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Summary

This paper deals with the welfare analysis of green tax reforms. The aims of this paper are to highlight misinterpretations of policy assessments in the double dividend literature, to specify which of the efficiency costs and benefits should be ascribed to each dividend, and then, to propose a definition for the first dividend and the second dividend. We found the Pigou’s dividend more appropriate for policy guidance, in contrast to the Ramsey’s dividend usually found in mainstream literature. Therefore, we take up some authors’ recent claims about the need of unambiguous and operative definitions of these dividends both for empirical purposes, and political advice. Finally, the paper analyzes a green tax reform for the US economy to illustrate the advantages of our definitions for policy assessment. The new definitions proposed in this paper i) overcome some shortcoming of the mainstream current definitions in the literature regarding overestimation of the efficiency costs; and, ii) provide information by themselves and not as a partial view of the whole picture.

Keywords: Double Dividend, Green Tax Reforms, Ramsey’s Dividend, Pigou’s Dividend

JEL Classification: H23, Q58

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1. Introduction

This paper is concerned with the welfare analysis of *green tax reforms*, a two-step policy scheme consisting of setting a tax on emissions and then devoting the tax revenue to finance reductions in incentive-distorting taxes (e.g., labour or income taxes). As a result, the government may reap a *double benefit or dividend*: a cleaner environment, and additionally a less distorting tax system. The implementation of each policy step linked to this kind of tax reform, however, involves efficiency costs and benefits both on the consumption of environmental and non-environmental commodities.

The aims of this paper are to highlight misinterpretations of policy assessments in the double dividend literature, to specify which of the efficiency costs and benefits should be ascribed to each dividend, and then, to propose a definition to the first dividend and the second dividend. Therefore, we take up the recent claims about the need of unambiguous and operative definitions of these dividends both for empirical purposes, and policy advice. Finally, we analyze a green tax reform for the US economy to illustrate the advantages of our definitions for political implementation.

The case for green tax reforms is well rooted as academic research on the double dividend hypothesis within the so-called[1] "environmental view," (see Tullock, 1967, Terkla, 1984, Lee and Misiolek, 1986, and Pearce, 1991). These authors were mainly interested in the first dividend, assuming that reducing distorting taxes results in a welfare improvement, i.e., a positive second dividend. Their analysis, however, was built on a partial equilibrium approach, and had two important shortcomings: first, none of the proponents provided a full characterization of both dividends to allow for an unambiguous definition and policy analysis; and second, they failed to identify the interaction effects of environmental taxes with other distorting taxes, which might bring with some efficiency losses and would require a more general framework[2].

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[1] Schöb (1997) used the terms *environmental* and *public finance* view to classify the double dividend literature.

[2] See Goulder (1995), Parry (1995), and Parry, Williams and Goulder (1999). Among others, Bovenberg and de Mooij (1994), Bovenberg and Goulder (1996) and Parry (1995, 1997) pointed

Along the 90's a different strand of the literature, usually known as the "public finance" view, intended to overcome these difficulties by placing the discussion into the realm of optimal taxation in the general equilibrium framework previously developed by Sadmo (1975) (see Goulder, 1995, Bovenberg 1999, and Bovenberg and Goulder, 2002, for subsequent surveys). This line of research was mainly interested in the possibility of Goulder (1995)'s *strong double dividend*, taking for granted that setting an environmental tax improves the welfare related with the environment, i.e., a positive first dividend is achieved.[3] The main conclusion that can be drawn from this literature is that a strong double dividend occurs under rather "limited" circumstances (e.g., an initial non-optimal tax menu).

Yet the "public finance" approach may be subject to two critiques. First, the fact that the strong version of the double dividend hypothesis compares the equilibrium after the tax reform with the previous status quo, instead of analysing the two policy changes (i.e., the new environmental tax and the recycling of revenues), has lead several authors to assign incorrectly efficiency costs and benefits: the first dividend strictly accounts for the environment-related welfare changes after the green tax scheme is fully implemented, that is, the entire decrease of the externality; whereas the remaining non-environmental welfare changes are integrated in the second dividend. Consequently, this definition of the second dividend considers the non-environmental benefits and costs of green tax reforms. However, the goods being levied by the environmental tax accounts for a reduction in their consumer and producer surpluses; therefore, i) they are costs needed to improve efficiency and, ii) they should not treated as efficiency costs as some authors have done in the public finance approach, who consider "that an environmental tax is *distortionary*[,

out that the double dividend hypothesis is flawed because it ignores the *tax-interaction effect*, i.e., by raising costs and prices, environmental taxes aggravate the distortions of pre-existing taxes (by reducing the labor supply below its already suboptimal level).

[3] That is, whether an environmental tax reform enhances not only environmental quality but also non-environmental welfare, so that gross efficiency costs are negative after substituting an environmental tax for a distortionary tax (Bovenberg, 1999).

which would] imply a redefinition of this term as commonly understood" (Bohm, 1997, p.121)[4].

Actually, the definitions provided by the proponents of the "public finance" approach seem of not great help to avoid these misunderstandings. For example, Bovenberg and van der Ploeg (1994) definition of the "double dividend" hypothesis[5] focused the discussion on the behavior of the labor market considering the effects on employment as the second dividend.[6] Others have considered different definitions, such as fiscal benefits;[7] economic growth in terms of GDP and consumption;[8] increased output and economic welfare;[9] or a mixture of them.[10] These vague definitions, noted also in Pezzey and Park (1998, p.545), may lead to misinterpretations of policy assessments, since it overestimates the true efficiency costs of green tax reforms;[11] in addition, some authors, like Patuellia, Nijkamp and Pels (2005), recognize the difficulty to undertake an empirical analysis of the double dividend as long as "there is no 'standard' definition of the double dividend (or a standard method of recycling environmental tax revenues) in the literature." (p.566-567), and claim for "the choice of an operative definition of the double dividend to be kept constant throughout our [empirical] analyses." (p.576)

The second critique deals with the fact that the definitions of the first and second dividends do not provide information by themselves, but they represent

[4] For example, the Royal Society (2002) distinguishes four effects of green tax reforms, describing the *tax interaction effect* as "the distortionary effect of the pollution tax through its effects on raising the price of polluting goods." (p.5). Accordingly, Royal Society considers that an environmental tax on polluting goods reduces their consumer surpluses, which represents an efficiency cost. Another example, Bovenberg (1999) denotes all gross costs as efficiency cost.

[5] "The hypothesis that higher pollution taxes associated with more environmental concern would not only improve the environment but also boost employment (and hence the tax base)."

[6] See, for example,_ Bossier and Bréchet (1995), Kuper (1996), Carraro, Galeotti, and Gallo (1996), Majocchi (1996), Ligthart and Van Der Ploeg (1999), Jansen and Klaassen (2000), or Bayındır-Upmann (2004)

[7] For example, Morris, Révész, Zalai and Fucskó (1999).

[8] See Garbaccio, Ho, and Jorgenson (1999).

[9] See Jorgensen and Wilcoxen (1993).

[10] Bovenberg and van der Ploeg (1998) or Chiroleu-Assouline, and Fodha (2005).

[11] In this respect, it is illustrative that Bovenberg and Goulder (2002) have to state, to avoid misleading interpretations, that "these distortions in consumption patterns or input choice (primary costs) are desirable on environmental grounds" (p. 1501). They also recognize that "the failure of the double-dividend claim does not imply that green tax reforms are inefficient." (p. 1502).

a partial view of the whole picture. These definitions account for a global acceptance or rejection of a green tax reform, and not for the suitability of setting an environmental tax or the need to reform the tax system. Actually, we could trace the roots of this characterization in Ramsey's optimal taxation theory when externalities are absent; so, the second dividend, as the way it is treated in the public finance approach, could be termed then as the *Ramsey's dividend*. As a consequence, the requirement of a positive second dividend (as defined above) as a criterion to implement a green tax reform seems to be a very restrictive condition for the double dividend hypothesis. As Goulder (1994) noted, a positive second dividend would only prove the necessity to reform the current tax system, abstracting from any environmental concern.[12]

Clearly, these two previous critiques could have been avoided with an unambiguous definition for both dividends that did not create confusion among competing policy objectives, namely to reduce the level of an externality and to alleviate the tax distortions provoked by the fiscal system.

