(N))F'(N) && \text{for } h = 1, ...H && (2) \\
\sum_{h=1}^{H} \alpha_h \frac{\partial U^h\left(c^h, l^h, E\right)}{\partial E} + \mu &= 0 &&
\end{aligned}$$

where λ and μ are the Lagrangian multipliers, which are positive as long as individual preferences are monotonic.[6] The optimal allocations are given by $\left\{\{\hat{c}^h, \hat{l}^h\}_{h=1}^{H}, \hat{E}\right\}$.

[4]Capital K could also be considered. However, since the model is static, the stock of capital is always constant.

[5]Additionally, we could consider that the firms may reduce pollution with some kind of technology, this will be done with a decreasing and concave technology $A()$, with an increasing and convex abatement cost function $c()$. Remember that a biological and natural regeneration should also be taken into account.

[6]The maximization process have been designed by considering that $\Lambda(Y) \leq E$, although this constraint always holds with equality. We are concern on the sign of multipliers and, otherwise, the multiplier μ would be negative.

After several transformations, we find the optimal condition:

$$\sum_{h=1}^{H} \frac{-\frac{\frac{\partial U^h(c^h,l^h,E)}{\partial E}}{\frac{\partial U^h(c^h,l^h,E)}{\partial c}}}{F'(N) - \frac{\frac{\partial U^h(c^h,l^h,E)}{\partial l}}{\frac{\partial U^h(c^h,l^h,E)}{\partial c}}} = \frac{1}{\Lambda'(F(N))F'(N)} \tag{3}$$

That is to say, the social marginal rate of substitution, a summation over all consumers, equals the social marginal rate of transformation.

2.2 The private property competitive equilibrium.

Household wealth comes from the payments for labor (real wages $\frac{w}{P}$). Household h maximizes the utility $U^h(c^h, l^h, E)$ subject to her restrictions:

$$c^h = \frac{w}{P}(T - l^h)$$

given the externality E. Due monotonicity of preferences, the budget constraint is always binding in equilibrium. The first order conditions are as follows:

$$-\frac{\partial U^h(c^h, l^h, E)}{\partial l} + \frac{\partial U^h(c^h, l^h, E)}{\partial c}\frac{w}{P} = 0 \tag{4}$$

This condition is the individual h's supply functions for labor $n^{hs} = (T - l^{hs}) = S_n^h\left(\frac{w}{P}, E\right)$ and, then, we can find the private good demand: $c^{hs} = D_c^h\left(\frac{w}{P}, E\right) = \frac{w}{P}n^{hs}$.

The representative firm maximizes over labor N to produce the private good and, as a consequence, to emit pollution. This externality is not taken into account in this competitive case, so the firms solves their problem as this does not exit. Since perfectly competitive conditions and constant returns of scale are assumed, the firm's returns will be zero.[7] Then, the representative firm maximizes profits

[7] In the case the firm carry out an abatement program, we can think the representative firm problem as the aggregation of two firms. The first firm produces two outputs with a technology F with the required input labor N: the private good Y and a pollution good $\tilde{E}$. The private good can be transformed at zero cost into consumption good and an abatement investment good A, i.e., $\sum_h^H c^h + A = Y$. The second firm transforms pollution $\tilde{E}$ into clearness R and pollution E with a technology that uses as input the abatement capital A. The cost to acquire this technology is a convex increasing function $c()$.

Hence each firm's problem is, respectively,

$$\begin{array}{rl} \max_{\tilde{E},Y,N} & \left[PY + (-t_E)\tilde{E}\right] - wN\rho + \rho T_F \\ \text{s.t.} & Y = F(N\rho) \\ & \tilde{E} = \Lambda(F(N\rho)) = \Lambda(Y) \end{array}$$

and

$$\begin{array}{rl} \max_{\tilde{E},Y,N} & t_E R - c(A) - wN(1-\rho) + (1-\rho)T_F \\ \text{s.t.} & R = R(N(1-\rho), \tilde{E}, A) \end{array}$$

$\pi(E,N) = Y - \frac{w}{P}N$ subject to

$$\begin{aligned} Y &= F(N) && (5) \\ E &= \Lambda(Y) && (6) \end{aligned}$$

given the input price $\frac{w}{P}$. The demand function for labor is given by

$$F'(N) = \frac{w}{P} \tag{7}$$

The aggregate supply of goods and the stock of pollution is obtained as a residual in (5) and (6).

