Environ Resource Econ (2018) 71:605–624
https://doi.org/10.1007/s10640-016-0070-y

Environmental Taxation, Inequality and Engel's Law: The Double Dividend of Redistribution

David Klenert[1,2,3] · **Gregor Schwerhoff**[1] · **Ottmar Edenhofer**[1,2,3] · **Linus Mattauch**[1,4]

Accepted: 24 September 2016 / Published online: 19 October 2016

Abstract Empirical evidence shows that low-income households spend a high share of their income on pollution-intensive goods. This fuels the concern that an environmental tax reform could be regressive. We employ a framework which accounts for the distributional effect of environmental taxes and the recycling of the revenues on both households and firms to quantify changes in the optimal tax structure and the equity impacts of an environmental tax reform. We characterize when an optimal environmental tax reform does not increase inequality, even if the tax system before the reform is optimal from a non-environmental point of view. If the tax system before the reform is calibrated to stylized data—and is thus non-optimal—we find that there is a large scope for inequality reduction, even if the government is restricted in its recycling options.

Keywords Environmental tax reform · Double dividend · Revenue recycling · Inequality · Distribution · Non-homothetic preferences

JEL Classification D58 · D62 · E62 · H21 · H23

✉ David Klenert
klenert@mcc-berlin.net

Gregor Schwerhoff
schwerhoff@mcc-berlin.net

Ottmar Edenhofer
edenhofer@pik-potsdam.de

Linus Mattauch
linus.mattauch@ouce.ox.ac.uk

1 Mercator Research Institute on Global Commons and Climate Change (MCC), Torgauer Str. 12-15, 10829 Berlin, Germany

2 Potsdam Institute for Climate Impact Research, P.O. Box 601203, 14412 Potsdam, Germany

3 Department of Economics of Climate Change, Technical University of Berlin, Berlin, Germany

4 Institute for New Economic Thinking at the Oxford Martin School and Environmental Change Institute, School of Geography and the Environment, University of Oxford, Oxford, UK

1 Introduction

A widespread reservation against environmental taxation is that this policy might increase inequality (Bento et al. 2005; Bento 2013; Wier et al. 2005) at least in developed countries.[1] A major reason why this policy is considered regressive is that poor households spend a larger fraction of their income on pollution-intensive goods than rich households. This is reminiscent of Engel (1857)'s work on subsistence levels of food consumption. In principle, the environmental tax revenue can be recycled in a progressive way. However, it is unclear to what extent the recycling of the tax revenue can offset the regressive effect of the tax itself.

The main novelty of this article is that we quantify the distributional effect of *optimal* environmental tax reforms. We also compare different recycling mechanisms for environmental tax revenue in terms of their equity implications. For this purpose, we analyze an increase in regressive environmental taxes which is induced by a change in preferences for environmental quality. We assume that the government has different options for recycling the tax revenue such as linear/non-linear income tax cuts and uniform lump-sum transfers. We determine the distributional effects of such a tax reform by comparing different economic variables before and after the tax reform in two settings: first, in a setting in which taxes are set optimally before the tax reform (from a non-environmental point of view); second, in a calibrated setting in which the initial tax system is suboptimal. We find that the overall distributional impact of such a reform depends on the initial tax structure and the available revenue recycling options.

Specifically, our main findings are: (1) If the pre-existing tax system is optimal, the regressive effect of the environmental tax can be largely or even completely offset by the recycling of the tax revenue: an environmental tax reform is even slightly progressive if the government can use a combination of lump-sum transfers and non-linear income tax cuts to redistribute the tax revenue. If uniform lump-sum transfers are unavailable for redistribution, the tax reform is slightly regressive. (2) If the pre-existing tax system is non-optimal, an environmental tax reform can have a large scope for inequality reduction.

In the cases in which inequality is reduced through an environmental tax reform, we talk about a *double dividend of redistribution*. Our double dividend of redistribution, however, is different from the classical double dividend (Goulder 1995; Bovenberg 1999).[2] The reason is that in a setting with heterogeneous households, the classical double dividend is of limited interest, since constraining the government to using either income tax cuts or uniform lump-sum transfers for revenue recycling will inevitably lead to welfare losses. In fact, we show that an optimal environmental tax reform requires adjustments in both lump-sum and income taxes.

There are two separate strands of literature which analyze questions of (optimal) taxation and distribution in the presence of (environmental) externalities: First, the optimal taxation literature, which models pollution as a by-product of the consumption of polluting goods and an environmental tax hence as a tax on the polluting commodity. Models in this strand of the literature assume linear production functions which lead to constant prices (with the

[1] We are only concerned with the (intra-generational) distribution between different households at a given point in time, since increased intra-generational inequality is one of the most commonly used arguments against environmental policy (Combet et al. 2010; Ekins 1999). For an article that considers both intra- and inter-generational distributional effects of environmental taxation see Jacobs and van der Ploeg (2010).

[2] In this strand of literature it is argued that using environmental tax revenue for reducing distorting taxes might lead to a reduction in the gross costs of an environmental tax reform, compared to lump-sum recycling (Goulder 1995; Bovenberg 1999).

exception of Cremer and Gahvari 2001). The second strand analyzes the effect of increased environmental taxes on factor prices (and sometimes on the distribution between heterogeneous households). These publications, however, are not concerned with the optimality of the tax system.

The optimal taxation literature analyzes questions such as under what conditions the second-best externality tax can be set to the first-best Pigouvian level, when it suffices to set linear corrective taxes, if income and commodity taxes can be formulated independently of externality-correcting taxes[3] and if the optimal (income, commodity and environmental) tax rules change in a second-best setting. This literature, however, does not make statements about the distributional effects of an optimal environmental tax reform.