The present paper aims to clarify the debate about what should be included as efficiency benefits and costs in the measurement of the environmental and second dividend. In tune with Terkla (1984)'s spirit on the double dividend conjecture, the first dividend will measure the welfare costs and benefits after the implementation of environmental taxes when revenues are given back to households by lump-sum transfers. This first dividend comprises the net benefits from reducing external costs, the primary motivation for the environmental policy, which could be denoted as the *Pigou's dividend*, in contrast to the *Ramsey's dividend* in the public finance approach[13]. On the other hand, the second dividend will measure the welfare changes from recycling green tax revenues through lower distorting taxes instead of lump sum transfers; this second dividend comprises the net benefits from reducing

[12] In fact, some authors, like Bovenberg and Goulder (2002), have recognized that the environmental taxes could play an important role to ease political constraints to reform suboptimal initial tax systems, stating that "[...] environmental taxes are the lubricating oil that makes possible a tax reform to eliminate particularly bad taxes" (pp. 1507-08).

[13] It could be interpreted also in terms of Pigou's taxes in opposition to Ramsey's taxes. This terminology have been extensively used in the literature. See for example Mayeres and Proost (1997) or Bovenberg and Goulder (2002).

distorting taxes, the secondary motivation for green tax reforms, i.e., the "efficiency value of tax revenues" in Terkla (1984)'s terminology[14].

The proposed definitions show up two important advantages. First, it is avoided misunderstandings usually found in the double dividend literature, such as the identification between the second dividend and the efficiency costs of green tax reforms. Second, our definitions of the first and second dividends provide information by themselves and not as a partial view of the whole picture. Hence, the regulatory office is assisted to determine whether only a green tax should be set out regardless of the implementation of a green tax reform; or whether, additionally, raised revenues should decrease any distorting taxes. In fact, these definitions could be considered as a reformulation of Goulder (1995)'s weak form of the double dividend hypothesis,[15] which compares two policy changes with different recycling options. In addition, Goulder (1995)'s strong form is equivalent to the sum of the new first and second dividends put forward in this paper.

For illustration purposes, we calibrated the theoretical model with a numerical example for the US economy on 1995. We simulated a green tax reform by introducing a $10 tax per ton of carbon with revenues devoted to reduce the income tax. We show that alternative definitions for both dividends arrive to very different conclusions: following the public finance approach we might conclude that the green tax reform improves welfare, but there is a negative second dividend as expected. However we found a positive double dividend when we use the new definition proposed in this paper.

The paper develops through the following sections. In Section 2 we present the Pareto-optimal allocation and the competitive equilibrium in our general

[14] Interestinlgy, this definition was already writen in Mayeres and Proost (1997, footnote 12) but as a result of a misinterpretation of Goulder (1995)'s terminology. There are several problems with Mayeres and Proost (1997)'s terminology: (i) the absence of a proper definition, (ii) it is not clear if their first dividend includes only welfare effects related to changes in the externalities only, and (iii) we can not be sure what they are really measuring by their first and second dividend in their empirical exercise when we compare explanations in main text, Table 2a and footnote

[15] That is, efficiency costs of a revenue-neutral environmental tax reform are lower if the additional revenues from the environmental taxes are recycled in the form of lower distortionary taxes compared to the case that these revenues are recycled in a lump-sum fashion.

equilibrium framework. A feature of the model is that it allows to understand the magnitude of the inefficiency of market allocation of resources in the presence of externalities, and to compare the results (even graphically) in a general equilibrium setting with those found in well-known standard partial equilibrium analysis. Section 3 is concerned with the welfare effects of green tax reforms, and it aims to measure the first and second dividends in a general equilibrium set-up. It presents the competing approaches in the double dividend literature and shows that the "public finance" view overestimates the efficiency costs of green taxes. As a consequence, this section proposes a definition for the first and second dividends. Section 4 carries out a numerical example for the US economy showing that a positive double dividend could be possible, as opposed to the public finance approach, to conclude that the green tax reform will raise *gross efficiency costs*. Finally, Section 5 summarizes conclusions and policy implications.

2. The social optimum and the decentralized allocation

This section presents a framework to determine the social optimum and the decentralized market equilibrium allocation of resources with externalities. This will be the benchmark set-up for further discussion on green tax reforms along subsequent sections. One contribution of this section is to establish the correspondence between the well-known partial equilibrium and the general equilibrium counterpart through a graphical analysis.

We develop a static rational general equilibrium model with an externality. There are two types of agents: heterogeneous households in preferences, and firms. There are a number of perfectly price-taker competitive firms and a technology with constant returns of scale; therefore, a single aggregate polluting firm could be considered. Labor N is the only input required to produce a private good $Y = F(N)$ and pollution $E = \Lambda(F(N))$. This formulation recognizes the complementary relationship between the production of the private good Y and emissions E. We will consider this relationship to be represented by a real monotonically increasing function $\Lambda()$. Hence, the production function can be considered a homomorphic function Ψ on R_+^2 such that $\Psi(N)=(Y,E)=\left(F(N),\Lambda(F(N))\right)$.

Each household *h* is endowed with *T* units of time (e.g., hours per year) that are allocated between working time n^h and leisure time l^h. The model is static, so there are neither savings nor capital accumulation. Households enhance welfare by consuming the private good c^h and leisure time l^h and, in addition, the pollution E produced by firms affects each negatively. Their preferences are represented by a twice-differentiable continuous utility function $U^h(c^h,l^h,E)$, verifying $\partial U^h/\partial c$, $\partial U^h/\partial l$ are positive and $\partial U^h/\partial E$ is negative, and $\partial^2 U^h/\partial c^2$ and $\partial^2 U^h/\partial l^2$ are negative while $\partial^2 U^h/\partial E^2$, $\partial^2 U^h/\partial c\partial l$ and $\partial^2 U^h/\partial l\partial c$ are positive[16].

The Pareto social optimum level of emissions. The social planner maximizes the agents' weighted welfare function subject to the technology to produce pollution and the private good, and the feasibility conditions: consumption of goods equals private good production, $\sum_{h=1}^{H} c^h = Y$; the total number of hours worked at firms is equal to the sum of labour made by each households, $\sum_{h=1}^{H} n^h = N$; and, each household endowment of time is devoted to working activities and leisure, $n^h + l^h = T^h$.

The Pareto optimal allocations are given by $\left\{\{\hat{c}^h,\hat{l}^h\}_{h=1}^{H},\hat{Y},\hat{N},\hat{E}\right\}$ following the optimal Samuelson-Lindalh condition,

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

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

and

$$\frac{\partial U^h\left(\hat{c}^h,\hat{l}^h,\hat{E}\right)/\partial l}{\partial U^h\left(\hat{c}^h,\hat{l}^h,\hat{E}\right)/\partial c} = F'(\hat{N})\left[1-\frac{\hat{\mu}}{\hat{\lambda}}\Lambda'(F(\hat{N}))\right] \tag{1}$$

where λ and μ are the positive Lagrangian multipliers, namely the former represents the social marginal utility from individual consumption of the private good, whereas the latter stands for the social marginal utility from pollution. Under this condition, the marginal rate of substitution between leisure and consumption equals the marginal productivity of labor at the optimum. In other words, an individual supplying one extra unit of working time increases production and their consumption, but also it rises the environmental damages suffered by society which the social planner must internalize.

Decentralized level of emissions. In the decentralized competitive equilibrium firms maximize their profits, which must be equal to zero as long as we assume price-taker competitive firms and constant returns to scale. As a consequence, labour payment will be the only source of income, although households are the owners of the firms. Each household h maximizes utility subject to the income restriction $c^h = \frac{w}{P}(T-l^h)$, where the real wage is $\frac{w}{P}$. There is not a market for pollution; therefore, competitive firms do not care about the externality and each household takes the amount of pollution as given. Then we find the optimal market allocations given by $\left\{\{c^{h*},l^{h*}\}_{h=1}^{H},Y^*,N^*,E^*\right\}$, and the first order condition for allocation of resources. As a result, the marginal rate of substitution between leisure and consumption equals the marginal productivity of labor at the market equilibrium:

$$\frac{\partial U^h(c^{h*},l^{h*},E^*)/\partial l}{\partial U^h(c^{h*},l^{h*},E^*)/\partial c} = F'(N^*) = \left(\frac{w}{P}\right)^*. \tag{2}$$

Individual self-interest leads each agent to equate their private marginal rate of substitution (or transformation) between leisure and the private good to relative prices, which results in the equalization of private rates among agents. On the contrary, Pareto optimality requires the equalization of social rates and, therefore, conditions (1) and (2) permit us to show that the competitive equilibrium with externalities is not Pareto efficient.

