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New Green Tax Reforms: an Economic Appraisal

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Abstract

Green tax reforms have traditionally consisted in a revenue-neutral substitution of conventional levies by environmental (and energy-related) taxes. Yet a new type of green tax reform, with a less constrained use of environmental tax receipts, has been increasingly preferred by policymakers since the onset of the economic crisis. This paper employs a general equilibrium approach, which is calibrated for the U.S. economy, to provide one of the first environmental and economic assessments of the most common revenue uses seen in recent green tax reforms: support of renewable energy sources, promotion of energy efficiency, and distributional compensations to consumers. The paper shows that renewable and energy-efficiency motivated tax reforms could reduce emissions and increase welfare if the environmental tax rate is sufficiently high whilst also allowing for economic growth if the tax rate is below a certain threshold.

Keywords: Distribution, efficiency, energy, general equilibrium, renewables

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1. Introduction

For economists, environmental taxes have always been the most desirable policy tool for correcting negative externalities given their static and dynamic efficiency-enhancing properties. Yet, since Tullock (1967) first mentioned it, the potential existence of an additional economic benefit (or 'dividend') from the use of environmental revenues has generated considerable academic debate, reaching its peak during the 1990s. The likelihood of huge revenues from the introduction of carbon taxes to fight climate change, then seen as a major environmental problem for the first time, led numerous environmental and public economists to study the so-called 'Green Tax Reforms' (GTR) and conformed the 'double dividend theory'.

Rather surprisingly, many governments showed quick and remarkable interest in optimizing environmental revenues and by the early 1990s a few countries were already implementing GTRs. Fifteen years later, most European governments had introduced or considered some sort of GTR; and proposals were spreading to other developed and emerging countries elsewhere. In a recent paper, Gago et al. (2014) distinguished between two generations of GTRs throughout this period: the first applications in the 1990s (Scandinavian model), built around carbon or other explicit environmental tax and whose revenues were mainly employed to reduce personal income taxes; and a second approach during the pre-crisis years of this century (German model), which focused on a more general use of energy-related taxes whose revenues were mostly directed towards reducing labor taxes paid by employers. Both generations, in any case, were based on the standard recipe of the double dividend theory: a revenue-neutral use of environmental receipts to reduce other conventional, distortionary taxes.

Gago et al. (2014) also indicated a remarkable shift in the implemented GTRs after 2008 and the birth of a third generation of experiences, much less related to mainstream double-dividend ideas. Although some countries like Ireland and Sweden continued using the standard approach, in many cases allocating environmental revenues to fiscal consolidation (which could be interpreted as a reduction of future distortionary taxation increases), innovation in applied GTRs has grown significantly. A few examples may suffice: in 2008 Switzerland introduced a carbon tax whose revenues were partly devoted to promoting energy efficiency in buildings and distributional compensations for affected households and firms (FOEN, 2010). France's recently (2014) introduced carbon tax also implemented 'non-conventional' uses of revenues that were supposed to finance the so-called energy transition and deal with distributional concerns. Outside Europe,

Australia's 2012 climate change program introduced carbon taxes whose revenues were partly devoted to reducing income taxes, protecting firm competitiveness and funding renewable and energy-efficiency programs (Spencer et al., 2012).

Within this context, the paper uses a general equilibrium approach, calibrated for the U.S. economy, to provide one of the first environmental and economic assessments of the most common revenue uses seen in recent GTRs: support of renewable energy sources, promotion of energy efficiency, and distributional compensations to households.

The article is organized in six sections, including this introduction. After an overview of the economic literature relevant to this paper in the next section, the paper presents a theoretical model capable of addressing these issues and goes on to develop its equilibrium conditions (Section 3). Section 4 describes the above-mentioned GTR alternatives, and explores their theoretical effects. Subsequently, Section 5 presents a simulation of these alternatives in the U.S. economy, with a careful sensitivity analysis on the adopted environmental tax. Finally, the paper concludes with its main findings and implications.

2. Findings and gaps in the economics of Green Tax Reforms

As indicated in the previous section, the efficiency-enhancing potential of environmental tax revenues was first advanced about 50 years ago. Environmental taxes were then no more than an academic curiosity, a recent invention by economists aimed at correcting external damage associated to pollution. Connecting the benefits of externality reductions and those coming from revenue-neutral tax shifts on the one hand kept the efficiency-enhancing rationale of environmental taxes and, on the other, it provided more reasons to implement these instruments, especially in the wake of growing climate change concerns (Pearce, 1991). Indeed, a few years earlier Lee and Misiolek (1986) had provided the first formal analysis of GTRs through a partial equilibrium approach supporting this fiscal solution.

However, by the mid 1990s it was clear that obtaining a positive second dividend from environmental revenue use ['strong double dividend' in the words of Goulder (1995)] would be no easy task. Bovenberg and de Mooij (1994) showed, in a general equilibrium setting, that taxes on polluting goods would increase, rather than alleviate, pre-existing tax distortions through a so-

called 'interaction effect' that would only be partially offset by the revenue 'recycling effect'. Rich and extensive theoretical 'double dividend' literature stemmed from this paper the following years, incorporating intermediate goods (Bovenberg and Goulder, 1996), dynamics and capital mobility (Bovenberg and the Mooij, 1997), involuntary unemployment (Bovenberg and van der Ploeg, 1998), pre-existing differential tax distortions (Parry and Bento, 2000), industrial oligopolies (Sugeta and Matsumoto, 2005) or informal economy and tax evasion (Bento et al., 2013; Liu, 2013), among other things. Although skeptical of generalized positive second dividends, this literature also provides support for real-world GTRs because it usually finds that reducing other distortionary taxes ['weak double dividend' in the words of Goulder (1995)] is still the best recycling alternative for environmental taxes. In this setting, a related strand of papers has dealt with optimal environmental tax schedules that consider the reduction of external damages as well as the positive fiscal effects deriving from revenue recycling [e.g. Fullerton (1997)].

The double dividend literature provided a basis for and, in some cases, was useful to assess pre-crisis GTRs, yet the new solutions many countries implemented after 2008 are largely lacking in academic support and evidence. It is true that Bovenberg (1999) already incorporated distributional aspects in a standard second-generation GTR setting; and Fullerton and Monti (2010) studied the effects of a GTR with revenues devoted to reductions in labor taxes (social security contributions) levied on low-income households. However, the disparity between theoretical enquiries on these matters and the widespread extension of distributional devices in the new generation of GTRs is clear. One recent exception is Chiroleu-Assouline and Fodha (2014) who theoretically analyze the distributional effects of GTRs by considering the presence of heterogeneous households.

It now seems clear that, for almost two decades, double dividend ideas spared carbon and energy-related taxation from the prevalent revenue earmarking (usually for environmental purposes) seen in environmental taxes elsewhere (see Heine et al., 2012). However, new implemented GTRs show policymakers' preference to 'reinforce' the effects of corrective taxes by allocating revenues to climate change mitigation, mostly in the form of direct support to energy efficiency and renewable promotion but also by providing funds for Research and Development (R&D) related activities. Again, with few exceptions such as Böhringer et al. (2013) on an energy tax with revenues devoted to subsidizing renewables and Chang (2014) on revenue use for R&D in pollution abatement, the academic literature is scarce and it lacks a comprehensive approximation to these matters.

3. A Model to assess new GTRs

3.1. Model

In line with the existing theoretical literature on GTRs and particularly with Silva et al. (2013a), we use a general equilibrium model in continuous time with several sectors: homogenous final-goods, energy, renewable resources and non-renewable resources. The final-goods and the energy sectors are perfectly competitive; although we introduce monopoly power in the resource sectors because firms related to natural-resource exploitation generally have a certain extent of monopoly power[1]. Consumers are also shareholders of the monopolistic firms; this guarantees that profits will remain in the economic system, even though we abstract from capital accumulation. We also abstract from leisure since deciding how many hours to work, although important, makes no contribution to this analysis. Yet we do explicitly include environmental benefits, given the need to consider them in tax reforms designed with corrective purposes.