A competitive equilibrium ε is a set of goods, time and emissions and a factor price $\left\{\left\{c^{*h}, l^{*h}\right\}_{h=1}^{H}, E^{*}, \left(\frac{w}{P}\right)^{*}\right\}$ such that: [1] for each agent, $\left\{c^{*h}, l^{*h}\right\}$ is a solution to agent h's maximization problem, given pollution emissions E and the equilibrium price $\frac{w}{P}$; [2] $\{N^{*}, E^{*}\}$ is a solution to the representative firm, given the equilibrium price $\frac{w}{P}$; and [3] good and labor markets clear: $\sum_{h=1}^{H} c^{h} = F(N)$; and $\sum_{h=1}^{H} n^{hs} = N^{d}$.

Self-interest maximization leads each agent to equate her private marginal rate (of substitution or transformation) to the price ratio and results in the equalization of private rates, whereas Pareto optimality requires the equalization of social rates. The former can be seen by comparing (4) for each household h and (7):

$$\frac{\frac{\partial U^{h}(c^{h*}, l^{h*}, E^{*})}{\partial l}}{\frac{\partial U^{h}(c^{h*}, l^{h*}, E^{*})}{\partial c}} = F'(N^{*}) = \left(\frac{w}{P}\right)^{*}. \tag{8}$$

The latter is found in (1) and (2) for each h,

$$\frac{\frac{\partial U^{h}\left(\hat{c}^{h}, \hat{l}^{h}, \hat{E}\right)}{\partial l}}{\frac{\partial U^{h}\left(\hat{c}^{h}, \hat{l}^{h}, \hat{E}\right)}{\partial c}} = F'(\hat{N}) - \frac{\hat{\mu}}{\hat{\lambda}}\Lambda'(F(\hat{N}))F'(\hat{N}) \tag{9}$$

where the second term is positive. Therefore, this two conditions permit us to show that the competitive equilibrium with externalities is not Pareto optimal.

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where ρ is the portion of total workers who works at private good firm and $(1-\rho)$ is the portion who works at abatement firms. The aggregation of both firms gets the representative firm problem

$$\begin{aligned} \max_{A,\tilde{E},Y,N} \quad & \left[PY + (-t_{E})(\tilde{E} - R)\right] - wN - c(A) - T_{F} \\ \text{s.t.} \quad & Y = F(N\rho) \\ & \tilde{E} = \Lambda(F(N\rho)) = \Lambda(Y) \\ & R = R(N(1-\rho), \tilde{E}, A) \end{aligned}$$

where $E = \tilde{E} - R$.

Often the firm generating negative externalities will produce too much. However, the general equilibrium effects, namely the changes in price income variables, may countervail these intuitive results of partial equilibrium analysis (see Laffont, 1988, p.14). The same could happen here. First, taking $N(E) = (\Lambda \circ F)^{-1}(E)$, the function $\psi^*(E) = F'(N(E))$, at the left hand side of (8), is decreasing with pollution. Intuitively, the more emissions the more production is required and, then, the more labor; given the diminishing returns of the production function F, the productivity of labor decreases. The function $\hat{\psi}(E) = \psi^*(E)[1 - \sigma(E)]$, at the left hand side of (9), is also decreasing and always below $\psi^*(E)$, where $\sigma(E) = \frac{\mu}{\lambda}\Lambda'(F(N))$. See Figure1.