Pareto social optimum and decentralized level of emissions: a graphical analysis of partial and general equilibrium approaches. We can illustrate the previous conclusion with the usual partial equilibrium analysis (see Figure 1). The MPB curve represents the Marginal Private Benefits from polluting activities, which is the sum of the consumers and producers surplus. In absence of public regulation, the competitive equilibrium at the level of emissions E^* is determined by the condition of null marginal private benefits from extra consumption and production.

Figure 1. Social optimum and decentralized level of pollution in partial equilibrium analysis

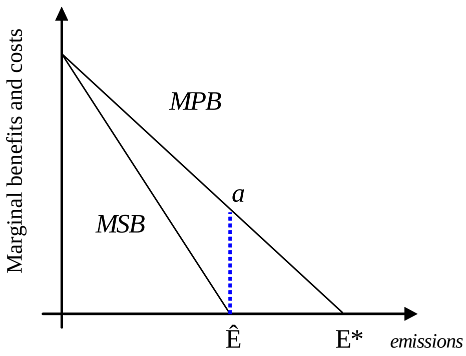


Figure 1a

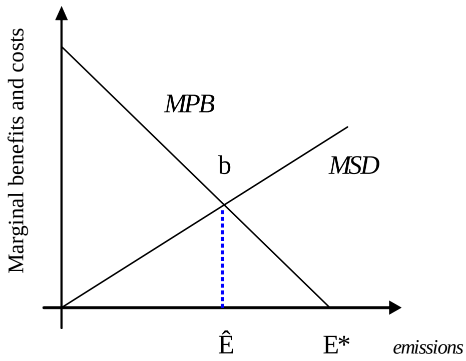


Figure 1b

source: the authors

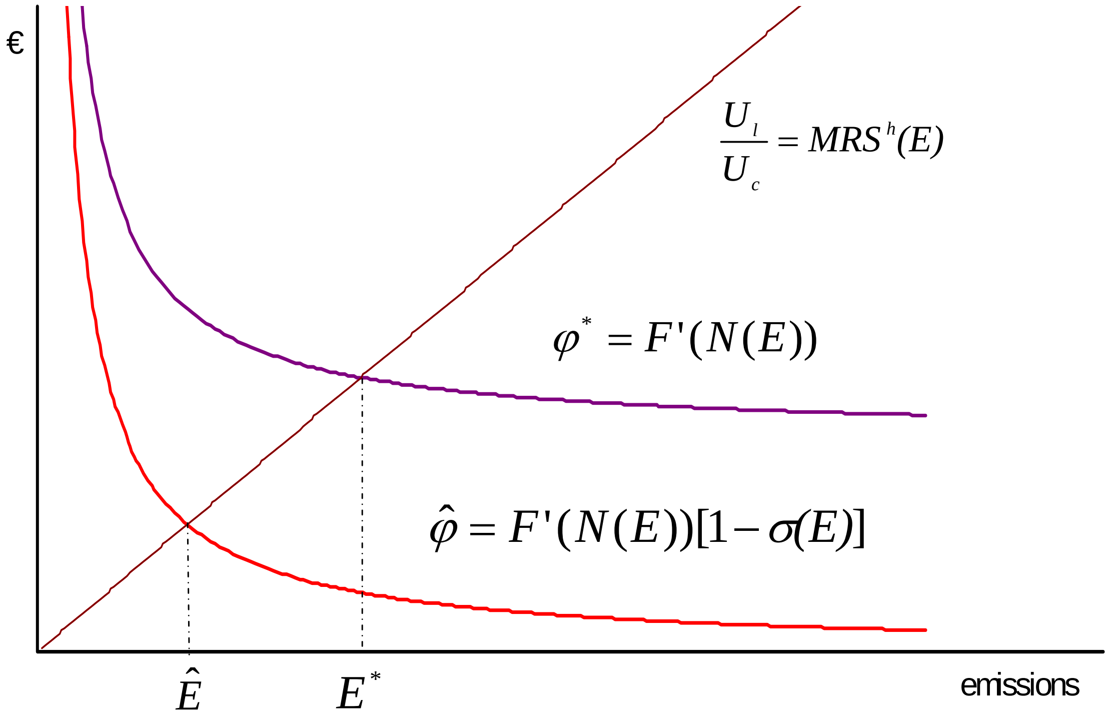
The social optimum is determined by the intersection point between the Marginal Social Damage from emissions (MSD), that is the monetarization of the negative externality, and marginal private benefits (MPB) in Figure 1b. This result could be also represented graphically with the level of pollution that makes null the Marginal Social Benefits from emissions (MSB), i.e. MPB minus

MSD. Therefore, the area (integral) under the MSD function in Figure 1b in the range $\left[\hat{E}, E^*\right]$, over all individuals, represents the external social costs.

It is straightforward to establish the graphical equivalence between the partial equilibrium analysis in Figure 1 and our general equilibrium framework. First, denote the function $N(E) \equiv \left(\Lambda \circ F\right)^{-1}(E)$. Then, the function $\varphi^*(E) \equiv F'(N(E))$, at the right hand side of (2), is decreasing with pollution because of the decreasing returns to scale of the production function F. Intuitively, the increase in labor is more than proportional to the increase in production and emissions. Finally, the function $\hat{\varphi}(E) \equiv \varphi^*(E)[1-\sigma(E)]$, on the right hand side of (1), is also decreasing and always below $\varphi^*(E)$ as $\sigma(E) = \frac{\mu}{\lambda}\Lambda'(F(N)) > 0$. Second, the left hand side of (1) and (2) is the marginal rate of substitution between labor and consumption, $MRS^h(E) = \frac{\partial U^h\left(c^h(E), l^h(E), E\right)/\partial l}{\partial U^h\left(c^h(E), l^h(E), E\right)/\partial c}$.

Figure 2 provides some hints about the amount of external costs in our general equilibrium setup. The term $\sigma(E)$, which is the difference between $\varphi^*\left(E\right)$ and $\hat{\varphi}\left(E\right)$, is the marginal damage from one extra unit of labor supplied by agent h. Thus the area (integral) between these two functions in the range $\left[\hat{E}, E^*\right]$, over all individuals, represents the external social costs. Therefore, it is straightforward to establish the equivalence between the partial equilibrium analysis in Figure 1a and our general equilibrium framework in Figure 2.

Figure 2. Social Pareto optimum and decentralized level of pollution in general equilibrium analysis.



source: the authors

The firm generating negative externalities will often produce too much, as in the partial equilibrium illustration in Figure 1. However, the general equilibrium effects, namely, the changes in price and income variables, may countervail these intuitive results of partial equilibrium analysis (see Laffont, 1988, p.14). The same could happen here. Note first that the slope of $MRS^h(E)$ depends on the functional forms where the derivative is

$$MRS^{h\prime}(E) = MRS^h(E)\left[\frac{\partial^2 U^h\left(c^h(E),l^h(E),E\right)/\partial l\partial E}{\partial U^h\left(c^h(E),l^h(E),E\right)/\partial l} - \frac{\partial^2 U^h\left(c^h(E),l^h(E),E\right)/\partial c\partial E}{\partial U^h\left(c^h(E),l^h(E),E\right)/\partial c}\right], \quad (3)$$

which could either take a positive or a negative sign. We explore three extreme cases for functional forms. First, pollution could be separable in the utility function, not related to other variables, e.g., the quasilinear approach $U^h(c^h,l^h,E) = u^h(c^h,l^h) + v^h(E)$. In this case, pollution has no effect on labor supply, the $MRS^h(E)$ function is constant and then the competitive stock of pollution is greater than the optimum, i.e., $E^* > \hat{E}$. The same happens if the individuals' preferences will be specified such that pollution only affects the "quality" of consumption, for example, $U^h(c^h, l^h, E) = v^h(c^h, E) + l^h$: $MRS^h(E)$ has a positive slope and again $E^* > \hat{E}$. However, if the preferences have been represented by a quasilinear utility function with a complementary relationship between pollution and leisure, i.e., $U^h(c^h, l^h, E) = c^h + v^h(l^h, E)$, then the $MRS^h(E)$ would be decreasing. Firms will pollute less than optimum, i.e., $E^* < \hat{\hat{E}}$, if there is a strong enough complementary relationship between pollution and leisure, that is, in the case that the $MRS^h(E)$ slope is lower than the $\varphi(E)$ slope in Figure 2. This result could never arise in partial equilibrium analysis as described in Figure 1.

In the real world, however, a complementary relationship between pollution and leisure as well as between pollution and consumption are expected, so whether the $MRS^h(E)$ slope is greater than the $\varphi(E)$ slope in Figure 2 is an empirical issue to be tested.