We focus on the decentralized equilibrium; that is to say, there is no central planner in this economy. The dynamic general equilibrium is defined by the path of resource allocation and prices, such that: (i) consumers and firms solve their maximization problems; (ii) R&D free-entry conditions are met; and (iii) markets clear.

In order to analyze distributional issues, we consider two types of individuals, qualified workers (Q) and non-qualified workers ($\overline{Q}$). Within the mass [0,1] of individuals, we assume a fixed proportion of qualified (η) and non-qualified ($1-\eta$) workers is present at any given moment. The heterogeneous individuals own assets and, given that there is no population growth, all aggregate variables can be interpreted as *per capita* quantities[2]. As in Silva et al. (2013b), consumers have the following instantaneous utility function,

$$U(C,P) = \ln C_{jt} - \varphi \ln P_t \qquad (1)$$

[1] This assumption also simplifies our calculations since resource firms become price-makers instead of price-takers.
[2] The model focuses on the effects of natural resources use on the environment and economic growth, hence the non-consideration of other production factors and population growth.

where $j = Q, \overline{Q}$ and $\varphi > 0$ reflect the strength of environmental preferences. Consumer utility increases with consumption (C) and decreases with polluting emissions (P); that is, individuals value a clean environment. The marginal utility of consumption is positive, $U_C > 0$, but decreasing, $U_{CC} < 0$, whereas pollution reduces utility, $U_P < 0$, but does so at an increasing rate, $U_{PP} > 0$. It is obvious that in this setting any policy action increasing private consumption and/or decreasing pollution has positive effects on utility. Individuals maximize their intertemporal utility subject to the budget constraint,

$$\dot{B}_{qt} = i_t B_{qt} + (w_{qt} + \Gamma_{qt}) - C_{qt} \tag{2}$$

where $q = Q, \overline{Q}$; B represents the assets owned by individuals and corresponds to the monopoly gains given that consumers are also shareholders of the monopoly firms; i is the interest rate; w is the wage earned by each worker; and Γ is a lump-sum transfer to the consumers that may, or may not, exist depending on the policy scenario. The maximization condition for consumers leads to the usual Euler equation,

$$g_{C_t} = i_t - \rho \tag{3}$$

where ρ is the discount rate; g_x is the growth rate of any variable x; and $g_{C_t} = g_{Y_t}$ because consumption is a given proportion of output ($C_t = \Lambda Y_t$) in steady-state. This expression reflects that individuals postpone consumption if saving (i.e. earning the return rate) compensates for the rate of time-preference and the marginal value change of consumption.

N ($n = 1,...,N$) final-good producers face perfect competition. Each firm has a production function as depicted in Allan et al. (2007) and Gonand (2014),

$$Y_t = \theta \varepsilon_t^{\alpha} h^{Q} Q_t^{\beta} \overline{Q}_t^{1-\alpha-\beta} \tag{4}$$

where θ is a parameter representing the general efficiency of the economy; $\varepsilon = \mu_t E_t$ represents efficient energy units; μ represents the technical progress concerning energy efficiency ($\mu \geq 1$); and E is the energy used to produce the output Y. α can be interpreted as the elasticity of output in relation to ε; β the elasticity of output in relation to Q; and ($1-\alpha-\beta$) the elasticity of output in

relation to $\overline{Q}$. The term h^Q represents an absolute productivity advantage of qualified workers over non-qualified ones (see Acemoglu and Zilibotti, 2001). Given that effects of the elasticity of substitution are of no interest to us, we employ a Cobb-Douglas production function as do many other papers in this area (see e.g. Barbier, 1999; Di Vita, 2006; Stiglitz, 1974; Smith, 1974). This implies that the resources are imperfect substitutes, i.e., all of them are always necessary for production and no resource will be completely driven out of the market (see Fisher and Newell, 2008). In any case, this assumption has no effect on the qualitative results of the analysis.

K (*k = 1,...,K*) energy producers also face perfect competition and have the following production function,

$$E_t = \phi R_t^{\gamma} F_t^{1-\gamma} \tag{5}$$

where Φ is a parameter representing the general efficiency in producing energy; γ is the elasticity of energy generation in relation to renewable resources (*R*); and (1- γ) the elasticity of energy generation in relation to non-renewable resources (*F*). The use of fossil fuels generates polluting emissions, which are assumed to be a proportion (Ω) of non-renewable resources consumption ($P_t=\Omega F_t$).

In the renewable resources sector a monopolistic firm 'extracts' renewable resources at a constant extraction cost (c_R) and sells them to energy producers. We do not consider scarcity or regeneration for renewable resources and, consequently, we do not contemplate truly extractable resources. Hence, these costs are not necessarily physical extraction costs; they refer to electricity generation costs from renewable resources, such as wind, water or the sun.

In the non-renewable resources sector another monopolistic firm extracts resources at a constant cost (c_F) and sells them to final-good producers. The extraction of the non-renewable resource decreases the amount of resource available. This firm therefore faces resource scarcity. The non-renewable resource stock evolves according to $\dot{S}_t = -F_t$. Therefore, $g_{S_t} = -\frac{F_t}{S_t}$.

As the paper deals with alternative uses of revenue from public policies, the government plays a key role in the analysis. There are three alternative GTR scenarios, which are compared to a no-

policy baseline. In all the scenarios the government imposes a tax (τ_t) on the consumption of non-renewable resources, which can be interpreted as an energy-related environmental or carbon tax. In the first scenario, the government employs tax revenues to promote renewable resource use through a direct subsidy to renewable resource extraction/production (σ_t). In the second scenario it uses revenues to improve the rate of technical progress towards energy efficiency (μ_t), which could be also viewed as a direct investment to promote energy efficiency. Finally, in the third scenario the government uses the revenues to decrease inequality among workers by giving a lump-sum transfer ($\Gamma_{\overline{Q}}$) to non-qualified workers, assumed to have lower incomes than qualified workers. The three alternatives could actually be implemented together, although, for the sake of simplicity, the paper analyzes them separately to subsequently compare the results. Revenue neutrality is guaranteed in all the scenarios because the amount the government spends is exactly the same as the revenue it raises through energy-related environmental tax.

3.2. Equilibrium

The equilibrium of the economy results from the joint consideration of the household sector and all the production sectors. Final-good producers, who face perfect competition, maximize their profit subject to their production function. Normalizing final-goods price to 1 and knowing that the labor supply of each type of worker is fixed and equal to $Q = \eta$, $\overline{Q} = 1 - \eta$, we see that the first order conditions lead, respectively, to the demand function for energy and the wages of both types of workers[3] after aggregation.

$$E = \left(\frac{\theta \mu^{\alpha} h^{\eta} \eta^{\beta} (1-\eta)^{1-\alpha-\beta} \alpha}{P_E} \right)^{\frac{1}{1-\alpha}} \tag{6}$$

$$w_Q = \theta (\mu E)^{\alpha} h^{\eta} (1-\eta)^{1-\alpha-\beta} (\beta \eta^{\beta-1} + \eta^{\beta} \ln h) \tag{7}$$

$$w_{\overline{Q}} = \frac{\theta (\mu E)^{\alpha} h^{\eta} \eta^{\beta} (1-\alpha-\beta)}{(1-\eta)^{\alpha+\beta}} \tag{8}$$

where P_E is the price of energy.

[3] For simplicity, we have omitted time subscripts in all the equations of this section.