Second, the right hand side of (8) and (9) is the marginal rate of substitution between labor and consumption, $MRS^h(E) = \frac{\frac{\partial U^h\left(c^h(E), l^h(E), E\right)}{\partial l}}{\frac{\partial U^h\left(c^h(E), l^h(E), E\right)}{\partial c}}$. Its slope depends on the functional forms, since the derivative is

$$MRS^{h\prime}(E) = MRS^h(E)\left[\frac{\frac{\partial U^h\left(c^h(E), l^h(E), E\right)}{\partial l \partial E}}{\frac{\partial U^h\left(c^h(E), l^h(E), E\right)}{\partial l}} - \frac{\frac{\partial U^h\left(c^h(E), l^h(E), E\right)}{\partial c \partial E}}{\frac{\partial U^h\left(c^h(E), l^h(E), E\right)}{\partial c}}\right]$$

The sign of the $MRS^h(E)$ is uncertain. Two extreme cases. If the individuals' preferences are specified such that pollution only affects the "quality" of consumption, for example, $U^h(c^h, l^h, E) = v^h(c^h, E) + l^h$, then $MRS^h(E)$ is increasing and the competitive stock of pollution is higher than the optimum, i.e., $E^* > \hat{E}$. However, if the preferences are represented by a quasilinear utility function with a complementarity relation between pollution and leisure, i.e., $U^h(c^h, l^h, E) = c^h + v^h(l^h, E)$, then the $MRS^h(E)$ is decreasing. In this case the firm pollutes less than optimum, i.e., $E^* < \hat{\hat{E}}$. The explanation of this opposite results stems from the fact that in this model $MRS^h(E)$ is the labor supply. In fact, Figure 1 represents the labor market, since the direct monotonic proportionality between labor and pollution. The agents do not internalize the externality, by not being conscious that the more labor they supply, the more pollution are produced. Then $MRS^h(E)$ will be negative, and then the individual h's supply of labor is downwards slope, only if leisure is an inferior good for individual h. We should expect that substitution effect is higher than income effect in the labor market, so it is important for the over-pollution market solution.[8] If a positive supply of labor is assumed as the reasonable individual behaviour, this equilibrium we will find that the degree of pollution is not efficient, and firms generating negative externalities will produce too much.

In summary, firms optimize their profits by producing and hence polluting as desired. Households have some benefits for this behaviour, since they increase their income and consume more, but also receive costs, because a high degree of pollution makes them unhappy.

[8]However, one should take care on this issue when policy advise or a change on the tax scheme, are recommended.

3 Alternative mechanisms: The first-best solution.

Given that the equilibrium of the sort studied above results in an inefficient level of the externality, some kind of mechanisms can be implemented to achieve the Pareto optimal allocations. Any of these mechanisms must include the extraction of rents from those agents who produces the negative externality, and a transfer of income to those who suffers it. The literature has proposed several market institutions to achieve the first-best, where revelation of the true demand for the public good is required. We present two alternative possibilities: the creation of markets by specifying property rights and the personalized transfers mechanism.

3.1 Creation of markets by specifying property rights mechanism.

Suppose that each household h's consumption of the pollution has a market; that is, think of each household's consumption of the pollution as a distinct commodity with its own market. In addition, suppose that there exists a competitive firm that "sell" the pollution good (buy the "property rights" to households) with the input pollution from the firms which produces the private good. The firm is viewed as producing a bundle of H bads with a fixed-proportions technology, so the level of production of each personalized good is necessarily the same. This firm "buys" pollution from polluted firms (in fact, these firms pay to the former to receive pollution) and it is able to price each of them a (real) personalized price $\frac{\phi^h}{P}$, different across households. Thus this firm solves,

$$\max_{E} \quad \frac{q}{P}E - \sum_{i=1}^{h} \frac{\phi^h}{P}E$$

The profit maximization by the firm yields

$$\sum_{i=1}^{h} \frac{\phi^h}{P} = \frac{q}{P} \tag{10}$$

The problem of the representative firm changes. The profits are reduced since it must buy property rights (i.e., "sell" pollution) for producing the private good. Firm maximizes profits $\pi(E,N) = \left[Y - \frac{q}{P}E\right] - \frac{w}{P}N$ subject to (5)-(6). The first-order conditions are given now by