The conclusions from these studies differ, depending on the tax instruments available to the government: Jacobs and De Mooij (2015) show that when the income and the externality tax are both linear or both non-linear, and uniform lump-sum taxes are available, the government should set the externality tax at its Pigouvian level; optimal income and optimal environmental taxes can be determined independently.[4] Cremer et al. (1998) demonstrate, in a setting in which uniform lump-sum transfers are not available, that this does not hold anymore for the combination of linear externality taxes with non-linear income taxes and that the additivity property breaks down in this case. Still excluding price effects, Kaplow (2012) analyzes different environmental tax reform designs under equity constraints.

When the production side is accounted for explicitly, as is done in the second strand of the literature, substitution effects between pollution and other factors of production occur, that do not exist when prices are assumed to be constant (Fullerton et al. 2001; Dissou and Siddiqui 2014). In fact, Fullerton and Heutel (2007, 2010) show that the incidence of an environmental tax on the firm side can have strong distributional effects. Dissou and Siddiqui (2014) demonstrate that these effects are likely to be progressive.

Both strands of literature have gained important insights, but they are also of limited applicability: Regarding optimal taxation, statements about changes in abstract tax rules and an exclusive focus on households do not suffice to make quantitative statements about the distributional effects of environmental tax reforms. On the other hand, models from the second strand of the literature often do not account for heterogeneous households (and thus for non-linear income taxes) and they analyze tax reforms away from the optimum. If they account for heterogeneity the latter point of critique still holds (Chiroleu-Assouline and Fodha 2014; Fullerton and Monti 2013; Klenert and Mattauch 2016).

Our study bridges the gap between these two strands: we present a hybrid model in which the modeling of the household side is based on the first and the modeling of the firm side is based on the second strand of the literature. The government is modeled as a Stackelberg leader which anticipates the actions of the other agents, while these agents take the policies imposed by the government as given. Solving this model numerically, we illustrate the distributional consequences of such a tax reform by quantifying the changes in the tax rates and in inequality.

[3] Sandmo (1975) called this principle the *additivity property*.

[4] This contribution and related research is centered around the question whether the marginal cost of public funds equals unity or not. Kaplow (2004) was the first to argue that these are indeed equal to one, if Mirrleesian income taxes and optimal public good supply are set simultaneously. Jacobs and De Mooij (2015) extend Kaplow's thesis to the case of Pigouvian taxes combined with optimal income distribution. This holds when uniform lump-sum transfers are available to the government, in which case there are no environmental double dividends possible.

We use the following assumptions from the aforementioned studies, which we consider the most empirically relevant, to extend the small analytical model described in Klenert and Mattauch (2016) to a numerical model which includes prices effects and determines optimal policies: First, as Fullerton and Heutel (2007; 2010), we model pollution as a production input, and an environmental tax hence as a tax on this input (and not on the polluting commodity). Second, we focus on the case of a non-linear income tax combined with a linear tax on pollution, to account for the redistributive role of income taxes and since the pollution tax is levied directly in production. Third, we determine optimal policies as in Cremer et al. (1998), Cremer and Gahvari (2001) and Jacobs and De Mooij (2015). Finally, we focus on the case of a non-homothetic utility function to reflect the empirical finding that poor households spend a higher share of their income on pollution-intensive goods (Grainger and Kolstad 2010; Levinson and O'Brien 2015; Flues and Thomas 2015). Note that these findings mainly concern developed countries: in developing countries an environmental tax can have a less regressive or even a progressive effect (Sterner 2011). The present study is the first to combine these assumptions.

The remainder of this article is structured as follows: The model is outlined in Sect. 2, which also includes subsections on the calibration of the model and its numerical solution. We describe the adjustment in the optimal income and lump-sum taxes that accompany an optimal environmental tax reform in Sect. 3. In Sect. 4, we modify some of the modeling assumptions such as the tax instruments available to the government, the assumption of non-homothetic preferences and values of key parameters. In Sect. 5 we apply the framework from the preceding sections to a calibrated economy. We show that, if the pre-existing tax system is suboptimal, there is a large scope for inequality reduction. Section 6 concludes.

2 The Model

We use a two-sector general-equilibrium model with Mirrleesian income taxation, in which N households are distinguished by their productivity. Households consume two goods with different pollution intensities. There is a subsistence level of polluting consumption, which we model with a Stone–Geary utility function. Households derive utility from consumption of the two goods, leisure and environmental quality. Individual households cannot affect pollution, so only the government can regulate it. Within this framework we assess the distributional effects of an optimal environmental tax reform.

Firms There are two representative firms, one produces a clean consumption good C, the other produces a polluting consumption good D. Pollution Z is a by-product of production. We assume that production $F_j(T_j, Z_j)$, with $j \in \{C, D\}$, is a function of pollution Z_j and a resource T_j, which is bought from the households.[5] The resource T_j can, in our model, be interpreted as a fixed amount of a tradable resource such as labor, land or capital. In that sense leisure is the amount of this resource which is used at home. For the sake of simplicity we will refer to the resource sold to the firm as labor and to the resource used at home as leisure.