Energy producers solve a similar maximization problem by optimizing profit subject to their production function and taking into account the tax they pay for using non-renewable resources for energy generation. The first order conditions provide the demand functions for renewable and non-renewable resources,

$$R = F\left(\frac{P_E \phi \gamma}{P_R}\right)^{\frac{1}{1-\gamma}} \tag{9}$$

$$F = R\left(\frac{P_E \phi (1-\gamma)}{P_F + \tau}\right)^{\frac{1}{\gamma}} \tag{10}$$

where P_R and P_F are, respectively, the prices of renewable and non-renewable resources. Intuitively, we can see the complementarity between consumption of renewable and non-renewable resources. Additionally, a higher energy price constitutes an extra incentive to produce and thus consume more renewable and non-renewable resources. The monopolist in the renewable resource sector maximizes profits as she is a price maker aware of the demand function for renewable resources (9). The first order condition of the maximization problem gives the price of renewable resources in equilibrium (11), which can also be interpreted as the renewable resource supply function,

$$P_R = \frac{c_R - \sigma}{\gamma} \tag{11}$$

As expected, the renewable resource price changes with the subsidy to renewable resources production (first policy or GTR scenario).

The monopolist in the non-renewable sector solves an intertemporal maximization problem because of the resource depletion. She, too, is a price maker and knows the non-renewable resource demand function (10). The first order conditions provide the price of the non-renewable resource, which again can be interpreted as the non-renewable resource supply function (12), and the law of motion of the shadow price for non-renewable resource reserves (13),

$$P_F = \frac{c_F + \lambda + \tau}{1 - \lambda} \tag{12}$$

$$\frac{\dot{\lambda}}{\lambda} = \rho \tag{13}$$

where λ is the dynamic multiplier of the non-renewable resources stock, i.e. the variation in profits induced by an infinitesimal change in non-renewable resources reserves, also interpreted as the shadow price of non-renewable resource reserves.

In equilibrium, the demand for each type of resource equals the supply of that resource. Using the functions determined above, we can obtain,

$$R = F\left(\frac{P_E \phi \gamma^2}{c_R - \sigma}\right)^{\frac{1}{1-\gamma}} \tag{14}$$

$$F = R\left(\frac{P_E \phi (1-\gamma)^2}{c_F + \lambda + \tau}\right)^{\frac{1}{\gamma}} \tag{15}$$

which are the equilibrium amounts of used renewable (14) and non-renewable resources (15). These expressions allow us to obtain the equilibrium energy price of the economy,

$$P_E = \frac{(c_F + \lambda + \tau)^{1-\gamma} (c_R - \sigma)^{\gamma}}{\phi (1-\gamma)^{2(1-\gamma)} \gamma^{2\gamma}} \tag{16}$$

This price increases with the energy-related environmental tax and decreases with the subsidy to renewables. Replacing equation (16) in (6), we can define the energy use of the economy,

$$E = \left(\frac{\theta \alpha \mu^{\alpha} h^{\eta} \eta^{\beta} (1-\eta)^{1-\alpha-\beta} \phi (1-\gamma)^{2(1-\gamma)} \gamma^{2\gamma}}{(c_F + \lambda + \tau)^{1-\gamma} (c_R - \sigma)^{\gamma}}\right)^{\frac{1}{1-\alpha}} \tag{17}$$

This expression indicates that energy consumption increases with energy efficiency (rebound effect) and with the subsidy for renewable resources, and it decreases with the energy-related

environmental tax. The equilibrium wages of both types of workers can be determined by incorporating equation (17) into expressions (7) and (8),

$$w_Q = \alpha^{\frac{\alpha}{1-\alpha}}\theta^{\frac{1}{1-\alpha}}\mu^{\frac{\alpha}{1-\alpha}}h^{\frac{\eta}{1-\alpha}}\eta^{\frac{\beta\alpha}{1-\alpha}}(1-\eta)^{1-\frac{\beta}{1-\alpha}}\left[\frac{\phi(1-\gamma)^{2(1-\gamma)}\gamma^{2\gamma}}{(c_F+\lambda+\tau)^{1-\gamma}(c_R-\sigma)^{\gamma}}\right]^{\frac{\alpha}{1-\alpha}}(\beta\eta^{\beta-1}+\mu^{\beta}\ln h) \quad (18)$$

$$w_{\bar{Q}} = (1-\alpha-\beta)\alpha^{\frac{\alpha}{1-\alpha}}\theta^{\frac{1}{1-\alpha}}\mu^{\frac{\alpha}{1-\alpha}}h^{\frac{\eta}{1-\alpha}}\eta^{\frac{\beta}{1-\alpha}}(1-\eta)^{-\frac{\beta}{1-\alpha}}\left[\frac{\phi(1-\gamma)^{2(1-\gamma)}\gamma^{2\gamma}}{(c_F+\lambda+\tau)^{1-\gamma}(c_R-\sigma)^{\gamma}}\right]^{\frac{\alpha}{1-\alpha}} \quad (19)$$

Replacing equation (17) in the final-goods production function we obtain,

$$Y = \frac{\alpha^{\frac{\alpha}{1-\alpha}}\theta^{\frac{1}{1-\alpha}}\mu^{\frac{\alpha}{1-\alpha}}h^{\frac{\eta}{1-\alpha}}\eta^{\frac{\beta\alpha}{1-\alpha}}(1-\eta)^{1-\frac{\beta}{1-\alpha}}\phi^{\frac{\alpha}{1-\alpha}}(1-\gamma)^{\frac{2\alpha(1-\gamma)}{1-\alpha}}\gamma^{\frac{2\alpha\gamma}{1-\alpha}}}{(c_F+\lambda+\tau)^{\frac{\alpha(1-\gamma)}{1-\alpha}}(c_R-\sigma)^{\frac{\alpha\gamma}{1-\alpha}}} \quad (20)$$

which indicates that, under certain parameter values, the energy efficiency and the subsidy have a positive effect on output, whereas the tax has a negative effect.

From expressions (14) and (16), together with the energy production functions, we reach,

$$F = \frac{\alpha^{\frac{1}{1-\alpha}}\theta^{\frac{1}{1-\alpha}}\mu^{\frac{\alpha}{1-\alpha}}h^{\frac{\eta}{1-\alpha}}\eta^{\frac{\beta}{1-\alpha}}(1-\eta)^{\frac{1-\alpha-\beta}{1-\alpha}}\phi^{\frac{\alpha}{1-\alpha}}(1-\gamma)^{\frac{2-2\alpha\gamma}{1-\alpha}}\gamma^{\frac{2\alpha\gamma}{1-\alpha}}}{(c_F+\lambda+\tau)^{\frac{1-\alpha\gamma}{1-\alpha}}(c_R-\sigma)^{\frac{\alpha\gamma}{1-\alpha}}} \quad (21)$$

This equation shows that a higher subsidy induces a higher level of non-renewable resource use. As indicated before, this is given by a certain level of resource complementarity.

The expression for *R* is easily obtained from equations (14), (16) and (21)

$$R = \frac{\alpha^{\frac{1}{1-\alpha}}\theta^{\frac{1}{1-\alpha}}\mu^{\frac{\alpha}{1-\alpha}}h^{\frac{\eta}{1-\alpha}}\eta^{\frac{\beta}{1-\alpha}}(1-\eta)^{\frac{1-\alpha-\beta}{1-\alpha}}\phi^{\frac{\alpha}{1-\alpha}}(1-\gamma)^{\frac{2\alpha-2\alpha\gamma}{1-\alpha}}\gamma^{\frac{2+2\alpha\gamma-2\alpha}{1-\alpha}}}{(c_F+\lambda+\tau)^{\frac{\alpha-\alpha\gamma}{1-\alpha}}(c_R-\sigma)^{\frac{1+\alpha\gamma-\alpha}{1-\alpha}}} \quad (22)$$

which indicates that, for the same level of resource complementarity, a higher tax leads to a lower use of renewable resources.