$$F'(N)\left(1 - \frac{q}{P}\Lambda'(F(N))\right) = \frac{w}{P} \tag{11}$$

Each household h maximizes the utility over consumption, the labor and the total amount of the externality (i.e., the total amount of her property rights on pollution emissions), subject to the budget constraint

$$c^h \;=\; \frac{w}{P}(T - l^h) + \frac{\phi^h}{P}E \tag{12}$$

The first order conditions for each household h are (4) and

$$\frac{\partial U^h(c^h, l^h, E)}{\partial E} + \frac{\phi^h}{P}\frac{\partial U^h(c^h, l^h, E)}{\partial c} \;=\; 0 \tag{13}$$

We thus obtain the individual h's supply functions for labor, and the supply of the property rights on the externality, as a function of the input prices and the personalized externality price $\frac{\phi^h}{P}$.

The property rights equilibrium is similar to the one defined above, where a set of equilibrium personalized prices $\{\frac{\phi^{**h}}{P}\}_{h=1}^{H}$ and a pollution price $\left(\frac{q}{P}\right)^{**}$ exists, and the supply of pollution equals it demand. Each household h is compensated by the negative externality they suffer. The equilibrium allocations resulting from the property rights mechanism are Pareto-efficient. Given that the firms' equilibrium level satisfies (10), together with the equilibrium conditions (11) and (13), we can find the optimal condition (3). This can be intuitively understood in Figure 1. We find a version of equation (8) from (11) and (13)

$$\frac{\frac{\partial U^h(c^{h**}, l^{h**}, E^{**})}{\partial l}}{\frac{\partial U^h(c^{h**}, l^{h**}, E^{**})}{\partial c}} = F'(N^{**})\left(1 - \left(\frac{q}{P}\right)^{**}\Lambda'(F(N^{**}))\right) = \left(\frac{w}{P}\right)^{**}.$$

Comparing this with (9), we can understand that the introduction of a property rights market moves the function $\psi^*(E)$ towards the origin, i.e., by obtaing $\psi^{**}(E) = \psi^*(E)\left(1 - \left(\frac{q}{P}\right)^{**}\Lambda'(F(N(E)))\right)$, until it matches with $\hat{\psi}(E)$. That is, when $\sigma(E) = \left(\frac{q}{P}\right)^{**}\Lambda'(F(N(E)))$ then the optimum is achieved.

Two final comment. First, the externality is eliminated, since the existence of this firm providing the pollution bad has two consequences. The agents who suffer the pollution can appropriate, through income transfer, from the firm's benefits of its pollution emission; and each household, taking the price of her personalized market as given, fully determines her own level of consumption of the externality bad. Second, this mechanism is very similar to the Lindalh mechanims usually refered in the public good literature.

3.2 Pigovian tax mechanism.

The inefficiency of the decentralized equilibrium can be restored by a suitable governmental tax/transfer scheme. Given that the firm pollution emission through production is larger because of its high returns, the government may penalize the generation of this negative externality by tax collection and, then, by compensating to those agents who suffer it. Think of a feasible scheme of taxes/transfers where each unit of pollution emitted by any firm is penalized. This tax finances a set of (real) personalized transfers $\{\frac{\phi^h}{P}\}_{h=1}^H$ that indicates what agent h is subsidize for each unit of the pollution emitted. Finally, the government budget constraint is balanced, i.e. $t_E E = \sum_{h=1}^H \frac{\phi^h}{P} E$.

The problem of the representative firm now is affected by the taxes. Firm maximizes profits $\pi(E, N, t_E) = [Y - t_E E] - \frac{w}{P} N$ subject to (5)-(6). The first-order conditions are given by

$$F'(N)\left(1 - t_E \Lambda'(F(N))\right) = \frac{w}{P} \tag{14}$$

Each household h maximizes the utility over consumption, the labor and the total amount of the externality (i.e., pollution emissions), subject to (12) The first order conditions for each household h are (4) and (13). We thus obtain the individual h's supply functions for labor, as a function of the input prices and personalized taxes, $\frac{\phi^h}{P}$.