3. The double dividend of green tax reforms.

This section is concerned with the welfare effects of green tax reforms, and it aims to measure the first and second dividends of green tax reforms in a general equilibrium set-up. The main results in this section are the following: (i) the usual definitions of first and second dividends in the literature overestimates the efficiency costs of green tax reforms; and (ii) the analysis and definitions proposed below clarifies the welfare contributions of green tax reforms schemes, an issue of great interest for academic and political discussion on this kind of environmental regulation, as it will be shown in section 4.

The decentralized equilibrium allocations found in the previous section are not Pareto optimal because of the externality. However, the government could achieve a higher level of social welfare by affecting agents' behavior with taxes, resulting in second-best allocations.[17] We proceed first by illustrating green tax reforms as a second-best solution when distortionary taxes finance the public budget. Suppose that there is a Public Tax Office, an agency authorized by the central government to tax private agents, both households and firms, in order to finance some (exogenous) lump-sum transfers to households, i.e., T^h for $h \in H$. The menu of taxes $\{t_w, t_c, t_E\}$ consists of taxes on income t_w, on consumption goods t_c, and on pollution t_E. The budget constraint of the public sector is,

$$\sum_{h=1}^{H} T^h = t_E E + t_w \frac{w}{P} \sum_{h=1}^{H} (T - l^h) + t_c \sum_{h=1}^{H} c^h . \tag{4}$$

The representative firm maximizes profits subject to technological constraints and each household *h* maximizes its utility subject to the budget constraint, $(1 - t_c)c^h = (1 + t_w)\frac{w}{P}(T - l^h) + T^h$. Then it is straightforward to find that the optimal condition for equilibrium is the following, given the government budget constraint:

$$\frac{\partial U^h\left(\tilde{c}^h, \tilde{l}^h, \tilde{E}\right)/\partial l}{\partial U^h\left(\tilde{c}^h, \tilde{l}^h, \tilde{E}\right)/\partial c} = \tau F'(\tilde{N})\left[1 - t_E \Lambda'(F(\tilde{N}))\right],$$

where

$$\tau = \frac{1 - t_w}{1 + t_c}$$

represents the individual value of one extra unit of net income of taxes. Therefore, in a second-best equilibrium, the marginal rate of substitution equals the market productivity of labor net of taxes. Observe that a rise on any of the tax rates moves the right-hand side downwards.

Next we analyze the welfare effects of green tax reforms. For the sake of easier exposition, suppose that the welfare function is separable between consumption

[17]It might be Pareto optimal if the consumption, labor and pollution taxes are set as $t_c = -t_w$ and $t_E = \frac{\mu}{\lambda}$, but we presume positive tax rates, uniform across all individuals. HoweverAn environmental tax like $t_E = \frac{\mu}{\lambda}$ is not possible in the real world because of two reasons: (a) it should take a different value for each individual (actually, it is the value for optimal compensations); and, (b) it is supposed to be a tax on polluters.

of environmental quality and consumption of other goods (leisure and the private good), so that any agent h's utility function is given by $U^h\left(c^h, l^h, E\right) = u^h\left(c^h, l^h\right) + v^h\left(E\right)$. The social welfare function is the weightened aggregation of individual welfare levels, that depends on the tax menu defined by the Public Tax Office,

$$U(t_E, \tau) = u\left(C(t_E, \tau), L(t_E, \tau)\right) + v\left(E(t_E, \tau)\right) \equiv$$

$$\equiv \sum_{h=1}^{H} \left[\alpha_h u^h\left(c^h(t_E, \tau), l^h(t_E, \tau)\right) + \alpha_h v^h\left(E(t_E, \tau)\right)\right]$$

where *C* and *L* are the aggregate level of consumption and leisure, respectively, and α_h is the weight for household h.

We characterize two scenarios: the pre-reform case with no environmental taxes (denoted as the benchmark case), where the tax menu is given by $\left\{t_E, t_c, t_w\right\} = \left\{0, t_c^0, t_w^0\right\}$; and, the post-reform after the green tax reform, where the tax menu will change to $\left\{t_E, t_c, t_w\right\} = \left\{t_E^1, t_c^1, t_w^1\right\}$. In the benchmark case the social welfare level is given by $U(0, \tau^0) = u\left[C(0, \tau^0), L(0, \tau^0)\right] + v\left[E(0, \tau^0)\right]$, whereas $U(t_E^1, \tau^1) = u\left[C(t_E^1, \tau^1), L(t_E^1, \tau^1)\right] + v\left[E(t_E^1, \tau^1)\right]$ is the welfare level achieved after the green reform. Therefore, the difference between the two scenarios welfare level, $U(t_E^1, \tau^1) - U(0, \tau^0)$, represents the gains or losses of implementing the green tax reform.

Finally, the welfare changes from green tax reforms could be decomposed between the first and the second dividend, following the double dividend hypothesis. A *first* or *environmental dividend* exists because environmental taxation reduces pollution and other negative externalities. There is a *second dividend* when reductions in incentive-distorting taxes results in a lower excess of burden. As pointed out by several authors (e.g. Labandeira, 1998), these definitions are too vague to permit a single interpretation or a precise measurement, and the literature shows alternative views on the double dividend hypothesis, gathered into two main strands referred to as the "environmental" and the "public finance" approaches.

3.1. The environmental approach

The "environmental view" is the departure point for the double dividend hypothesis, and was originated on the research of Tullock (1967), Terkla (1984), Lee and Misiolek (1986), and Pearce (1991). This view stresses the desirability of environmental taxation because they could give some extra-benefits to society: first, they are one of the most efficient instruments for pollution control; and second, they provide an extra efficiency value when revenues finance reductions on other distorting taxes, instead of bringing them back to households by lump-sum transfers (see Terkla, 1984).

Their analysis, built on a partial equilibrium approach, makes use of Figure 1 to highlight that emission level above $\hat{E}$ represents an inefficient allocation of resources. Therefore, it is necessary to reduce emissions and consumption in order to improve efficiency and social welfare. The area under the marginal private benefit (MPB) curve in the range [$\hat{E}$, E^*] represents the costs of reducing inefficient levels of emissions and consumption (i.e., lower consumer surplus from polluting goods). As a consequence, they concluded that there are no deadweight losses (efficiency losses) from green taxes as resources get closer to the social planner efficient allocation as shown in Section 2.

But this is only true within a partial equilibrium analysis. The interaction of green taxes with other distorting taxes may raise some efficiency losses (see Goulder, 1995; Parry, 1995; and Parry, Williams and Goulder, 1999). Unfortunately, due to the extensive use of partial equilibrium approaches, this view does not provide a full characterization of both dividends to allow for an unambiguous definition and policy analysis.

3.2. The public finance approach

The "public finance" view has become the most widespread in literature in the 90's (see Bovenberg and Goulder, 2002, for a survey). This literature is mainly concerned with the non-environmental side of welfare changes from green tax reforms taking for granted a positive environmental dividend, which probably stems from the difficulty of economic evaluation of the environmental benefits. By circumventing these problems, this approach studies the efficiency gains or losses in the tax system after the introduction of environmental taxes, thus undertaking cost-effectiveness analysis that may be suitable for policymaker advice.

Unlike the previous view, the use of general equilibrium tools within the "public finance" approach allows for a full charaterization of the first and second dividend (as an illustration, see Schöb, 1996; Hakonsen, 2001; Mayeres and Proost, 2001). The first dividend strictly accounts for the environmentally related welfare changes after the green tax scheme is completely implemented, i.e., the decrease of the externality, and it could be formalized as

$$FD_{PF} = u\left[E(t_E^1, \tau^1)\right] - u\left[E(0, \tau^0)\right].,$$

whose positiveness is assumed by the public finance view. The remaining non-environmental welfare changes are integrated in the second dividend, that is

$$SD_{PF} = u\left[C(t_E^1, \tau^1), L(t_E^1, \tau^1)\right] - u\left[C(0, \tau^0), L(0, \tau^0)\right].$$

Thus, the focus of the "public finance" view is on the second dividend and, mainly, on the efficiency of the tax system to raise fiscal revenues. Actually, we could trace the roots of this characterization in Ramsey's optimal taxation theory when externalities are absent. So the second dividend, as the way it is treated in the public finance approach, could be termed then as the *Ramsey's dividend*.