Consumption is a fraction (Λ) of output, as previously stated. Given that consumers receive the profits of the monopolistic firms, we may obtain the expression for welfare (W) of the economy,

$$W = \ln\left(\frac{\Lambda}{\Omega^{\varphi}} \frac{\alpha^{\frac{\alpha(1-\varphi)}{1-\alpha}} \theta^{\frac{(1-\varphi)}{1-\alpha}} \mu^{\frac{\alpha(1-\varphi)}{1-\alpha}} h^{\frac{\eta(1-\varphi)}{1-\alpha}} \eta^{\frac{\alpha(1-\varphi)}{1-\alpha}} (1-\eta)^{\frac{(1-\alpha-\beta)(1-\varphi)}{1-\alpha}} \phi^{\frac{\alpha(1-\varphi)}{1-\alpha}} (1-\gamma)^{\frac{(2\alpha-2\alpha\gamma)(1-\varphi)}{1-\alpha}} \gamma^{\frac{2\alpha\gamma(1-\varphi)}{1-\alpha}}}{(c_F+\lambda+\tau)^{\frac{\alpha-\varphi-(1-\varphi)\alpha\gamma}{1-\alpha}} (c_R-\sigma)^{\frac{\alpha\gamma(1-\varphi)}{1-\alpha}}}\right) \quad (23)$$

As indicated by Chiroleu-Assouline and Fodha (2014), in this setting we cannot distinguish between the environmental and non-environmental components because pollution and production affect each other; thus the two impacts on welfare are non-separable. In this context, an alternative way to reinterpret the welfare effects of GTR would be to characterize the double dividend by the simultaneous decrease of pollution (P) and an increase in welfare (which also depends on the pollution level). The discussion on the definition of the dividends from environmental taxes is beyond the objective of this paper so, given the model characteristics, we will henceforth follow Chiroleu-Assouline and Fodha's convention. Note, in any case, that we will refer to double dividends of a GTR with respect to a no-policy baseline, whereas the standard literature in this area usually compares revenue-neutral tax changes to other alternatives. Therefore, our adopted convention, makes it compatible to achieve a double dividend in the simulated GTRs without fulfilling the conditions for a strong or weak double dividend (see Section 2) as compared to GTR, which devotes all environmental revenues to reducing other distortionary taxes (not considered in this paper).

4. Policy scenarios under a GTR

As shown before, the three policy scenarios correspond to alternative GTRs that are close to recently implemented experiences. The first case uses energy-related environmental tax revenues to promote renewable energy; the second case uses revenues to promote energy efficiency; and the final scenario uses revenues to reduce wage inequality by providing a monetary transfer to non-qualified workers. Next we provide the analytical description of the preceding scenarios within the general model.

4.1. First scenario: Renewable promotion

This scenario uses environmental tax receipts to finance renewable resources through direct subsidization without further policy changes (i.e. $\mu=1$ and $\Gamma_Q = \Gamma_{\bar{Q}} = 0$). We depart from the balanced budget constraint of the government ($\tau F=\sigma R$) to obtain the equilibrium value of the subsidy, $\sigma = \tau \frac{F}{R}$. After some algebra we obtain,

$$\sigma = \frac{c_R (1-\gamma)^2}{\frac{(c_F + \lambda)\gamma^2}{\tau} + \gamma^2 + (1-\gamma)^2} \tag{24}$$

Therefore $\frac{\partial \sigma}{\partial \tau} > 0$, that is, an increase in the environmental tax rate always leads to an increase in unitary subsidy to renewable resources under the GTR. However, the combined policy package leads to opposite effects for most variables; so, the final outcome may be positive or negative. We must therefore calibrate the model to compare the effects of GTRs on consumption, pollution and welfare.

4.2. Second scenario: Investment in energy efficiency

This scenario employs all revenues in promoting energy efficiency. We assume a simple energy efficiency accumulation function, $\dot{\mu}_t = \mu_0 I_t$, where I is the amount invested without further policy changes (i.e. $I=\tau F$). For simplicity, we consider $\mu_0=1$. Given this relationship, we can obtain the equilibrium expression for the rate of technical progress of energy efficiency in the scenario,

$$\mu = \tau^{\frac{1-\alpha}{1-2\alpha}} \left[\frac{\alpha \theta^{\frac{\alpha}{1-\alpha}} h^{\eta} \eta^{\beta} (1-\eta)^{1-\alpha-\beta} \phi^{\alpha} (1-\gamma)^{2-2\alpha\gamma} \gamma^{2\alpha\gamma}}{(c_F + \lambda + \tau)^{1-\alpha\gamma} (c_R - \sigma)^{\alpha\gamma}} \right]^{\frac{1}{1-2\alpha}} \tag{25}$$

The effect of an increase in τ over μ follows a U-shape and therefore depends on the initial environmental tax level. For a low (high) initial tax level, increasing the tax decreases (increases) the energy efficiency indicator[4]. This may happen because, for low tax levels, increased tax rates decrease the amount of non-renewable resources used (*F*) and thus reduce total tax revenues (τF). The tax rate increase more than compensates the decrease in *F* for higher tax levels, so the increase in total revenues allows for more investment in energy efficiency.

With initial low tax levels, this scenario conforms a GTR that depresses the main macroeconomic variables (output, energy, wages, renewable and non-renewable resources, and consumption). We later perform a calibration for the U.S. to assess the effects on global welfare in this case given the opposing impacts of reduced consumption and lower emissions.

4.3. Third scenario: Distributional compensations

This scenario uses energy-related environmental tax receipts to decrease income inequality between workers and provides a monetary transfer to non-qualified workers equal to $\Gamma_{\bar{Q}} = \tau F$. We can observe in the equilibrium equations that this transfer only affects the wage difference between both types of workers, so the macroeconomic impacts are only associated to the economic effects of the energy-related environmental tax[5]. The simulated GTR leads to a reduction of these variables (output, energy, wages, renewable and non-renewable resources and consumption); but the overall effect on welfare is once again uncertain, so we use calibration for the U.S. economy to analyze this case.

5. Empirical analysis

In this section we present the results of the preceding simulations for the U.S., with a special focus on the electricity sector. We feel that the paper provides a relevant and useful application on the differential effects of new GTRs given the significance of renewable and non-renewable

[4] These relationships have been tested using reasonable parameter values.
[5] This scenario only departs from traditional, pre-crisis, GTRs in the lack of revenue-neutral tax compensations in other distortionary taxes.

resources (and related emissions in relative terms) in the operation of the electricity sector, its strong linkage to energy efficiency issues, and the global importance of the U.S. economy.

We first deal with the calibration of the main parameters of the model that, given the ambiguities of the theoretical outcomes (see Section 4), provides us with numerical results for each scenario and, ultimately, an assessment of the different variations of new GTRs in relative terms. Finally we carry out a sensitivity analysis on a crucial issue for GTRs: environmental tax levels.

5.1. Calibration

For the sake of simplicity, we only include one non-renewable and one renewable source in the electricity generation structure. In the first case, we opt for coal given that it has been the most widely used and cheapest non-renewable generation alternative over the last few years in the U.S. (and even more in other major economies) despite the increasing relevance of natural gas. We have excluded hydropower, an already mature source, from renewable sources and have instead chosen offshore wind power, a clearly developing option that is still maturing in terms of costs. Indeed, offshore wind has undergone significant growth and become closely competitive with other sources over the last few years. In terms of parameter selection, we use levelized cost of electricity (LCOE) for the cost of using the non-renewable and renewable resources. This allows us to compare such very different technologies (IEA et al., 2010) more accurately. In particular, we consider c_F=*0.07249* and c_R=*0.1012*. In line with Lin and Zhang (2011), we set the shadow price of coal at 39.8 USD/tonne for which, given that the electricity generated from coal is around 2.46 MWh/tonne in the U.S., the shadow price is 16.18 USD/MWh.