The personalized taxes equilibrium is similar to the one defined in Section 3, where the government budget constraint is always balanced for a set of equilibrium personalized transfers, $\{\frac{\phi^{***h}}{P}\}_{h=1}^H$, and an equilibrium tax rate on emissions t_E^{***}. The equilibrium allocations resulting from the personalized taxes mechanism are Pareto-efficient. Given the government budget constraint, the equilibrium conditions (14) and (4), we can find the optimal condition (3). The same intuition as above can be found in Figure 1. The Pigovian tax moves the function $\psi^*(E)$ towards the origin, i.e., by obtaing $\psi^{***}(E) = \psi^*(E)\left(1 - t_E^{**}\Lambda'(F(N(E)))\right)$, until it matches with $\hat{\psi}(E)$. Notice that nature of government intervention corrects agents' behavior towards an appropriate provision of the externality by presenting a suitable tax scheme permits that $\sigma(E) = t_E^{**}\Lambda'(F(N(E)))$ to achieve the optimum.

4 The second-best solutions

If the government could pay a transfer to each household h an amount $\frac{\phi^{**h}}{P} E^{**}$ to offset the prejudices they suffer from the externality pollution emission, the Pareto optimum would be achieved, $E^{**} = \hat{E}$. The difficulty stems from the informational requirement that the preferences of households must be discovered in order to calculate the appropriate transfers. Since households do not sell emissions in the market, each household's level of supply E cannot be observed, nor is it possible for the government to verify that supply is the same as the production E^s, given her personalized transfer $\frac{\phi^h}{P}$. Intuitively, function $\psi(E)$ must move downwards and the $MRS^h(E)$ has to pivot. So the difficulty in implementing a demand revelation mechanism lead some authors to consider a second-best solution (see Laffont, 1988, Chap.7).

In order to find second best allocations, we first present the problem of the public sector. Suppose that there exists a Public Tax Office, an agency authorized by the central government to tax private agents, both households and firms, and to pay for public sector good expenditures. This Regulatory government office has a menu of implementable taxes to spend in the public sector good, g. This menu of taxes consists on a vector $\left\{\{T^h\}_{h=1}^{H}, t_w, t_c, T_F, t_E\right\}$; that is, some (exogenous) transfers to households T^h for $h \in H$, taxes on income t_w, on profits T_F, on consumption goods t_c, and on pollution t_E. The public sector budget constraint is

$$g + \sum_{h=1}^{H} T^h = t_E E + T_F + t_w \frac{w}{P} \sum_{h=1}^{H} (1 - l^h) + t_c \sum_{h=1}^{H} c^h \tag{15}$$

where the taxes t_E, T_F, t_w and t_c, and the household transfers T^h for all $h \in H$ are given. For the sake of simplicity we can assume that $g = 0$, so the government intend to get closer to the first best only by distorting prices. Observe the effect of each tax on equation (8). Taxes on on income, t_w, and pollution, t_E, moves the right hand side downwards. Taxes on income, t_w, transfers to households T^h and on consumption goods t_c, moves the left hand side. Each of the resulting allocations can be a second-best solution.

The the representative firm maximized profits $\pi(E, N, t_E, T_F) = [(-t_E E + Y) - \frac{w}{P} N - T_F]$ subject to (5)-(6), and given real wages $\frac{w}{P}$, and taxes t_E and T_F. The first-order conditions are given by

$$F'(N)\left(1 - t_E \Lambda'(F(N))\right) = \frac{w}{P} \tag{16}$$

Each household h maximizes the utility over consumption, and the labor supplied, subject to the budget constraint

$$(1 + t_c) c^h = (1 - t_w) \frac{w}{P} (T - l^h) + T^h$$

The first order conditions for each household h are

$$-\frac{\partial U^h(c^h, l^h, E)}{\partial l} + \frac{1 - t_w}{1 + t_c} \frac{w}{P} \frac{\partial U^h(c^h, l^h, E)}{\partial c} = 0$$

We thus obtain the individual h's supply functions for labor, as a function of the input prices and the taxes t_c, t_E and T^h.