Firms produce with a constant returns to scale technology $F_j(T_j, Z_j),\ j \in \{C, D\}$:

$$F_j(T_j, Z_j) = \begin{cases} (\epsilon_j T_j^r + (1-\epsilon_j) Z_j^r)^{\left(\frac{1}{r}\right)}, & \text{if } Z_j \leq x T_j \\ 0, & \text{if } Z_j > x T_j \end{cases} \tag{1}$$

[5] This is a common approach when assessing the equity and efficiency impacts of environmental policy in a general equilibrium (see e.g. Fullerton and Heutel 2007; Fullerton and Metcalf 2001; Copeland and Taylor 1994).

with $\sigma = 1/(1-r)$ being the elasticity of substitution between labor and pollution Z_j and ϵ_j the factor share in the respective sectors. The additional inequality (with $x > 0$) in the production function implies that the firms allocate some of their labor to production and the rest to pollution abatement activities (see Appendix A in Copeland and Taylor 1994 for more details). The firms sell their good at price p_j and pay wages w for the production factor T_j.

The firms choose their production factors so as to equalize factor payments with marginal productivities:

$$w = \frac{\partial F_j(T_j, Z_j)}{\partial T_j} \tag{2}$$

and

$$\tau_Z = \frac{\partial F_j(T_j, Z_j)}{\partial Z_j}, \tag{3}$$

with τ_Z denoting a pollution tax levied by the government.

Households Households are distinguished only in their productivity ϕ_i. There are N households, ordered from 1 for lowest to N for highest productivity. Households all have the same total time endowment T, which they can either dedicate to leisure l_i or to production. Each household receives an after tax income of

$$I_i = (1 - \tau_{w,i})\phi_i w(T - l_i). \tag{4}$$

with $\tau_{w,i}$ representing non-linear income taxes, levied by the government. We follow Ballard et al. (2005) in modeling the fact that households need a minimal level of polluting consumption D_0, with non-homothetic preferences. All households have the same preferences and maximize the following utility function:

$$V_i = U(C_i, D_i, l_i) + E(Z) = C_i^{\alpha}(D_i - D_0)^{\beta} l_i^{\gamma} + (E_0 - \xi(Z_C + Z_D)^{\theta}), \tag{5}$$

with the environmental quality E(Z) being defined as

$$E(Z) = E_0 - \xi(Z)^{\theta}, \quad \text{with} \quad Z = Z_C + Z_D. \tag{6}$$

E_0 is the initial stock of environmental quality which suffers damages from total pollution Z emitted in the production sectors.

The budget equation of each household is given by

$$C_i \cdot p_C + D_i \cdot p_D = I_i + L. \tag{7}$$

Here, L is a uniform lump-sum transfer (or, if negative, a linear lump-sum tax).[6] Each household chooses its leisure time share and consumption in both goods to maximize the utility function with respect to the budget equation, which yields the following first-order conditions:

$$\left(\frac{\partial U_i}{\partial C_i}\right) \Big/ \left(\frac{\partial U_i}{\partial D_i}\right) = \frac{p_C}{p_D}, \tag{8}$$

$$\left(\frac{\partial U_i}{\partial D_i}\right) \Big/ \left(\frac{\partial U_i}{\partial l_i}\right) = \frac{p_D}{(1 - \tau_{w,i})\phi_i w}. \tag{9}$$

[6] Following Jacobs and De Mooij (2015), we include uniform lump-sum transfers as a possible policy instrument. We analyze the case of a government restricted to income taxes in Sect. 4.1 and find that the uniform lump-sum transfers play a significant role in optimal taxation.

Government The government maximizes total welfare W, i.e. the sum of all agents' utilities:

$$W = \sum_{i=1}^{N} V(C_i, D_i, l_i, E). \tag{10}$$

Taxes are primarily used to finance the government's revenue requirement G, which remains constant during the analysis. The government's budget equation is thus given by:

$$G = -NL + \sum_{i=1}^{N} \tau_{w,i}\phi_i w(T - l_i) + \tau_Z(Z_C + Z_D). \tag{11}$$

We assume that the government is unable to observe the individual productivity of each household. To ensure that agent i prefers his bundle $\{C_i, D_i, I_i\}$ to the bundles of all other agents $j \neq i$, we implement the following Mirrlees (1971) type incentive compatibility constraint:

$$U_i \geq U_i^j. \tag{12}$$

U_i^j is the utility of household i pretending to be household j. It is given by

$$U\left(C_j, D_j, T - \frac{I_j}{(1 - \tau_{w,j})\phi_i w}\right). \tag{13}$$

The optimal income tax system is a result of the welfare maximization and the incentive constraints: the government chooses the income tax rates such that there is some redistribution between agents (due to the utilitarian welfare maximization), but not enough to destroy the agents' incentives to work (due to the incentive constraints).

Resource constraints and numeraire The following resource constraints apply:

$$T_C + T_D = \sum_{i=1}^{n} \phi_i(T - l_i), \tag{14}$$

$$p_C \sum_{i=1}^{n} C_i + \frac{1}{2}G = F_C p_C, \tag{15}$$

$$p_D \sum_{i=1}^{n} D_i + \frac{1}{2}G = F_D p_D. \tag{16}$$

The first equation describes the equilibrium on the labor market, while the last two equations describe the equilibrium in the market for clean and polluting goods. The government is assumed to consume equal shares of clean and polluting goods. We set the price w of the production input T_j as the numeraire.

2.1 Calibration

For the simulations below we set $N = 5$. The individual productivities are calibrated to match recent U.S. data on the income shares of different quintiles (see Table 1).