The "public finance" approach may be subject to criticism. First, the definition of the second dividend includes some costs that cannot be treated as efficiency costs, which otherwise would “imply a redefinition of this term as commomly understood” (Bohm, 1997, p.121). We showed in Figure 1 that primary costs[18], represented by the area under the MPB curve in the range $[\hat{E}, E^*]$, are the costs of reducing inefficient levels of emissions and consumption and should not be regarded as *efficiency* costs. As long as the Ramsey or second dividend, attending to the public finance view, considers the non-environmental efficiency benefits and costs of green tax reforms, this may lead to misinterpretations of policy assessments. Consequently, it overestimates the true efficiency costs of green tax reforms. In this respect, it is illustrative that Bovenberg and Goulder (2002) have to state, to avoid misleading interpretations, that "these distortions in consumption patterns or input choice (primary costs) are desirable on environmental grounds" (p. 1501), as well as to recognize that "the failure of the double-dividend claim does not imply that green tax reforms are inefficient" (p. 1502).

Therefore, it would be desirable to consider an unambiguous definition for both dividends which does not create confusion among competing policy objectives, namely to reduce the level of an externality and tax distorsions due to the fiscal system. Accordingly, it is attractive to have "a sort of separability in the tax structure, which might be taken to suggest that environmental taxes should be employed *first*, with the Ramsey taxes being used to fill up the tax revenue requirements" (Sandmo, 1995, p. 24).

The second critique refers to the fact that the definitions of the first and second dividends do not provide information by themselves, but they represent a partial view of the whole picture. These definitions accounts for a global acceptance or rejection of a green tax reform, and not for the suitability of setting an environmental tax or the need to reform the tax system. This global assessment is not in tune with Terkla (1984)’s spirit on the double dividend conjecture. As a consequence, the requirement of a positive second dividend (as defined above) as a criterion to implement a green tax reform seems to be a very restrictive condition for the double dividend hypothesis. Goulder (1995) noted that a

[18] For an illustration of the diverse effects related to environmental taxes, e.g., primary costs, tax interaction effect, and revenue recycling effects, see Parry, Williams and Goulder (1999).

positive second dividend would only prove the necessity to reform the current tax system, abstracting from any environmental concern.[19] Accordingly, we suggest that more orthodox analyses should consist of integrating Ramsey and Pigou approaches establishing a parallelism with Bovenberg and Goulder (2002, pp.1484-5).

3.3. A proposal of definition

Next, we propose a new definition for both dividends that overcome both critiques, and formalizes Goulder (1995)'s weak form of the double dividend hypothesis. The first dividend will measure the welfare costs and benefits after the implementation of environmental taxes when revenues are given back to households by lump-sum transfers, and it will be formalized as

$$FD_{new} = U(t_E^1, \tau^0) - U(0, \tau^0) =$$
$$= u\left[E(t_E^1, \tau^0)\right] - u\left[E(0, \tau^0)\right] + u\left[C(t_E^1, \tau^0), L(t_E^1, \tau^0)\right] - u\left[C(0, \tau^0), L(0, \tau^0)\right].$$

These are the net benefits from reducing external costs, the primary motivation for the environmental policy. Accordingly, it could be denoted as the *Pigou's dividend*, in contrast to the *Ramsey's dividend* in the public finance approach. Therefore, the Public Tax Office should set an environmental tax t_E whenever the first dividend has a positive sign. The second dividend will measure the welfare changes from recycling green tax revenues through lower distorting taxes instead of lump sum transfers, that is

$$SD_{new} = U(t_E^1, \tau^1) - U(t_E^1, \tau^0) =$$
$$= u\left[E(t_E^1, \tau^1)\right] - u\left[E(t_E^1, \tau^0)\right] + u\left[C(t_E^1, \tau^1), L(t_E^1, \tau^1)\right] - u\left[C(t_E^1, \tau^0), L(t_E^1, \tau^0)\right].$$

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[19] In fact, this author distinguishes between the *weak double dividend* and the *strong double dividend*. The latter stands whenever a positive second dividend exists. The former holds as long as green tax reforms achieve higher welfare levels by cutting existing distorting taxation, financed by environmental tax revenues, instead of returning the revenues to taxpayers by lump-sum transfers. There is no theoretical or empirical controversy about the achievement of weak double dividends by green fiscal reforms (lump-sum transfers do not provide any extra benefit to the economy). Researchers have turned to looking for conditions to get positive strong double dividends, assuming some effectiveness on pollution reduction. The *weak* and *strong dividend* definitions arose as a consequence of the rather limited meaning of the double dividend approach followed by the public finance view.

These are the net benefits from reducing distorting taxes, the secondary motivation for green tax reforms, i.e., the "efficiency value of tax revenues" in Terkla (1984)'s terminology. The reduction in distorting taxes affects labor supply and consumption which increase production and welfare as well; besides, some costs arise due to increased pollution from higher production levels go with, which also increase pollution.

Observe that our definitions make clearer Pezzey and Park (1998, sec.4) exposition, avoiding some shortcomings (see their footnote 3), and could be rewritten as follows. The *weak* form of the double dividend claim is that $U(t_E^1, \tau^1) > U(t_E^1, \tau^0)$, also known as the "revenue-recycling effect"; that is, welfare is raised by using the revenue of the environmental tax to lower the distortionary tax instead of to give taxpayers lump sum subsidies. And, the *strong* form is that $U(t_E^1, \tau^1) > U(0, \tau^0)$; that is, there is an economic benefit from the revenue-neutral substitution of a new environmental tax for a change in a typical distortionary tax, so that the regulatory office should fully implement a green tax reform. With regard to our proposal of definition, the strong form is equivalent to the sum of the new first and second dividends put forward in this subsection.

Our definitions of the first and second dividends have relevant implications for policy implementation, as they establish a criterium on whether only a green tax should be set out or whether, additionally, raised revenues should decrease any distorting taxes. Besides, it avoids misleading interpretations like identification of gross costs from green tax reforms with efficiency costs.

Next we show the advantages of our definition with respect to alternative one for political assessment in a numerical example for 1995 US data.

4. An illustration for the US economy

In this section, we undertake the experiment of introducing a green tax reform for the 1995 US economy. Our main goal is to compare our definition of the first and second dividend with that proposed by the public finance view, and to numerically assess the policy implications of the implementation of a green tax reform in a general equilibrium model.

The set-up is the same as the one studied in previous sections, except for one extension on the supply side. Instead of one technology that produces one output with the labor input, we will consider two technologies that produce two final goods in the economy: an energy-intensive good X and a non-energy-intensive good Y, both produced with two inputs, labor L and an intermediate pollution input, P (Power). These extensions will be shown to be useful for improving the model's ability to gauge the empirical significance of competing definitions for the dividends.[20] In the appendix, we compute analitically a simplified version of this general equilibrium model without intermediate inputs, which displays algebraically the relationship between different definitions of the first and second dividend[21]; furthermore, it allows us to understand why a green tax reform cannot achieve the optimal tax menu. In order to undertake a numerical example, we take the following functional forms.[22] The production technology for the two industries is a constant elasticity of substitution (CES) function,

$$X = [\gamma P_x^{\rho_i} + (1-\gamma) L_x^{\rho_i}]^{1/\rho_i}$$
$$Y = [\delta P_y^{\rho_i} + (1-\delta) L_y^{\rho_i}]^{1/\rho_i}$$
$$E_x = \Lambda(P_x) = \vartheta P_x$$
$$E_y = \Lambda(P_y) = \vartheta P_y$$
$$E = E_x + E_y$$

where γ, ϑ, δ and ρ_i are technological parameters and σ_i is the elasticity of substitution between inputs satisfying the condition that $\sigma_i = 1/(1-\rho_i)$. Preferences are also assumed to be represented by two nested CES utility

[20]For example, if there is only one good, it is easy to show that any tax menu is always burdened by the same item. Consequently, the equilibrium allocations after a green tax reform are exactly the same as the initial one. Interestingly, this means that the public finance view definitions of first and second dividends are both equal to zero, whereas ours are not zero but with the opposite sign.
[21]This approach is justified because derivation of first-order conditions from the numerical model is much more complicated and the expression for the dividends becomes meaningless.
[22]See Parry, Williams and Goulder (1999) for a similar approach. Analogous to that paper, we make use of the software package GAMS/MPSGE and the algorithm solver PATH to solve the numerical model.

functions with environmental damages included as a separable element affecting individual welfare: in the outer nest, the CES function combines the consumption of leisure l and goods produced by the firms C; while the inner nest combines the consumption of goods X and Y, That is,

$$U^h(c^h, l^h, E) = [\alpha C^{\rho_u} + (1-\alpha) l^{\rho_u}]^{1/\rho_u} - \phi E$$
$$C = [\beta X^{\rho_c} + (1-\beta) Y^{\rho_c}]^{1/\rho_c}$$

where α, β, ρ_c, ρ_u and ϕ are parameters of the preferences. The disutility from pollution, represented by ϕ, is taken from the benefits of carbon abatement (the marginal value of external damages), and set equal to $20 per ton of carbon, that is $\phi(E) = 20E$, which is an average of the estimations found in the literature (for instance, see Tol, 2005)[23]. Parameter ρ_u is related to the substitution possibilities between consumption of goods and leisure, and ρ_c is related to the substitution possibilities between consumption of X and Y. As in Parry *et al.* (1999), the parameter controlling the sensitivity of labor supply to the after-tax wage σ_u is equal to 1.20, which implies an uncompensated and compensated labor supply elasticity of 1.5 and 0.3, respectively; besides, non-sleep leisure time equals 0.3 times hours worked. For simplicity, we assume unitary elasticity of substitution between inputs and goods in the production and utility functions, respectively. That means a Cobb-Douglas function characterizing the consumption and production of final goods. Therefore, the elasticity of substitution σ_u between consumption C and leisure l in the welfare function and between labor L and energy P in the production function σ_i are equal to one. At the end of this section, we will undertake a sensitivity analysis to test the robustness of the results under different parameter values.