A regulatory equilibrium ε is a set of goods, time and emissions and a factor price $\left\{\left\{c^{*h}, l^{*h}\right\}_{h=1}^{H}, E^*, \left(\frac{w}{P}\right)^*\right\}$ such that: [1] for each agent, $\left\{c^{*h}, l^{*h}\right\}$ is a solution to agent h's maximization problem, given pollution emissions E and the equilibrium price $\frac{w}{P}$; [2] $\{N^*, E^*\}$ is a solution to the representative firm, given the equilibrium price $\frac{w}{P}$; [3] the government budget constraint holds; and [4] good and labor markets clear: $\sum_{h=1}^{H} c^h = F(N)$; and $\sum_{h=1}^{H} n^{hs} = N^d$.

This equilibrium allocations are not Pareto optimal due the existence of the externality. The government could achieve higher social welfare if a government office can affect agents behaviour with taxes.

The Regulatory Office may choose the tax menu by maximizing the welfare of the agents in the economy weighted, e.g., by a political criteria,[9]

$$\sum_h \hat{\alpha}_h U^h\left(c^h, l^h, E\right)$$

where $\hat{\alpha}_h$ is the weight to agent $h \in H$ So the regulatory office choose a menu of taxes and the supply of the public sector good $\left\{\{T^h\}_{h=1}^H, t_E, t_c, t_w, T_F, g\right\}$ that maximizes its utility function, subject to its budget constraint (15), and given agents decisions on consumption and labor. The solution of the problem allows to find a public optimal pollution $\tilde{E} = \Upsilon\left(g, t_c, t_w, T^h, T_F, t_E; \{\alpha_h\}_{h=1}^H\right)$. Since there is an externality and distortionary taxes involved, allocations are not Pareto efficient. Some of the equilibrium resulting of these tax menus, however, could be found to be a second best solution.

5 The first and the second dividend

Next we carry out the experiment of introducing a green tax. The benchmark is an economy where no pollution tax exists, i.e., $t_E = 0$. Then, the effects of the introduction of the green tax, i.e., $t_E > 0$ are computed. The first dividend is the direct welfare gains due the reduction of the pollution. However, some costs are involved, because the reduction of the pollution is carried out by reducing production and, then, a reduction on agents consumption. That is, the natural environment is no more a free good, and the production possibilities of private goods decrease. The second dividend consists on the indirect welfare when the government devotes the amount of the pollution tax to decrease other distorting taxes, like income or consumption taxes. This reduction affects labor supply and consumption demand increasing production, although some costs arises, since the increase in production increases pollution again. The resulting equilibrium is an increase on welfare due the reduction of pollution, although the final offset forces are not clear. Our main goal is to establish the relationship between both dividends and offer a measure of its magnitude (taken into account that they are correctly computed). We believe that the general equilibrium analysis permit us understand those effects.

The benchmark was described in the previous section, taken $t_E = 0$. Then, the introduction of this tax permits the regulator to reduce other distorted taxes, like the tax on consumption and on income. Therefore

$$t_E E = \left[t_w \frac{w}{P}\sum_{h=1}^{H}(T - l^h) + t_c \sum_{h=1}^{H} c^h\right] - \left[(t_w + \Delta t_w)\left(\frac{w}{P}\right)' \sum_{h=1}^{H}(T - l'^h) + (t_c + \Delta t_c)\sum_{h=1}^{H} c'^h\right]$$

As a first approach to illustrate the first and second dividend, we present a very simple example. There are H households with the utility function $U^h(c^h, l^h, E) =$

[9]Some literature maximizes the households welfare *and* the firms profits. Recall that we are in general equilibrium, and households are the owner of the firms.

$\frac{c^h}{E} + 2\left(\theta\frac{l^h}{E}\right)^{\frac{1}{2}}$, production function is linear $Y = F(N) = AN$, and pollution is proportional to production $E = \Lambda(Y) = \frac{B}{A}Y$.