The remaining parameters are chosen as displayed in Table 2. We choose the clean and the polluting consumption shares in the utility function in relation to the share of clean and polluting output produced (as do Fullerton and Heutel 2007; Goulder et al. 1999). The

Table 1 The households' productivities are calibrated to match data from the U.S. Census Bureau on the income shares of different quintiles in the benchmark scenario (DeNavas-Walt et al. 2012)

Quintile	1	2	3	4	5
Productivity (ϕ_i)	0.03	0.0825	0.141	0.229	0.511

Table 2 Calibration of the model parameters

Households		
α	Clean consumption share in utility	0.7
β	Polluting cons. share in utility	0.2
γ	Leisure share in utility	0.2
D_0	Subsistence level poll. consumption	0.5
θ	Damage exponent	1.0
ξ	Pref. for env. quality	0.1
Firm		
A_C, A_D	Total factor productivity	1
ϵ_C	Labor intensity clean production	0.995
ϵ_D	Labor intensity poll. production	0.92
σ	Elast. of subs. btw. labor and pollution	0.5
Government		
G	Government consumption	5

polluting sector is more pollution-intensive than the clean sector, which we assume to be almost pollution-free. We set D_0 such that it is at 44 % of the mean polluting consumption level and at 62 % of the polluting consumption level of the lowest income quintile before the tax reform. Government spending G is set at roughly 24 % of the GDP before the tax reform. We vary this value in Sect. 4.3 between 0 and 70 % of GDP and find that it does not change the results qualitatively.

2.2 Solving Numerically

We need to use numerical methods to solve the model for the following reasons: First, we calibrate the model to stylized data on income distribution and tax burden and calculate the change in optimal tax rates instead of tax rules to quantify the distributional effects of an environmental tax reform. Second, we model the production side to include price effects and an environmental tax as a tax on pollution which occurs in the production sector. Third, the government in our model acts as a Stackelberg leader, which means it anticipates the actions of all other actors, including firms, while firms and households take the actions of the government as given.

The variables C_i, D_i, l_i, p_C, p_D, T_C, T_D, Z_C, Z_D, L, τ_Z and $\tau_{w,i}$ are determined, in the general equilibrium, by the following optimization: We use the algebraic modeling system GAMS (Rosenthal 2014) to maximize total welfare (10) subject to the government's budget constraint (11), the incentive constraints (12), the resource constraints (14)–(16) and to the first-order conditions of the firms (2), (3) and the households (7)–(9), by varying the available policy instruments.

2.3 Measures of Distribution

Since the pollution tax is levied on the firm side, we need a measure of distribution which also includes price effects on consumption goods and effects on leisure, which occur when both leisure and pollution are an input in production. Traditional measures such as the Gini coefficient in income are hence not suitable for our purpose. An alternative is calculating the Gini coeffient in utility: this includes both price effects and changes in leisure levels. In the following, whenever we refer to the Gini coefficient, we refer to the Gini coefficient in utility. We use the non-environmental utility U for the calculation of the Gini coefficient in order to separate the inequality-reducing effect of avoided damages from the distributional effect of the environmental tax incidence and the revenue redistribution.[7]

3 Optimal Environmental Tax Reform

In this section we determine the optimal mix of non-linear income taxes, uniform lump-sum transfers and (linear) taxes on the polluting production input before and after an increase in the preference parameter for environmental quality ξ from zero to $\xi > 0$. This increase can, for instance, be interpreted as new scientific evidence on the detrimental effects of pollution on well-being. We call the adjustment of the policy instruments an optimal environmental tax reform (ETR).

The government can adjust the optimal tax and transfer levels freely. This setting is hence the most unrestricted one we analyze. In the subsequent sections we will gradually introduce more government constraints (non-availability of lump-sum transfers in Sect. 4.1 and a sub-optimal initial tax system and fixed ETR designs in Sect. 5). By comparing these sections to the current section the implication of each constraint becomes visible.

In this section, we obtain the following results: First, optimal income taxes hardly react to a change in environmental preferences (see Fig. 1, top left). Second, most additional revenue is redistributed in a lump-sum fashion (see Fig. 1, top right). Third, the Gini coefficient decreases (see Fig. 1, bottom left) and fourth, the government shifts away from lump-sum towards environmental taxes in the financing of its spending (see Fig. 1, bottom right).

We first describe the economy before the tax reform. The fixed government spending requirement is financed in large parts by lump-sum and income taxes, which are set such that the incentive constraints are binding. A smaller fraction is contributed by environmental taxes. Optimal environmental taxes are greater than zero even in the case of $\xi = 0$ because only from a certain environmental tax threshold on the firm will reduce production in response to the environmental tax. Even a government without a preference for environmental quality sets the environmental tax just below this threshold level because this does not distort production.[8]

We now detail the results: First, before ξ is increased, the income taxes are adjusted such that welfare is maximized and the incentive constraints are not violated. Due to the

[7] Bovenberg and van der Ploeg (1994, 1996) use the terms "blue welfare" for the non-environmental welfare component, and "green welfare" for the welfare component that depends on the environmental quality, to make this important distinction. Bovenberg and van der Ploeg (1996) and Ligthart and van der Ploeg (1999), further decompose welfare in a red and a pink component which accrue to changes in public consumption and employment, respectively. Since we assume constant government spending and full employment, there are no effects on public consumption or employment in our model.

[8] This threshold level is a consequence of the assumption that the firms allocate some of the labor to pollution abatement (see Eq. (1) and the subsequent paragraph). In Fig. 4 in Sect. 4.3 we gradually increase ξ from zero and hence demonstrate the existence of that threshold.