The baseline labor tax rate, is equal to 40%, which takes into account the sum of federal income, state income, payroll and consumption taxes: "This average rate is relevant for the participation decision" (Parry *et al*, 1999; p.65). This

[23] Actually, this represents a conservative parameter. Burtraw and Toman (2001) reviewed some empirical evidence about ancillary benefits in the US, and concluded that average ancillary benefits per ton of carbon reduction are greater than $30US (1996 dollars).

means that the distorting tax ratio τ^0 is equal to 60%. All tax revenues are given back to the households as a lump-sum transfer. This convenient simplification allows us to overlook public expenditures without loss of generality. The household's budget constraint is:

$$\left[X^h + \frac{P_y}{P_x}Y^h\right] = (1+\tau)\left[\frac{w}{P_x}(T - l^h) + T^h\right]$$

The benchmark data set for the US economy in the year 1995 is summarized in Table 1. As mentioned, only two final goods, X and Y, are produced in the economy ($455{,}124.7$ and $2{,}714{,}243.2$ millions of 1995 dollars). The consumption of energy P for the production of the two final goods, X and Y, is responsible for $1{,}423.6$ millions of tons of carbon emissions E to the atmosphere.[24]

Table 1. Benchmark data for the numerical model

	P	***X***	***Y***	***TIV***	***TCV***
P		47,349.1	5,795.3	53,144.4	
X					455,124.7
Y					2,714,243.2
L	53,144.4	407,775.6	2,708,447.9	3,169,367.9	
TOV	53,144.4	455,124.7	2,714,243.2		3,169,367.9
Leisure					932,167
E		1,268.4	155.2		

Source: own computations from Parry *et al* (1999, Table I).
Note: TOV is total output value; TIV total input value and TCV total consumption value. All values are in millions of 1995 US dollars except carbon emissions (in million tons).

Now we are ready to undertake a green tax reform and to compare different definitions of the first and second dividends. We simulate the introduction of an exogenously given green tax t_E^1 equal to \$10 per ton of carbon. This is a relatively low tax rate, so we follow a precautionary approach in order to derive robust conclusions from our analysis. It is similar to some international estimation of equilibrium prices for carbon permits in an international carbon market with grandfathering allocation of tradeable pollution permits for achieving Kyoto commitments (for instance, see the surveys by Springer, 2003, and Springer and Varilek, 2004).

[24]We suppose a constant technical relationship between consumption of energy and emissions. At the benchmark data, the consumption of one dollar of energy generates 0.026787394 tons of carbon emitted to the atmosphere.

The environmental tax is modelled as an excise tax on the consumption of energy P given the close relationship between consumption of this good and emissions. Revenue recycling through a lower labour tax rate complete the green tax reform with transfers fixed at the benchmark level, so that $\tau^1 =$60.48%. The effects of the green tax reform on emissions, production activities and prices are summarized in Table 2.

The increase in the price of energy P provokes, as expected, a significant reduction in the production and consumption of energy (-20.9%). That reduces carbon emissions to the atmosphere by the same rate. The rise in energy prices increases the costs in the energy-intensive sector X whose prices increase (+2.1%), and reduces activity levels in that sector. Accordingly, in the economy there is a substitution of non-energy intensive goods Y for energy intensive goods X which are now cheaper in relative terms (-0.3% reduction in relative prices for Y). As a consequence of all these changes in economic and environmental variables, there is a relative increase in welfare ($+0.112\%$) with respect to the benchmark, and equal to $4{,}561.98$ million 1995 US dollars as it is shown in Table 3. Therefore, the green tax reform is welfare-improving and it should be implemented.

Table 2. Results from simulated reforms. Relative changes (in percentage) on emissions, prices, production and welfare with respect to the benchmark

	Green Tax Reform		***Lump Sum***	
	Activity level	Prices	Activity level	Prices
P	- 20.9	+ 26.4	- 20.9	+ 26.8
X	- 2.1	+ 2.1	- 2.2	+ 2.5
Y	+ 0.3	- 0.3	+ 0.2	+ 0.1
L	0.0	0.0	- 0.1	0.0
E	- 20.9		- 20.9	
Total Welfare	+ 0.112		+ 0.086	

Note: Labor is the numeraire. Therefore all changes on prices are expressed as relative changes with respect to the price of labor.

The contribution of this section is to assign the welfare changes from the green tax reform between the first and the second dividends. In Table 3, we show the welfare gains after the implementation of the green tax reform, and the results from different definitions of dividends. These welfare measures were estimated using the definitions in Section 3 and the data in Table 2. The public finance approach concludes that there is not a positive double dividend because the second dividend is negative, as it is usually found in the literature (see the survey in Bovenberg and Goulder, 2002). That is, the effects of the green tax reform on consumption and leisure reduce the efficiency in the economy (using Goulder 1995's terminology).

Table 3. First and second dividends and welfare gains after the green tax reform.

	Public Finance		***New***	
	US$	%	US$	%
First Dividend	+ 5,953	+ 0.146	+ 3,514.75	+ 0.086
Second Dividend	- 1,398.7	- 0.034	+ 1,047.23	+ 0.026
Total Welfare Variation	+ 4,561.98	+ 0.112	+ 4,561.98	+ 0.112

Note: values in millions of 1995 US dollars. Percentage values with respect to welfare level at the benchmark.

However, we reached a very different conclusion when we used the definitions proposed in this paper (column denoted by "*New*"). The second dividend now has a positive sign, and the first dividend is still positive but lower than the counterpart for the public finance. Note that the value of the first dividend now corresponds to the welfare changes following the lump-sum reform as reported in Table 2; that is, the revenues from a $10 tax per ton of carbon are given back to households by lump-sum transfers and $\tau^0 = \tau^1$. So we can assert two conclusions: first, the environmental tax is welfare-improving, and therefore it should be implemented independently of the green tax reform; and, second, there is an efficiency value of revenues raised by the environmental tax so there exist some extra benefits from a green tax reform.

There are key policy implications stemming from these results. As mentioned above, the main interest of the "public finance" approach is on the second dividend for two main reasons: the difficulty of economic evaluation of environmental benefits, and the fact that the definition of the second dividend is appropriate for cost-effectiveness analysis. Following this approach, the green tax reform will be rejected by a policymaker because it reduces efficiency in public finance terminology by an amount equal to 1,398.7 million 1995 US dollars. As argued before, some costs included in this second dividend do not represent a drop in efficiency when we use careful analysis. Furthermore, rejection should take place only when a 20.9% reduction in carbon emissions is not enough to counterbalance the above drop in efficiency within a cost-effectiveness analysis. In general, we may conclude that inaccurate negative evaluations of green tax reforms by the "public finance" view may have been undermining their implementation in some OECD countries since the 90's.

Finally, we undertake a *sensitivity analysis* of the results involving the increase and reduction of 50% in the benchmark value of the elasticity parameters in the production and utility functions. Table 4 shows the relative changes (in percentage) in emissions E, aggregate welfare without pollution $U^h(c^h, l^h)$, and also total welfare $U^h(c^h, l^h, E)$ that includes environmental damages following the application of the green tax reform. In general, there is no significant change except some sensitivity of results to the value of substitution elasticity between inputs in the production. With that evidence, we may conclude that the results in Tables 2 and 3 are robust in qualitative terms, despite, of course, there exist some significant changes in quantitative values.