The benchmark model considers a tax menu $\{t_E, t_c, t_w\} = \{0, \bar{t}_c, \bar{t}_w\}$ with $T^h = 0$ for all household, $T_F = 0$ and $g = 0$. The first order conditions at the benchmark equilibrium gives us $\frac{\bar{l}^h}{\bar{E}} = \frac{\theta}{(A\bar{\tau})^2}$ and $\frac{\bar{c}^h}{\bar{E}} = \frac{A\bar{\tau}}{B}$, where $\tau = \frac{1-t_w}{1+t_c}$. The equilibrium level of pollution is given by $\bar{E} = \frac{BTH}{1+\frac{B\theta H}{(A\bar{\tau})^2}}$. Then any agent h's utility function is given by $\mathcal{U}^h(0,\bar{\tau}) = U^h\left(\bar{c}^h, \bar{l}^h, \bar{E}\right) = \frac{A\bar{\tau}}{B} + \frac{2\theta}{A\bar{\tau}}$. Therefore the aggregate utility function, given the equal weight for all households $\alpha_h = 1$, is $\mathcal{U}(0,\bar{\tau}) = \sum_h \alpha_h U^h\left(\bar{c}^h, \bar{l}^h, \bar{E}\right) = \left(\frac{A\bar{\tau}}{B} + \frac{2\theta}{A\bar{\tau}}\right)H$.

Now, if the government carries out a green tax policy, the tax menu will be change to $\{t_E, t_c, t_w\} = \left\{\tilde{t}_E, \tilde{t}_c, \tilde{t}_w\right\}$. The green tax equilibrium is similar to the described above after replacing the labor productivity, A, by $A(1-t_E)$. We will then obtain the ratios, $\frac{\tilde{l}^h}{\tilde{E}}$ and $\frac{\tilde{c}^h}{\tilde{E}}$, and the utility functions for individuals $\mathcal{U}^h(\tilde{t}_E, \tilde{\tau})$ and aggregate, $\mathcal{U}(\tilde{t}_E, \tilde{\tau})$. Observe that the new level of pollution $\tilde{E}$ is unclear since although it should be reduced because the increase of the pollution tax, it can be increased or decreased with the change in distorting taxes, i.e. if $\bar{\tau}$ is higher or lower than $\tilde{\tau}$.

The gains or losses in welfare are then given by the difference of $\mathcal{U}(\tilde{t}_E, \tilde{\tau}) - \mathcal{U}(0, \bar{\tau})$. Next we will distinguish between the first dividend and the second dividend. The first dividend is the welfare gain for decreasing pollution and increasing leisure, net of welfare loss for decreasing consumption when the pollution tax is introduced, that is, $FD = \mathcal{U}(\tilde{t}_E, \bar{\tau}) - \mathcal{U}(0, \bar{\tau})$. The second dividend is the welfare improvement resulting for changing the distorting taxes, i.e., $SD = \mathcal{U}(\tilde{t}_E, \tilde{\tau}) - \mathcal{U}(\tilde{t}_E, \bar{\tau})$. For the previous parametrization of preferences and production function, we can find the first dividend of this example as

$$FD = \mathcal{U}(\tilde{t}_E, \bar{\tau}) - \mathcal{U}(0, \bar{\tau}) = \tilde{t}_E\left[\frac{2\theta}{A\bar{\tau}(1-\tilde{t}_E)} - \frac{1}{B}\right]H$$

which should be positive in order the green tax policy has some sense of implementing. This first dividend given by the introduction of the pollution tax results on the decrease total pollution, an increase in leisure due to a lower production, but a lower level of individual consumption. The second dividend is given by

$$SD = \mathcal{U}(\tilde{t}_E, \tilde{\tau}) - \mathcal{U}(\tilde{t}_E, \bar{\tau}) = \Delta\tau\left[\frac{A(1-\tilde{t}_E)}{B} - \frac{2\theta}{A\tilde{\tau}\bar{\tau}(1-\tilde{t}_E)}\right]H$$

where $\Delta\tau = \tilde{\tau} - \bar{\tau}$, and given that government budget constraint must hold, i.e.,

$$\tilde{t}_E\tilde{E} = \left[\bar{t}_w\left(\frac{\bar{w}}{P}\right)\sum_{h=1}^{H}(T - \bar{l}^h) + \bar{t}_c\sum_{h=1}^{H}\bar{c}^h\right] - \left[\tilde{t}_w\left(\frac{\tilde{w}}{P}\right)\sum_{h=1}^{H}(T - \tilde{l}^h) + \tilde{t}_c\sum_{h=1}^{H}\tilde{c}^h\right]$$