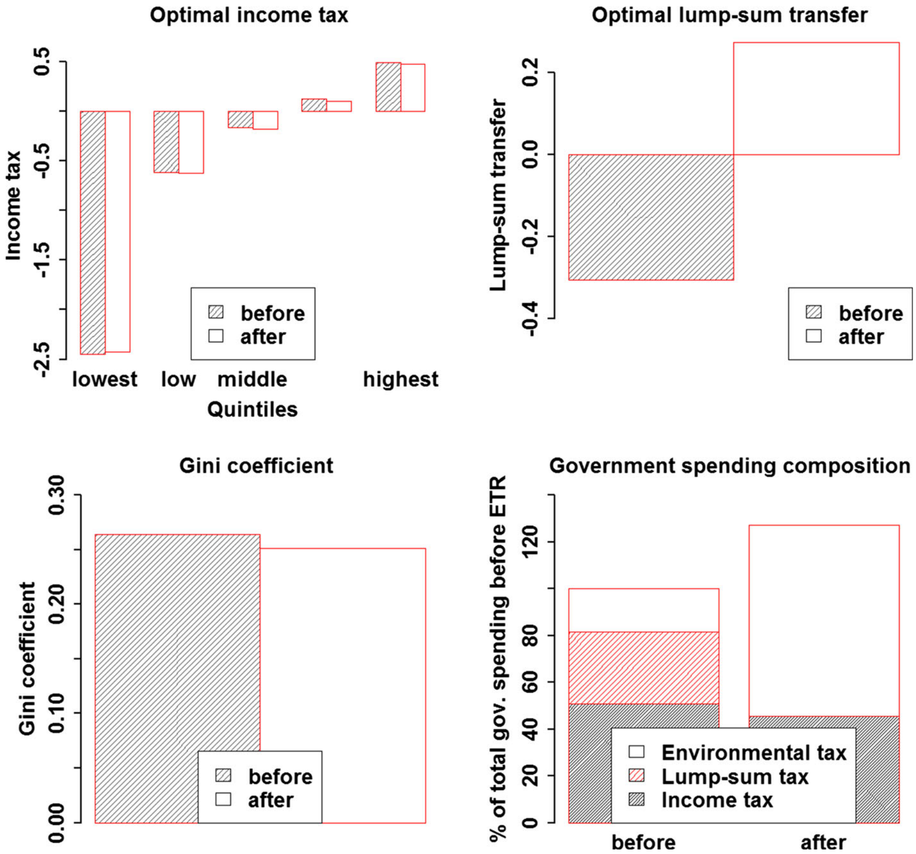

Fig. 1 Optimal non-linear income and lump-sum taxes, as well as the Gini coefficient and the government spending composition before and after an environmental tax reform. Government spending increases after the environmental tax reform since lump-sum transfers (which we include in the government spending) increase

high marginal utility of consumption of low-income households, we see high subsidies for low-income households and high-taxes for high-income households. The income tax system hardly changes in response to an ETR since a more progressive change in the tax system would violate at least one of the incentive constraints (Fig. 1, top left).

Second, lump-sum transfers are mainly a tool for balancing the government's budget: before the ETR they are negative. After the tax reform, when the government can meet a large part of its spending requirements with environmental taxes, lump-sum transfers are used for returning the excess revenue to the households (Fig. 1, top right). Since the income taxes are already set such that the incentive constraints are binding, more redistribution is only possible through lump-sum transfers. Therefore the overall effect of the ETR is slightly progressive.

The result concerning the Gini coefficient is a consequence of several opposing effects: on the one hand, an environmental tax has a regressive effect, since it increases the price of the polluting subsistence good relative to the price of the cleaner good. Poor households are hit disproportionally hard by this tax, since they spend a higher share of their income on polluting goods, due to our assumption of non-homothetic preferences. On the other hand, the environmental tax creates revenues which are used for redistributive purposes: the regressive lump-sum tax is abandoned. Instead, progressive lump-sum transfers are put into place. Due to the progressive effect of the lump-sum transfers, distortionary labor subsidies for the low-income quintile and distortive income taxes for the high income quintiles can be reduced (slightly). The overall result is a reduction in the Gini coefficient (Fig. 1, bottom left).[9]

Fourth, increasing the preference for environmental quality leads to an increase in the environmental tax and hence to an increase in the share of environmental tax-financed government spending. As a consequence, income taxes are slightly reduced and lump-sum taxes are completely eliminated (Fig. 1, bottom right).

In sum, these results demonstrate that if a tax system is already optimal (from a non-environmental view, i.e. when $\xi = 0$), an increase in the preference parameter for environmental quality ξ leads to a readjustment of optimal lump-sum transfers and income tax rates that renders the new tax system more progressive. A government, in our model, can thus use the additional revenue generated by environmental taxes to optimally adjust the tax system in a progressive way. We hence obtain a double dividend of redistribution even if the pre-existing tax system is optimal from a non-environmental point of view.

Our results quantify the impact of an optimal environmental tax reform not only on inequality, but also on optimal income tax rates and lump-sum transfers. We thus complement the optimal taxation literature by quantifying the change in the tax rates for different quintiles, instead of calculating the changes in abstract tax rules.

4 Robustness: lump-sum transfers, subsistence consumption and greening of preferences

This section includes additional experiments to facilitate the comparison of our results to the literature on optimal taxation in the presence of an environmental externality. Furthermore, it illustrates the consequences of the different modeling choices. In Sect. 4.1 we analyze the case in which uniform lump-sum transfers are unavailable to the government (a common assumption in the literature). In Sect. 4.2, we analyze the role of non-homothetic preferences by setting the subsistence level D_0 to zero in all scenarios (i.e. in Sects. 3 and 4.1). In Sect. 4.3 we vary critical parameters to analyze our results for robustness.

Detailed results and the differences to Sect. 3 are elucidated in more detail in the individual sections.