Table 4. Sensitivity analysis of results for the green tax reform

	$U^h(c^h, l^h)$	$U^h(c^h, l^h, E)$	E
Benchmark Case (Tables 2 and 3)	-0.034	0.112	-20.9
Production Elasticity (σ_i =1)			
σ_i =1.5	-0.047	0.157	-29.0
σ_i =0.5	-0.020	0.063	-11.9
Labour Supply Elasticity (σ_u =1.2)			
σ_u =1.8	-0.036	0.110	-20.9
σ_u =0.6	-0.032	0.114	-20.9
Consumption Elasticity (σ_c =1)			
σ_c =1.5	-0.035	0.116	-21.6
σ_c =1.5	-0.033	0.108	-20.2

Note: Percentage deviations (%) with respect to benchmark welfare levels and emissions. Benchmark case parameter's values are in brackets.

5. Conclusions

The popularity of green tax reforms as a relevant policy option increased rapidly at the beginning of the nineties to fall shortly at the end of the same decade. As argued in this paper, this quick rise and fall is related to the fact that mainstream double dividend literature advocated divergent approaches at different moments in time. Now tradable pollution permits have took the lead in the policymaker's agenda despite analyses showing that green tax reforms may be superior (see Parry, Williams and Goulder, 1999).

The double dividend hypothesis argues that two benefits or "dividends" may be attained, namely a better environment and a less distorting tax system, so that it could represent a win-win policy. Thus, a correct definition and, therefore, a correct measurement of both dividends are of great relevance for policy-makers advice, and for any policy recommendation. In this paper we specified which of the efficiency costs and benefits should be ascribed to the first dividend and the second dividend, highlighting misinterpretations of policy assessments in the double dividend literature.

For this purpose, the paper presents a general equilibrium set-up with a pollutionary externality and provides a new definition for the first dividend and the second dividend conformed to the double dividend hypothesis. Our definitions show up two important advantages. First, it is avoided misunderstandings such as the identification between the second dividend and the efficiency costs of green tax reforms, usually found in the double dividend literature. Second, they provide information by themselves and not as a partial view of the whole picture. Hence, the regulatory office is assisted to determine whether only a green tax should be set out regardless of the implementation of a green tax reform; or whether, additionally, raised revenues should decrease any distorting taxes. Accordingly, we believe that these definitions will contribute to clarify the debate and represent operative definitions of the double dividend for empirical research, as claimed by some authors like Patuellia, Nijkamp and Pels (2005).

As an illustration, we calibrated the theoretical model with a numerical example for the US economy on 1995. We simulated a green tax reform by introducing a $10 tax per ton of carbon with revenues devoted to reduce the income tax to find that alternative definitions reached very different conclusions: while the public finance approach concludes that the green tax reform improves welfare but -as expected- there is a negative second dividend, the new definition proposed in this paper recognizes a positive double dividend.

Regarding to policy implications, a relevant conclusion refers to the fact that the "public finance" approach overestimates the efficiency costs of green taxes: negative evaluations of green tax reforms by the "public finance" view might have been undermining their implementation in some OECD countries since 90's. Thus the results obtained by either the empirical and theoretical literature might have lead economists and policymakers to favour the use of instruments like grandfathering pollution permits instead of taxes, which represents a departure from the polluters pay principle.

We do not intend to be exhaustive about their reasons, but other considerations mainly regarding political feasibility issues are important (Stavins, 1998). For example, entrepreneurs constituted in lobbying groups prefer freely allocated tradable permits since they convey rents to firms with allocation surpluses and may raise entry barriers. In addition, policymakers may also favor them because they hide to some extent the costs of the environmental protection, over highly visible green policies, such as environmental taxes and auctioned permits. Concerns on competitiveness and distributional issues play also an important role in the comparisons among instruments.

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APPENDIX

Measuring the dividends in an analytical example

In this appendix, in a simple analytical example, we illustrate the definitions of first and second dividends proposed above and we compare them with those proposed by the public finance approach. Besides, this analytical framework will be useful for showing that a green tax reform does not need to be an optimal taxation policy.

Consider the same economy as that studied in Section 2, but now there are two goods in the economy: X is produced with a dirty technology and Y is produced with a clean technology. The budget constraint is:

$$(1+t_c)\left[X^h + \frac{P_y}{P_x}Y^h\right] = (1-t_w)\left[\frac{w}{P_x}(T-l^h)+T^h\right]$$

There are H identical households with preferences represented by the utility function $U^h(c^h,l^h,E)=[\alpha_1 c^\rho + \alpha_2 l^\rho]^{1/\rho} - \phi(E)$, with $c=[\beta_x X^\sigma + \beta_y Y_y^\sigma]^{1/\sigma}$ taken from Parry *et al* (1999), where $\phi()$ is an increasing and concave function that represents disutility from pollution. In order to compute the equilibria analytically, we choose $\rho = 1$ and $\sigma = 0$, set $\beta_2 = (1-\beta_1)$ and $\alpha_2 = (1-\alpha_1)$, and reparametrize $\alpha \equiv \alpha_1$ and $\beta \equiv \beta_x$. The production technology for both goods is linear, $X = F(N_x) = AN_x$ and $Y = F(N_y) = DN_y$, and pollution is proportional to production $E = \Lambda(Y) = \frac{B}{A}X$. This greatly simplifies the labor market equilibrium by setting the real wages at the infinitely elastic demand $\frac{w}{P_x} = A - t_E B$, and the consumption goods price ratio $\frac{P_y}{P_x} = \frac{A-t_E B}{D}$.

The interior competitive equilibrium. Consider the proposed menu of taxes and the supply of the public sector good are $\left\{\{T^h\}_{h=1}^H, t_E, t_c, t_w, g\right\}$. For simplicity, we will assume that there is no public expenditure. The competitive equilibrium when all taxes are considered, that is, $\left\{t_E, t_c, t_w\right\}$ and $g=0$, where tax revenue is evenly given back to households T^h, is obtained from the first-order conditions and government budget constraint:

$$l^h(\tau,t_E) = T - \frac{\alpha}{1-\alpha}\frac{\tau}{A}(A - t_E B\beta)A1 \quad \text{(A1)}$$

$$\left(X^h(\tau,t_E), Y^h(\tau,t_E)\right) = \left(\beta\frac{\alpha}{1-\alpha}\tau(A-t_E B), (1-\beta)\frac{\alpha}{1-\alpha}D\tau\right)A2 \quad \text{(A2)}$$

$$T^h(\tau,t_E) = \frac{\alpha}{1-\alpha}\frac{(A-t_E B)}{A}\left[A - \tau(A - t_E B\beta)\right]A3 \quad \text{(A3)}$$

$$\left(N_x(\tau,t_E), N_y(\tau,t_E)\right) = \left(\beta\frac{\alpha}{1-\alpha}\frac{H}{A}\tau(A-t_E B), (1-\beta)\frac{\alpha}{1-\alpha}H\tau\right)A4 \quad \text{(A4)}$$

$$E(\tau,t_E) = \beta\frac{\alpha}{1-\alpha}\frac{BH}{A}\tau(A-t_E B)A5 \quad \text{(A5)}$$

where $\tau = \frac{1-t_w}{1+t_c}$. Consequently, we find the individual indirect utility function

$$U^h(\tau,t_E)=U^h\left(c^h(\tau,t_E),l^h(\tau,t_E),E(\tau,t_E)\right)=$$
$$=K_0+K_1\tau(A-t_EB)^{\beta}-\frac{\beta\alpha}{A}\tau(A-t_EB)-\phi(\frac{\beta\alpha}{1-\alpha}\frac{BH}{A}\tau(A-t_EB))$$

with $K_0=(1-\alpha)T$, and $K_1=\frac{\alpha^2}{1-\alpha}\beta^{\beta}[(1-\beta)D]^{(1-\beta)}$. The aggregate utility function is $U(\tau,t_E)=\sum_h\alpha_hU^h\left(c^h,l^h,E\right)$, where α_h is the household weights for the government which, for simplicity, will be set equal for all, $\alpha_h=1$.

A green tax reform. The benchmark is an economy where the menu of taxes without supply of the public sector good is $\left\{\{T^h\}_{h=1}^H,t_E,t_c,t_w,g\right\}=\left\{\{T^{h0}\}_{h=1}^H,0,t_c^0,t_w^0,0\right\}$. That is, all tax revenue is always given back to households, and no pollution tax exists, i.e., $t_E^0=0$. A benchmark competitive equilibrium is (A1)-(A5) for (τ^0,t_E^0).