The proportion of qualified workers (η) is assumed to be 0.4 for the U.S. (Fullerton and Monti, 2010). As in Giraud and Kahraman (2014), the elasticity of output relative to efficient energy (α) is assumed at around 0.67. Taking this value and the preceding proportion of qualified workers in the U.S. into account, we obtain an elasticity of output in relation to qualified work (β) of 0.132. Simultaneously, the elasticity of output relative to non-qualified work ($1-\alpha-\beta$) is 0.198. For the elasticity of energy generation with respect to renewable resources (γ), which can also be interpreted as the share of renewable resources in energy generation, we use the value of 11.1% (U.S. Energy Information Administration, 2013). To simplify, Ω is assumed to be 0.1, but a higher proportion of emissions for non-renewable resources consumption would not affect our results

qualitatively. In line with Ferreira-Lopes et al. (2012), φ is assumed to be 0.6, which means that consumers value a clean environment but they do not value it as much as they value consumption.

For simplicity, the general efficiency of the economy (θ) and the general efficiency in energy production (Φ) are assumed to be 1. Following Acemoglu and Zilibotti (2001) we calibrate h so that 1.1 is obtained for the term h^Q. According to EUROSTAT data for 2013[6], we assume that the output proportion consumed (Λ) is 0.7. Finally, the adopted discount rate is 2% (Chakravorty et al. 1997; Kurosawa, 2004) and, as in Davidson and Segerstrom (1998), we consider an interest rate of 3%. All the preceding values are summarized in Table 1.

Table 1 Model calibration

Renewables extraction cost	c_R	0.1012
Non-renewables extraction cost	c_F	0.07249
Reserves shadow price	λ	0.01618
Proportion of qualified workers	η	0.4
Elasticity of output in relation to efficient energy	α	0.67
Elasticity of output in relation to qualified workers	β	0.132
Elasticity of energy generation in relation to renewables	γ	0.111
General efficiency of the economy	θ	1
General efficiency of the energy generation	Φ	1
Productivity advantage of qualified workers	h^Q	1.1
Proportion between non-renewables use and emissions	Ω	0.1
Strength of environmental preferences	φ	0.6
Interest rate	i	0.03
Discount rate	ρ	0.02
Marginal propensity to consume	Λ	0.7

5.2. Environmental tax level

In the three alternative scenarios, evaluated relative to a no-policy baseline, the government imposes a tax on the consumption of non-renewable resources. Following IEA et al. (2010), we

[6] See http://ec.europa.eu/eurostat/web/products-datasets/-/nama_gdp_c

consider a tax of 30 USD per tonne of CO_2 that results in a value of 0.0264 USD/kWh for U.S. coal generation technologies. Table 2 summarizes the policy values contemplated for the GTR scenarios described in the preceding section. As indicated before, we modify this baseline tax figure, upwards and downwards, in a subsequent sensitivity analysis[7].

Table 2 Policy values adopted in each scenario with a 30 USD/tCO_2 tax

	τ	σ	μ	$\Gamma_{\bar{Q}}$
Baseline	0	0	1	0
Scenario 1	0.0264	0.0948	1	0
Scenario 2	0.0264	0	1.34	0
Scenario 3	0.0264	0	1	0.74

5.3. GTR simulations

Table 3 summarizes the results obtained for each GTR scenario with an electricity tax that is equivalent to the above-mentioned carbon tax rate of 30 USD/tCO_2. Comparing the three scenarios with the no-policy baseline, we see that only the first GTR (revenues associated to renewable promotion) shows a significant variation in the prices of renewable and non-renewable resources. In this case, the revenue-neutral subsidy to renewable resources significantly decreases their price and brings about a strong increase in their use. However, the presence of a small increase in the relative price of non-renewable resources in all the cases, generates a subsequent reduction in non-renewable resource use (as shown by the ratio *R/F*, or share of renewable resources) and, hence, in emissions. The policy-induced relative price change in renewable/non-renewable resources has positive (partial) effects on welfare in all the scenarios.

Changes in the resource sectors, caused by the introduction of the carbon-related electricity tax, lead to increased energy price (electricity) in both the second and third GTRs (with revenues associated to energy efficiency and distributional purposes, respectively). However, such a tax effect on prices is more than compensated by the renewable resource subsidy (and the decrease of renewable resource price) in the first scenario. In equilibrium, the economy uses less energy to

[7] A discussion on the proper level of carbon taxation is beyond the objectives and capabilities of this paper. However we would like to point out that even though the adopted tax rate (central case) has been used as a benchmark in several academic and policy-oriented studies, its large differences with existing carbon prices or stronger incentives likely to be required to comply with ambitious exogenous targets (such as those set by the Paris agreement) make complementing these simulation results with others linked to lower and higher tax levels highly recommendable. For further discussion of these matters see e.g. Dietz and Stern (2015) and Tol (2014).

produce in the second and third GTRs, as a direct response to varying price effects, than it does in the first scenario. This direct relationship between energy use, production and consumption explains why policy-induced energy price change has positive (partial) effects on welfare in the first scenario but a negative effect in the other two GTRs.

Table 3 Simulation results. Tax rate=30USD/tCO$_2$

	Baseline	Scenario 1		Scenario 2		Scenario 3	
	Value	Value	Variation	Value	Variation	Value	Variation
p_R	0.912	0.058	-1471.63%	0.912	0.00%	0.912	0.00%
p_F	0.100	0.103	3.20%	0.103	3.20%	0.103	3.20%
p_E	0.181	0.168	-7.69%	0.228	20.68%	0.228	20.68%
w_Q	5.536	6.435	13.96%	6.270	11.71%	3.459	-60.06%
$w_{\bar{Q}}$	3.215	3.737	13.96%	3.641	11.71%	2.009	-60.06%
E	36.124	45.216	20.11%	32.452	-11.32%	17.901	-101.80%
Y	9.742	11.324	16.23%	11.034	13.26%	6.087	-37.52%
R	0.795	14.517	94.53%	0.900	11.71%	0.496	-60.06%
F	58.179	52.108	-11.65%	50.775	-14.58%	28.008	-107.72%
P	5.818	5.211	-11.65%	5.078	-14.58%	2.800	-107.72%
R/F	0.014	0.279	95.10%	0.018	22.94%	0.018	22.94%
C	6.819	7.927	16.23%	7.724	13.26%	4.261	-37.52%
W	0.863	1.080	25.08%	1.069	23.88%	0.831	-3.68%

It is interesting to note that wages only decrease precisely in the scenario where the government uses tax revenues to decrease wage inequality. This happens because, on the whole, the economy becomes worse (lower energy use, lower resources use and lower output), whereas in the other two GTRs a better economic performance leads to a wage increase for both types of workers. It is also worth pointing out that the wages of qualified and non-qualified workers respond similarly in all the scenarios, which indicates that the implemented GTRs do not directly affect wage inequality. In the third scenario, this inequality obviously decreases ex-post due to the government transfer of funds to non-qualified workers.

As hinted above, output and consumption (which, let us recall, is a fraction of output) increase with the renewable and energy-efficiency-motivated GTRs, although the energy-price effects lead to a better performance of the former on these variables, but they decrease in the 'redistributive' GTR. Paradoxically, the economic downturn that takes place with the implementation of the third GTR strongly reinforces the above-mentioned positive environmental impacts associated to the energy tax. As a consequence, welfare effects are clearly positive in the two GTR (as output increases and emissions decrease) but they are negative in the third scenario given that the

negative effects on consumption more than compensate the strongly positive effect on emissions and on welfare.