4.1 Optimal Taxation Without Lump-Sum Transfers

Most articles have not considered the possibility of *uniform* lump-sum transfers in an optimal taxation setting in the presence of an externality. Jacobs and De Mooij (2015) is one of the few exceptions that allow for uniform lump-sum transfers. We analyze the effect of this assumption in the current section, by performing the same analysis as in Sect. 3 without the possibility of optimally set uniform lump-sum transfers (taxes).[10]

We find that an increase in the preference parameter for environmental quality ξ leads to the following effects: First, since lump-sum taxes are not available to the government, redistribution of additional revenue occurs only through the income tax system. Optimal income taxes hence react strongly to a change in environmental preferences (see Fig. 2, top

[9] We use the Gini coefficient in non-environmental utility, see Sect. 2.3 for more details.

[10] This means all equations laid out in Sect. 2 remain the same, but we add the constraint that $L = 0$.

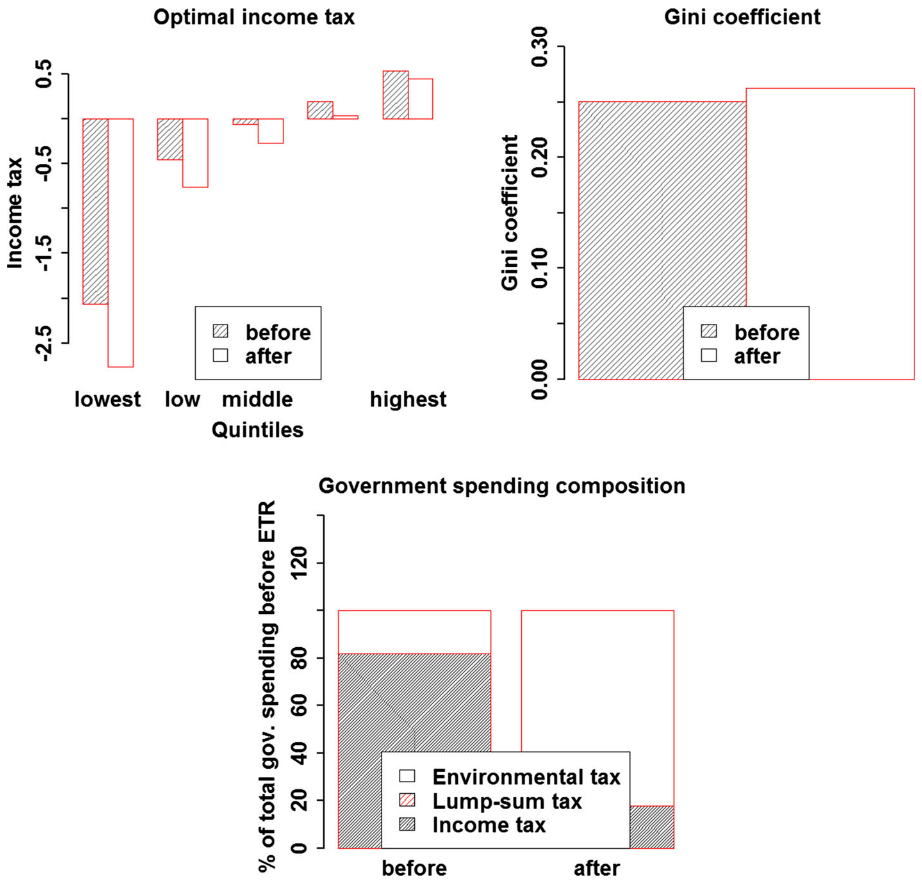

Fig. 2 Optimal non-linear income taxes, the Gini coefficient and the government spending composition before and after an environmental tax reform when uniform lump-sum transfers are not permitted

left). Second, this leads to a shift in the composition of government spending from income towards pollution taxes (see Fig. 2, bottom). Finally, the Gini coefficient increases by more than 1 % (see Fig. 2, top right).

Before the environmental tax reform, the fixed government spending requirement is financed in large parts by income taxes which are set such that the incentive constraints are binding. A smaller fraction is contributed by environmental taxes. Optimal environmental taxes are greater than zero for the same reason as in Sect. 3.

Setting $\xi > 0$ (and above the threshold value described in Sect. 4.3) creates additional environmental tax revenue which is used to lower distorting taxes. However, since the income taxes are already set such that the incentive constraints are binding, a tax cut must always involve all households—otherwise the incentive constraints would be violated. Subsidies for low-income households increase strongly, and income taxes for high-income households decrease more moderately—this increases the inefficiency in the tax system. In sum, these effects lead to an increase in the Gini coefficient, since the regressive effect of the environmental tax cannot be compensated completely by an optimal adjustment of the income taxes. Uniform lump-sum taxes are hence necessary to reduce inequality without violating the incentive constraints and to recycle the environmental tax revenue to the households in an efficient way.

Most of the differences to Sect. 3 are explained by the fact that the environmental tax revenue in the current section is redistributed via income tax cuts or income subsidies. Redistribution through the income tax system is more distortionary since the income taxes before the ETR are already set such that the incentive constraints are binding—the progressivity of the income tax system can hence not be increased further to offset the regressive effect of the environmental tax and the tax reform increases inequality. If instead lump-sum transfers are available, as in Sect. 3, the government can counteract the inequality-increasing effect of environmental taxes: uniform lump-sum transfers are progressive since richer households consume more of the polluting good in absolute terms and therefore pay more environmental taxes.

4.2 The Role of Non-homothetic Preferences

In this section we set the subsistence level of polluting consumption to zero and hence abandon our assumption of non-homothetic preferences. The experiment remains the same as in Sects. 3 and 4.1: by increasing the preferences for environmental quality from 0 to $\xi > 0$, we analyze the effect of an optimal environmental tax reform on tax and transfer levels, distribution and the composition of government financing. This section is hence analogous to Sect. 3, considering the case of homothetic preferences instead.