After the green tax reform has been fully implemented, the revenue from the pollution tax is devoted to reducing distorting taxes, and keeping the final households transfers at their initial level, i.e., $\left\{\{T^h\}_{h=1}^H,t_E,t_c,t_w,g\right\}=\left\{\{T^{h0}\}_{h=1}^H,t_E^1,t_c^1,t_w^1,0\right\}$. The new level of the distorting taxes ratio is

$$\tau^1=\frac{A(A\tau^0-t_E^1B)}{(A-t_E^1B\beta)(A-t_E^1B)}. \tag{A6}$$

given that the following government budget constraint must hold:

$$t_E^1E^1=\left[t_w^0\left(\frac{w}{P_1^0}\right)\sum_{h=1}^H(T-l^{h0})+t_c^0\sum_{h=1}^Hc^{h0}\right]-\left[t_w^1\left(\frac{w}{P_1^1}\right)\sum_{h=1}^H(T-l^{h1})+t_c^1\sum_{h=1}^Hc^{h1}\right]$$

The green tax equilibrium is (A1)-(A5) for (τ^1,t_E^1). The global gains or losses in welfare from the green tax reform are equal to the difference between $U(\tau^1,t_E^1)-U(\tau^0,0)$, so that a difference with a positive sign will justify its implementation.

The first and second dividend according to the public finance approach The public finance approach (see, i.e., Schöb, 1996, or Mayeres and Proost, 2001).compares the benchmark equilibrium with the resulting equilibrium after the green tax is fully implemented. The first dividend would be computed as the final effect of the

$$FD_{PF}=\phi(E(\tau^0,0)-\phi(E(\tau^1,t_E^1),$$

which is unambiguously positive when distorting taxes decrease, $\tau^1<\tau^0$; and, the second dividend is

$$SD_{PF}=\tau^1\left\{K_1\left(A-t_E^1B\right)^{\beta}+(1-\alpha)T-\frac{1}{A}\left(A-t_E^1B\beta\right)\right\}-\tau^0\left\{K_1A^{\beta}+(1-\alpha)T-1\right\}$$

where τ^1 is the distorting tax ratio found in (A6). However, the sign of the second dividend is uncertain, as there are some trade-offs between changes in consumption and leisure.

The first and second dividends in our definition. In order to compute our definitions, we need to establish a fictitious intermediate step in the full implementation of the green tax reform.

Taking the benchmark tax menu as a departure point, we introduce the environmental tax t_E^1 while keeping all other tax ratios constant τ^0, so that the additional tax revenues are given back to households in lump-sum transfers like those found in (A3); that is, $\left\{\{T^h\}_{h=1}^H, t_E, t_c, t_w, g\right\} = \left\{\{T^{h1}\}_{h=1}^H, t_E^1, t_c^0, t_w^0, 0\right\}$. Due to general equilibrium arguments, a new competitive equilibrium and a new tax revenue are obtained from (A1)-(A5) for (τ^0, t_E^1). Our definition of the first dividend following the introduction of the pollution tax gathers the welfare effects for reducing external costs:

$$FD_{new} = U(\tau^0, t_E^1) - U(\tau^0, 0) =$$
$$= \tau^0 \left\{ K_1[(A - t_E^1 B)^\beta - A^\beta] + \frac{B\beta}{A} t_E^1 \right\} + \left\{ \phi(E^0) - \phi(E(\tau^0, t_E^1)) \right\}$$

The sign of the first dividend is uncertain. Although the last difference is positive, because the tax reduces pollution, the first difference is probably negative. This is because the pollution tax is now distorting the allocation between consumption and leisure and therefore the utility from the aggregate of both must be lower than the benchmark level following the revealed preferences. The key innovation in our definition of first dividend is that it allows us to decide whether the regulatory office should apply a tax on pollution although no green tax reform would finally be implemented. That is, if the first dividend is positive, it will make some sense to consider the application of the pollution tax because there are some improvements in welfare (internalization of external costs).
Next, we measure the second dividend gathering the general equilibrium effects when the distorting taxes are reduced, or have to be increased to keep the same transfers level:[25]

$$SD_{new} = U(\tau^1, t_E^1,) - U(\tau^0, t_E^1) =$$
$$= [\tau^1 - \tau^0] \left\{ K_1 (A - t_E^1 B)^\beta - \frac{1}{A}(A - t_E^1 B\beta) \right\} + \left\{ \phi(E(\tau^0, t_E^1)) - \phi(E^1) \right\}$$
$$= t_E^1 \frac{\tau^0 \left[1 - \beta(A - t_E^1 B)\right] - A}{(A - t_E^1 B\beta)(A - t_E^1 B)} \left\{ K_1 (A - t_E^1 B)^\beta - \frac{1}{A}(A - t_E^1 B\beta) \right\} +$$
$$+ \left\{ \phi(E(\tau^0, t_E^1)) - \phi(E^1) \right\}$$

which may be positive or negative.

To sum up, there are important advantages of our definitions, for they allow us to show whether a pollution tax should be set to improve welfare, abstracting from green tax reforms. With regard to the public fiscal approach definitions of the first and second dividend, however, they only show if a green tax reform has to be implemented or not.

The green tax reform, and the optimal taxation scheme. Finally, the analytical example studied shows that a green tax reform does not necessarily achieve the optimal taxation. Let us take the parametrization for the disutility from pollution $\phi(E) = \phi E^2$. The optimal taxation menu $\{\tau^*, t_E^*\}$ in the example is given by $\partial U^h(\tau, t_E)/\partial \tau = 0$, and $\partial U^h(\tau, t_E)/\partial t_E = 0$ which gives us the following expression,

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[25]An extreme example is the case when there are no taxes initially, $\tau^0 = 1$, and then no tax revenue or household transfers $T^{h0} = 0$ exist. After a green tax reform with t_E^1, tax revenue is positive, and then some subsidy will be undertaken to keep household transfers to the initial zero level, that is, $\tau^1 > 0$ so $t_w^1 < 0$ or $t_c^1 < 0$.

$$t_E^* = \frac{A}{B} - \frac{1}{B}\left(\frac{\alpha}{K_1}\right)^{1/\beta}$$

$$\tau^* = \frac{\frac{\beta}{A}\left(A - \left(\frac{\alpha}{K_1}\right)^{1/\beta}\right) - (1-\alpha)}{\phi\left(\frac{\alpha}{1-\alpha}\beta BH\left(\frac{\alpha}{K_1}\right)^{1/\beta}\right)^2}$$

$$T^h(\tau^*, t_E^*) = \frac{\alpha}{1-\alpha} K_1^{1/\beta}\left[1 - \frac{AK_1^{1/\beta} - 1}{\phi\left(\frac{\alpha}{1-\alpha}BH\right)^2 \beta K_1^{1/\beta}}(A(1-\beta) + \frac{\beta}{K_1^{1/\beta}})\right]$$

Observe that the initial transfers T^{h0} for each $h = 1, \ldots \ H$ are not necessarily equal to $T^h(\tau^*, t_E^*)$, so the green tax reform will not mean to achieve optimal taxation. Furthermore, assume that the government never considered a pollution tax, so $t_E^0 = 0$, but it sets the available or existing taxes at its optimal taxation level. In this case, the distorting tax ratio is $\tau^{**} = \frac{K_1 A^\beta - \alpha}{\phi\left(\beta \frac{\alpha}{1-\alpha} BH\right)^2}$ and the households transfers are

$$T^h(\tau^{**}, 0) = \frac{\alpha}{1-\alpha} A\left[1 - \frac{K_1 A^\beta - \alpha}{\phi\left(\beta \frac{\alpha}{1-\alpha} BH\right)^2}\right]$$

In consequence, if the government later realizes that the tax menu could be modified with a green tax reform, the optimal taxation menu will never be achieved. First, observe that the distorting tax is obtained as in (A6), i.e., $\tau^1 = \frac{A(A\tau^{**} - t_E^* B)}{(A - t_E^* B\beta)(A - t_E^* B)}$. Then, initial transfers $T^h(\tau^{**}, 0)$ for each $h = 1, \ldots \ H$ will remain the same after the implementation of the reform, even in the case that the tax on pollution is taken at its optimal value t_E^*, which clearly differs from those obtained in optimal taxation, i.e., $T^h(\tau^1, t_E^*) \neq T^h(\tau^*, t_E^*)$. The issue here is that we cannot achieve the optimal taxation menu implementing a tax reform that imposes a constant transfers pattern set at its initial level.

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