In sum, the two first simulations show that their associated GTR scenarios lead to both an increase in consumption (and welfare) and a reduction of emissions (and thus an increase in welfare), which positively affects welfare and reduces pollution. That is to say, they achieve a 'double dividend', in the terminology of Chiroleu-Assouline and Fodha (2014). These simulations also reveal that the implementation of some GTRs allows for the simultaneous attainment of economic growth and environmental improvement. Although this compatibility is achieved through different channels in the renewable and energy-efficiency motivated GTRs, environmental and welfare outcomes are broadly similar for the two simulated GTRs[8]. The preceding results coincide with the work of Chang (2014), who obtained a double dividend with a similar tax on electricity whose revenues were devoted to fostering R&D efforts on emission abatement technologies. However, the conclusions of the paper differ from Böhringer et al. (2013), who showed that similar policies promoting renewables would only be welfare-improving in the case of low subsidy levels[9].

The third simulation, however, shows a remarkable reduction in output that brings about a significant decrease of welfare. Although an important environmental improvement is present with positive effects on welfare, this is largely related to poorer economic conditions so the compatibility between economic growth and emissions reductions is no longer achieved. Our results differ from those obtained by Chiroleu-Assouline and Fodha (2014), who found a double dividend with a 'distributive' GTR that, unlike the third scenario, was implemented through an increase in the progressivity of labor taxation.

5.4. Sensitivity analysis

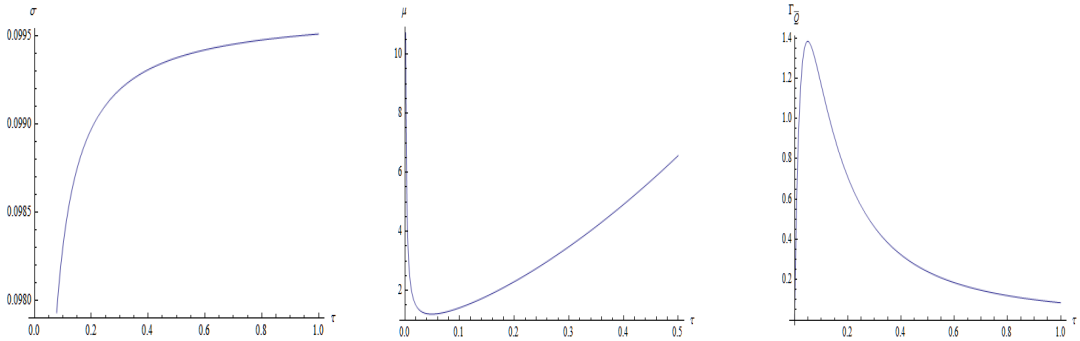
To examine the robustness of the preceding results and additionally contemplate different carbon-related electricity tax ranges (see footnote 6), we perform a sensitive analysis on the tax

[8] For the same environmental tax level, the first (renewable-oriented) GTR provides slightly better welfare results but with a slightly worse environmental performance than the second (energy-efficiency-oriented) GTR. The above-mentioned different price effects explain the varying outcomes.

[9] These authors actually consider, among other alternatives and with a different methodological approach, an electricity tax or the suppression of coal subsidies as a revenue source for the renewable promotion device.

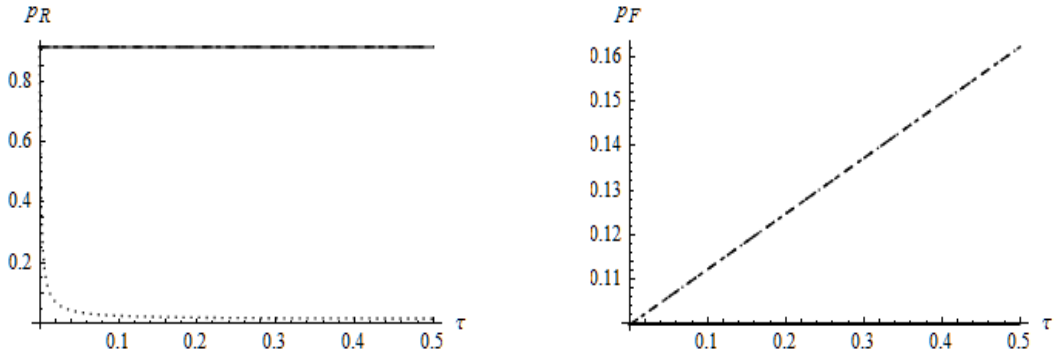
levels. We start by plotting the variables as a function of the tax level and then perform a specific example of an increased (+33%) and decreased (-33%) tax level as compared to the 30USD/tCO2 previously considered. This analysis also provides an indication of the optimal level of energy-related environmental taxation within the calibrated model for the U.S. economy. Figure 1 shows the relationship between the tax level and the other policy instruments considered in the three alternative GTRs. Figure 2 compares the evolution of the main variables in the three GTR scenarios plus the no- policy case.

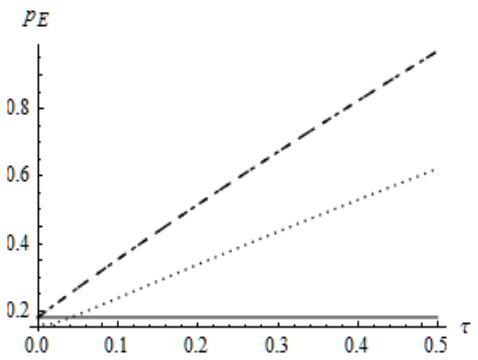
Figure 1 Relationship between the tax level and the other policy instruments in each GTR

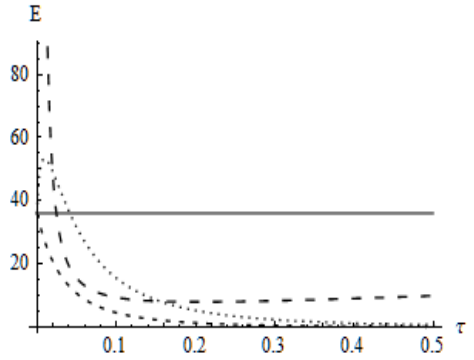


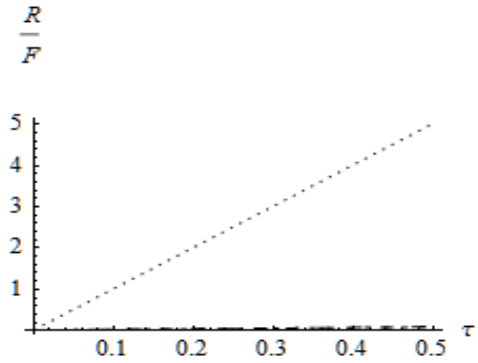
As depicted in Figure 1, a higher tax corresponds to a higher subsidy but the increase in the subsidy tends to stabilize given the erosion of the tax base in the first scenario. In the second GTR, as aforementioned, a higher tax initially corresponds to lower energy efficiency and beyond a determined tax rate corresponds to an increase in energy efficiency level. In the third scenario we can see that a higher tax initially leads to more transfers to non-qualified workers, but the amount available for the transfer decreases due to the erosion of the tax base.