The effect on pollution of the second dividend is unclear. For example, pollution will be even lower if $\Delta\tau > 0$. If $\Delta\tau < 0$ pollution increases, although it could (or could not) completely offset the previous reduction.

6 Conclusions

We have examined the first and the second dividend in a general equilibrium framework. The analysis clarifies the cost and benefits to be assigned to each dividend, which is blurred in the standard *ad-hoc* framework models. The model is ready for empirical analysis.

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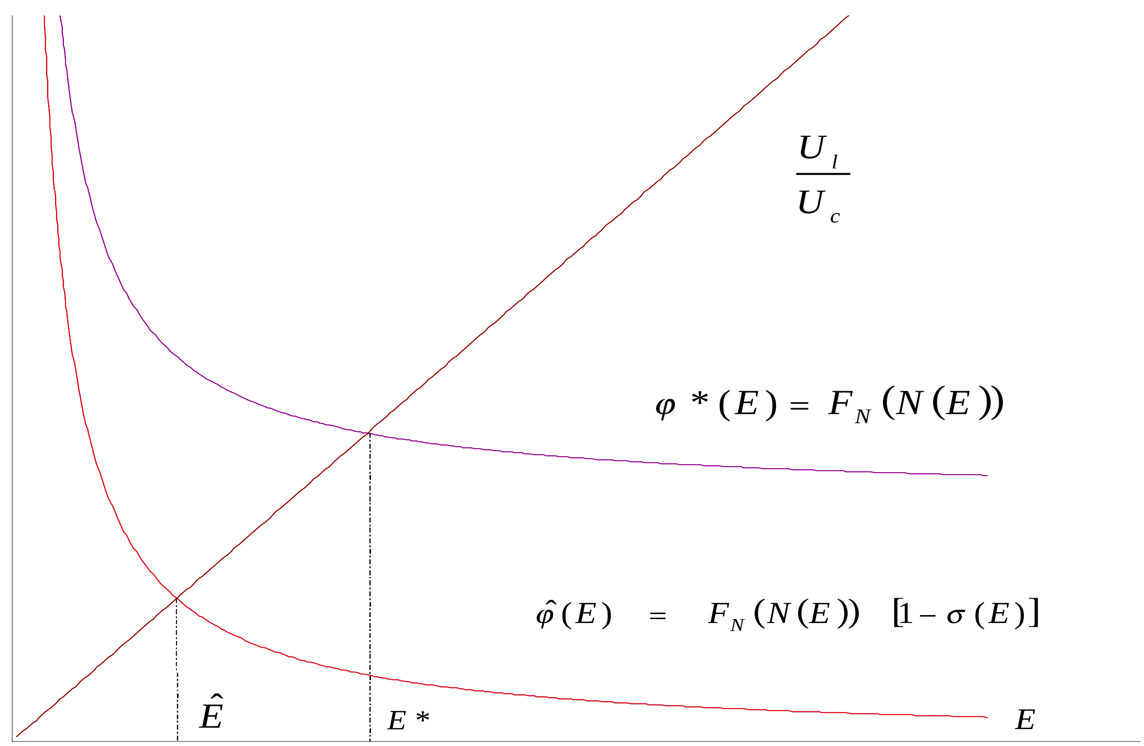
$\frac{U_l}{U_c}$
$\varphi^*(E) = F_N(N(E))$
$\hat{\varphi}(E) = F_N(N(E)) \; [1-\sigma(E)]$
$\hat{E}$
E^*
E