Non-homothetic preferences play an important role in our model: we use them to model the fact that an environmental tax is regressive due to the existence of a subsistence level of polluting consumption (D_0). The regressive effect can be seen by comparing the Gini coefficients in Figs. 1 and 3. By setting the subsistence level to zero, we remove the regressive effect of environmental taxation.

We find that if the government can adjust income taxes and uniform lump-sum transfers optimally (as in Sect. 3), the results remain qualitatively unchanged (see Fig. 3). In particular, inequality is still decreased by an optimal environmental tax reform. This is unsurprising, because we removed the mechanism responsible for the regressivity of the environmental tax.

We observe only small differences between an environmental tax reform when the environmental tax is assumed to be regressive (as in Sect. 3) and when an environmental tax is assumed to be neutral (as in the current section). This means that, if an optimizing government has access to both lump-sum and non-linear income taxes, an environmental tax reform, even if the environmental tax itself is assumed to be regressive, can be adjusted such that it is slightly progressive.

4.3 Parameter Sensitivity and Greening of Preferences

In this section we analyze the sensitivity of our main results in Sect. 3 to variations in key parameters such as the elasticity of substitution between labor and pollution (σ), the level of government spending (G), the share of labor in the polluting sector ϵ_D and the preference parameter for environmental quality (ξ). Except for an elasticity of substitution between labor and pollution above 0.98, we find that the results remain qualitatively unchanged. The detailed results of the sensitivity analysis are available upon request from the authors.

We vary σ, the elasticity of substitution between labor and pollution, between 0.2 and 0.999. We find that the changes in the optimal tax schemes remain qualitatively the same. However, the result concerning the Gini coefficient depends on σ: an environmental tax

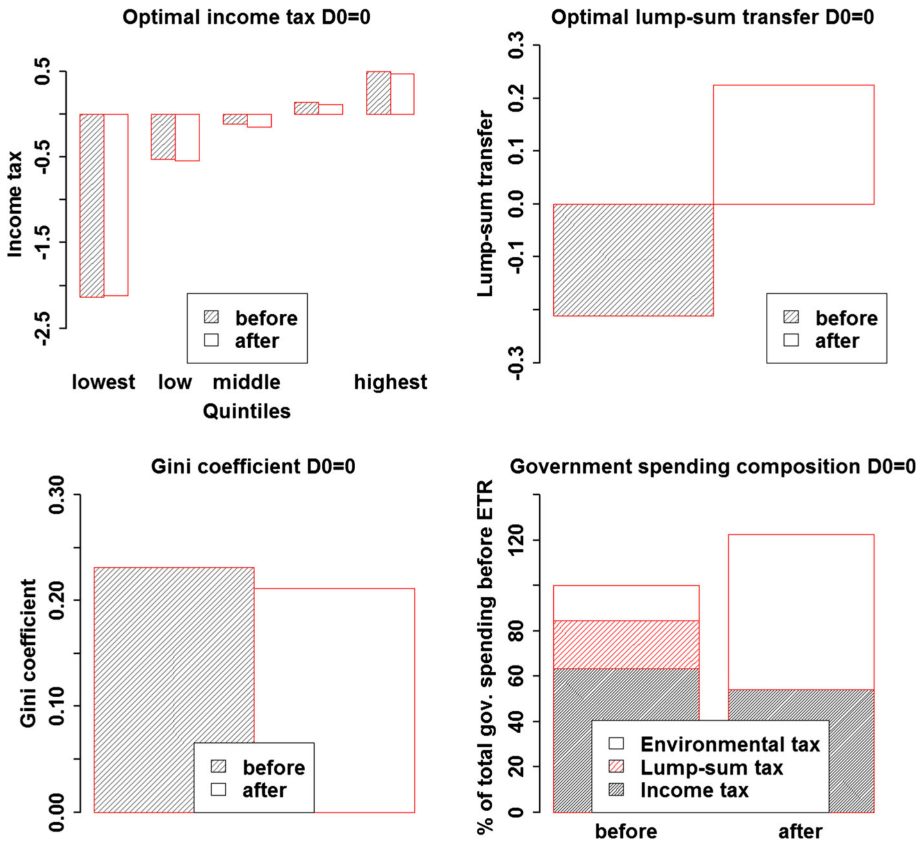

Fig. 3 Optimal non-linear income and lump-sum taxes, as well as the Gini coefficient and the government spending composition before and after an environmental tax reform when preferences are homothetic (i.e. $D_0 = 0$)

Table 3 Sensitivity of the Gini coefficient from Sect. 3 to changes in the elasticity between labor and pollution

σ	Gini (before ETR)	Gini (after ETR)
0.2	0.2551	0.2358
0.5	**0.2644**	**0.2582**
0.8	0.2648	0.2633
0.999	0.2649	0.2650

The highlighted case is our benchmark calibration

reform slightly reduces the Gini coefficient for σ between 0.2 and 0.98. It increases the Gini coefficient slightly if $\sigma \geq 0.99$. The detailed results are displayed in Table 3.