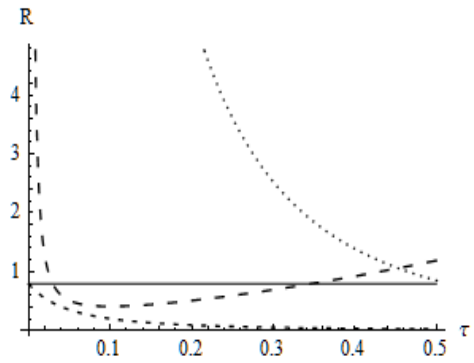
Figure 2 Evolution of the main variables in GTR scenarios




p_E
0.8
0.6
0.4
0.2
0.0
0.1
0.2
0.3
0.4
0.5
τ


E
80
60
40
20
0.1
0.2
0.3
0.4
0.5
τ


$\frac{R}{F}$
5
4
3
2
1
0.1
0.2
0.3
0.4
0.5
τ


R
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3
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1
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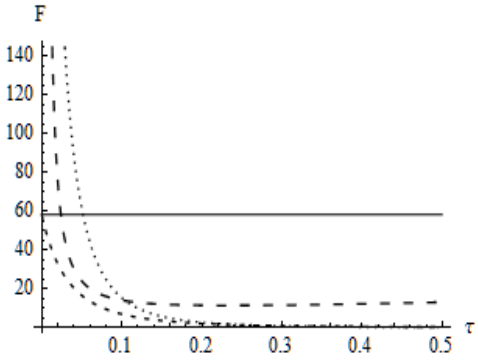
0.3
0.4
0.5
τ


F
140
120
100
80
60
40
20
0.1
0.2
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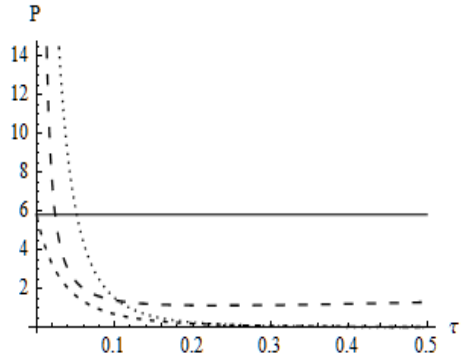
0.5
τ


P
14
12
10
8
6
4
2
0.1
0.2
0.3
0.4
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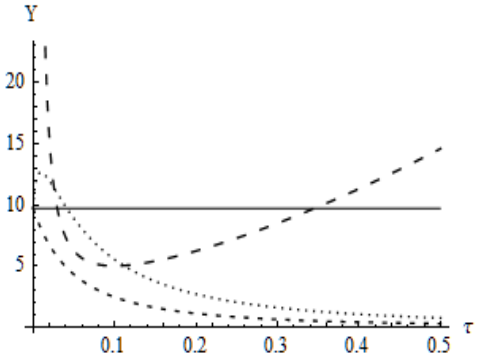
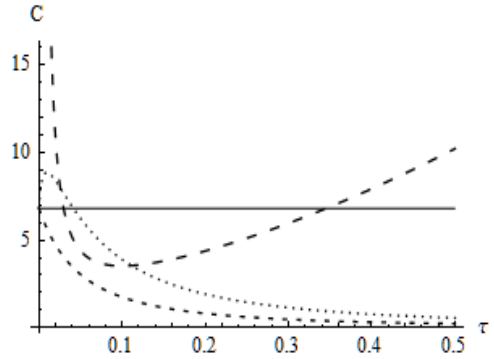
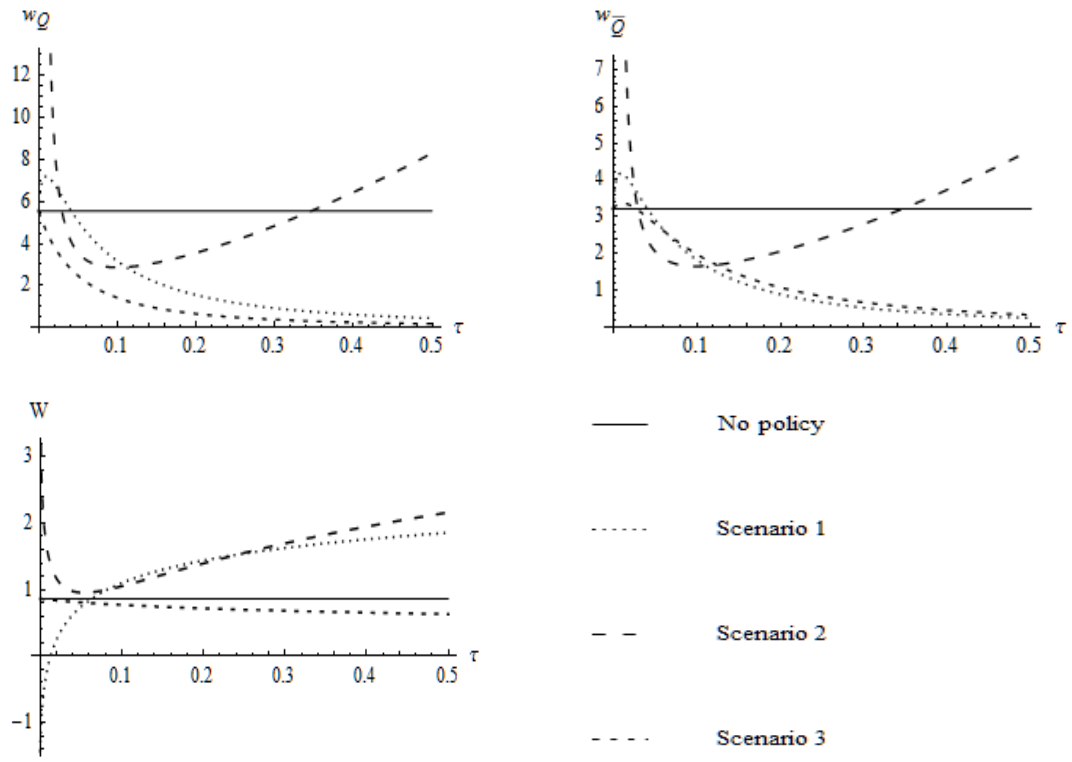
τ


Y
20
15
10
5
0.1
0.2
0.3
0.4
0.5
τ


C
15
10
5
0.1
0.2
0.3
0.4
0.5
τ



The renewables price is equal in all cases (including the no-policy), except for the GTR with renewable subsidies, in which case the price decreases significantly. The non-renewable price always increases with respect to the no-policy case. The changes in the resource prices are reflected in the energy price. In the first scenario, the energy price initially decreases as compared to the no-policy case given the strong decrease in the renewables price. Beyond a certain level, the energy price is always higher in any of the GTRs than it is without policy due to the tax burden imposed on the production side of the economy. When renewables or energy efficiency is promoted, the energy use increases for lower tax levels as compared to the no-policy case. In the first GTR scenario, this happens due to the decrease in energy price and in the second scenario it happens due to a strong rebound effect.

At the same time, the increase in the non-renewable price pressures its usage down, while the higher energy generation leads to greater use. We may see that the use of non-renewables follows a pattern similar to that of energy generation/use. Hence, an initial increase is present in the use of non-renewable energy as compared to the no-policy case in scenarios 1 and 2. This also dictates the behavior of emissions. The renewables use is mainly promoted in the first scenario, while it is extremely small in all other cases. This can also be observed in the ratio of renewables over non-renewables.

In the first and second scenarios output and consumption increase when compared to the no-policy case for low tax levels or, again, for very high tax levels in the energy efficiency scenario. The same pattern applies to wages, which shows that they are closely related to economic conditions. The diagram for non-qualified workers' wages includes the governmental transfer in the last scenario and reveals that wage inequality almost vanishes.

Finally, in terms of welfare, we can see that the second scenario is the most beneficial since welfare increases for all tax levels as compared to the no-policy case. Beyond a certain tax level, welfare also increases in the first scenario when compared to the no-policy case. This happens because the utility effect of the decrease in emissions more than compensates the effect of a lower consumption. The stronger increase in emissions has a negative net impact on utility for lower tax levels despite the increase in consumption. The third scenario always decreases welfare when compared to the no-policy case.

To perform a more accurate analysis, we next simulate two alternative tax values and their respective effects. Taking the outcomes associated to the 30 USD/tCO_2 tax rate as baseline for comparison, Tables 4 and 5 depict the simulation results from respectively increased and decreased electricity tax levels.

Table 4 Effects of a 33% increase in the tax level

	Scenario 1		Scenario 2		Scenario 3	
	Value	**Variation**	**Value**	**Variation**	**Value**	**Variation**
p_R	0.047	-18.12%	0.912	0.00%	0.912	0.00%
p_F	0.104	1.06%	0.104	1.06%	0.104	1.06%
p_E	0.175	4.36%	0.243	6.70%	0.243	6.70%
w_Q	5.901	-8.30%	4.690	-25.20%	3.032	-12.34%
$w_{\bar{Q}}$	3.427	-8.30%	2.724	-25.20%	1.761	-12.34%
E	39.730	-12.13%	22.751	-29.90%	14.706	-17.85%
Y	10.384	-8.30%	8.254	-25.20%	5.335	-12.34%
R	16.258	12.00%	0.673	-25.20%	0.435	-12.34%
F	44.419	-14.76%	35.308	-30.46%	22.824	-18.51%
P	4.442	-14.76%	3.531	-30.46%	2.282	-18.51%
R/F	0.366	31.38%	0.019	7.57%	0.019	7.57%
C	7.269	-8.30%	5.778	-25.20%	3.735	-12.34%
W	1.089	0.84%	0.997	-6.76%	0.823	-1.07%

It is worth noting that the (33%) higher electricity tax increases the renewable resource subsidy by only 1.23%. On the other hand, a 7.51% decrease in energy efficiency indicates that we are located in the 'low initial tax level' area identified in the theoretical analysis (see Section 4.2) and in the initial part of the sensitivity analysis. Finally, transfers to non-qualified workers increase by only 8.1%. In sum, the model shows that a tax rate increase with respect to the central case would not bring about similar changes in the subsidies/transfers to promote renewables, energy efficiency and income equality.

Indeed, the higher tax rate brings about a 1.05% increase in the price of non-renewable resources, which reflects a low elasticity of the resource price with respect to the tax level. Consequently, the consumption of non-renewable resources decreases in all the scenarios, particularly in the energy-efficiency-oriented GTR. The consumption of renewable resources also decreases, except in the first GTR scenario, even though said increase is relatively small given the slight ncrease in the subsidy and its complementarity with the use of non-renewable resources. Energy becomes more expensive in all cases due to the non-renewable resource price increase and the economy therefore uses less energy in equilibrium. Moreover, a reduction in the wages of both types of workers is present in all the scenarios. Output also decreases in all cases, reflecting the negative economic effects associated to the tax rate increase.

Table 5 Effects of a 33% reduction in the tax level

	Scenario 1		Scenario 2		Scenario 3	
	Value	Variation	Value	Variation	Value	Variation
p_R	0.078	34.70%	0.912	0.00%	0.912	0.00%
p_F	0.102	-1.06%	0.102	-1.06%	0.102	-1.06%
p_E	0.162	-3.63%	0.212	-6.76%	0.212	-6.76%
w_Q	6.936	7.79%	10.298	64.23%	3.987	15.27%
$w_{\overline{Q}}$	4.028	7.79%	5.980	64.23%	2.315	15.27%
E	50.570	11.84%	57.161	76.14%	22.131	23.63%
Y	12.205	7.79%	18.121	64.23%	7.016	15.27%
R	11.616	-19.98%	1.478	64.23%	0.572	15.27%
F	60.765	16.61%	90.219	77.68%	34.930	24.71%
P	6.077	16.61%	9.022	77.68%	3.493	24.71%
R/F	0.191	-31.38%	0.016	-7.57%	0.016	-7.57%
C	8.544	7.79%	12.685	64.23%	4.911	15.27%
W	1.063	-1.60%	1.220	14.14%	0.841	1.15%

The higher tax rate also leads to an improved environment, as emissions decrease proportionally more than output. Yet the best environmental improvement ratio with respect to output is

achieved by the first GTR, as confirmed by the evolution of welfare (only positive in this scenario with respect to the central-tax baseline). In any case, even if welfare shows a negative evolution with respect to the central-tax baseline, the second GTR still shows a higher welfare than the no-policy option. This means that the increased tax rate keeps a double dividend (following the aforementioned convention) in both the first and second GTR scenarios.

On the other hand and as expected, a 33% reduction in the tax level leads to opposite effects on related policy tools. Yet it is noticeable that the percentage changes are now higher than they were in the preceding tax simulation. This reflects a larger elasticity of the non-fiscal policy instruments to the tax reduction. In this sense, the renewable resource subsidy is reduced by 2.36%, energy efficiency increases by 19.05%, and the transfer to non-qualified workers goes down by 16.44%.

As happened before, the effects on the different variables have the opposite sign when compared to the preceding high-tax sensitivity analysis. Regarding the so-called environment-economy ratio, in the first GTR the percentage changes are similar (with opposite signs) for the tax increases and decreases with respect to the central tax simulation. However, raising the tax rate brings about a higher percentage reduction in output, whereas a tax reduction leads to a higher increase in emissions. The changes in tax rates therefore do not contribute to mitigating the economy-environment trade-off in the first GTR. Nevertheless, on the second and third GTR scenarios, reduced tax rates improve output relatively less than they harm the environment when compared to a rate increase in the central-tax situation. Slightly increasing the tax therefore improves the economy-environment trade-off in both cases, particularly in the second GTR.

Welfare decreases in the first GTR scenario and increases in the second and third GTR scenarios. This would be the most favorable setting for a decrease in the environmental tax level given the larger welfare increase seen in the second GTR scenario. In any case, welfare in the first and second GTRs is still higher than it is in the baseline (no-policy). However, with the new tax rate there is an increase in emissions in both GTRs with regard to the baseline. Therefore no double dividend is achieved in this case.

Summing up, in the first and second GTR (revenue-neutral renewable and energy efficiency promotion) only a sufficiently high energy-related environmental tax rate would allow for the achievement of a double dividend. Beyond a certain tax threshold, however, energy-efficiency

motivated GTRs undermine welfare. On the contrary, when environmental tax revenues are devoted to decreasing income inequality among workers, a double dividend would never be achieved. Indeed the third GTR, causing a fall in the main macroeconomic variables, is the worst performer in economic terms.

6. Conclusions and implications

This paper focuses on the so-called third generation of GTR, a post-crisis variation of standard reform solutions that makes no full devotion of environmental receipts to a reduction of distortionary taxes but rather adopts a more flexible and heterogeneous use of tax revenues. We have particularly explored three 'new' GTR solutions recently implemented in a number of countries with scarce academic analysis and evaluation: the use of environmental tax revenues to subsidize renewable energy, promote energy efficiency and reduce income inequality among workers.

The article incorporates an example of each of these new GTRs within a theoretical general equilibrium framework to analyze their impacts on the main macroeconomic variables, emissions and welfare. Given that the components of the GTRs under study brought about opposite effects for most model variables, the theoretical enquiry was inconclusive, thus making it necessary to calibrate and simulate the different policy alternatives. We did so for the U.S. economy, whose global relevance is unquestionable and where a number of GTR proposals have been considered over the last few years (C2ES, 2014). We interpreted the results following a double-dividend definition that fit the characteristics of the theoretical model. However, this approach differs from the more common weak/strong definition of double dividends due to different baselines for comparison. Outcomes were reassessed for different plausible levels of the energy-related environmental tax rate.

It is shown that the GTRs considered would lead to increased output, i.e. economic growth, and they would be welfare enhancing (with respect to a no-policy baseline) if environmental tax revenues were devoted to subsidizing renewable energy or promoting energy efficiency, as long as the environmental tax rate is not excessive. A reduction of emissions (environmental improvement) would also accompany this welfare increase, as long as the environmental tax rate is sufficiently high, and it would thereby lead to a double dividend from the preceding GTRs. On

the contrary, output and welfare would decrease if environmental receipts were earmarked to a reduction of income inequality among workers and, although a remarkable environmental improvement would take place (related to both the incentive effects from the environmental tax and the economic downfall), no double dividend would occur in this GTR.

Summing up, this paper yields one of the first theoretical and empirical analyses on the new generation of GTRs. The results show significant heterogeneity in the economic and environmental performance of each alternative that, given the rising popularity of such reforms, vindicate our enquiries and encourage future research efforts in this area.

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