We set the level of government spending G at 5 in the benchmark calibration (this corresponds to roughly 24 % of GDP before the tax reform). In order to assess the impact of varying this parameter, we analyze two extreme values: zero and 15. We find that the results do not change qualitatively. The level of government spending mainly influences the level of the lump-sum transfers: If $G = 15$, lump-sum transfers are negative, since the government

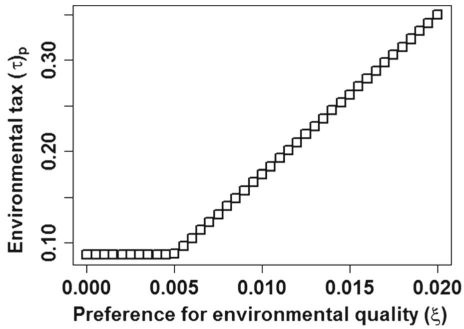

Fig. 4 The effect of a gradual increase of the preference for environmental quality on the optimal environmental tax level. There is a threshold at $\xi = 0.005$ from which on the optimal environmental tax reacts to an increase in ξ

uses them to raise revenue. If $G = 0$, lump-sum transfers are well above zero since they are used to return additional revenue to the households.

The share of labor in the polluting sector is $\epsilon_D = 0.92$ in the benchmark scenario. The results concerning inequality and optimal income tax schedules do not change qualitatively when ϵ_D is varied. However, the government spending composition reacts strongly to this parameter: Lower values of ϵ_D (e.g. $\epsilon_D = 0.7$) lead to a higher use of pollution in the production sector and thus to more government revenue through environmental taxes. This increase in government revenue induces a shift in the composition of government spending.

The effect of the preference for environmental quality can be illustrated by gradually increasing the parameter ξ. Figure 4 displays the optimal environmental tax as a function of ξ. For values of ξ between zero and 0.005, the environmental tax does not react to an increase in ξ. This explains the fact that a government sets a positive environmental tax even if $\xi = 0$: up to a certain threshold level the firms do not react to an increase in the environmental tax and the government hence sets the environmental tax at this level. This threshold level is a consequence of the assumption that the firms allocate some of the labor to pollution abatement (see Eq. 1 and the subsequent paragraph).

5 The case of a calibrated pre-existing tax system

Recently, it has been of great concern that inequality rises to levels that may be harmful to societies (OECD 2011): governments may fail to set taxes adequately to counteract undesirable levels of income inequality (Piketty 2014).[11]

This section applies the theoretical framework from Sect. 3 to a real-world setting with suboptimally high inequality. Instead of comparing optimal taxation scenarios as in the preceding sections, we calibrate the model to the actual income tax schedule of the U.S. economy (see Sect. 5.1 for details on the calibration). This implies that in the initial scenario both the pollution externality is undertaxed and there is too little redistribution. This constitutes a very stylized scenario for examining real-world inequality levels. The purpose of this section is to give insights on actual policy debates about the distributional impacts of environmental tax reforms.

[11] While some kinds of inequality may indeed be detrimental for society, others motivate people to work harder, and can be beneficial (Marrero and Rodríguez 2013). However, there seems to be evidence that inequality itself can have a negative effect on efficiency (Berg et al. 2012; Kumhof et al. 2015). At least for this reason, assuming suboptimally high levels of inequality is thus a credible premise and inequality-reduction a frequent policy goal.

Table 4 The pre-existing income tax rates are taken from the 2013 report of the Congressional Budget Office (CBO 2013)

Quintile	1	2	3	4	5
Income tax ($\tau^0_{w,i}$)	0.015	0.072	0.115	0.156	0.24

We additionally assume that the government is constrained to three realistic designs of an environmental tax reform: additional revenue can be recycled either via non-linear income tax cuts, via linear income tax cuts, or through uniform lump-sum transfers (the different scenarios are outlined in detail in Sect. 5.2).[12] Within this setting we compare the equity impacts of three designs of an ETR, when the preferences for environmental quality are increased from zero to $\xi > 0$.

Our main two results are as follows: First, we show that revenue recycling via non-linear income tax cuts and through uniform lump-sum transfers reduces inequality below initial levels. We call this effect the *double dividend of redistribution*. It occurs when inequality levels decrease through an environmental tax reform.[13] Second, we demonstrate that the optimal environmental tax rate depends on how the environmental tax revenue is recycled. For detailed results see Sect. 5.3.

These results have strong political consequences: In a calibrated scenario, in which inequality is suboptimally high, and in which the government cannot observe the individuals' skill levels, a government should not set a lower-than-optimal environmental tax out of distributional concerns. The optimal tax we refer to is the optimal environmental tax from Sect. 3, in which the government adjusts income, lump-sum and environmental taxes simultaneously. Instead, a government should combine an optimal environmental tax with a progressive revenue-recycling mechanism, in order to reduce inequality and enhance environmental quality at the same time.

5.1 Calibration of the Suboptimal Income Tax System

In this section, instead of determining the optimal income tax in the initial scenario, we use recent U.S. data on income taxation to perform a similar analysis as in Sect. 3 in a calibrated framework. The individual income tax rates are given in Table 4. These tax rates do not only include individual income taxes, but also corporate income taxes, social insurance taxes and excise taxes. For the sake of simplicity we refer to the sum of these taxes as the income tax. The remaining parameters are given in Sect. 2.1.

5.2 Revenue Recycling Scenarios

The purpose of this section is to describe the revenue recycling scenarios used in Sect. 5.3. The scenarios differ in the way the additional revenue of an environmental tax reform is returned to the households.

12 We refrain from displaying the results of revenue recycling through a combination of lump-sum transfers and non-linear income tax cuts, since it leads to the same outcome as the scenario with only non-linear income tax cuts. The reason for that is that the government uses all the environmental tax revenue to mitigate inequality in the income tax system and hence has no use for lump-sum transfers.

13 This concept is different, however, from the concept of the *environmental* double dividend in the sense of Goulder (1995) and Bovenberg (1999): In models with only one representative household such a (weak) dividend can occur, when recycling through income tax cuts is more efficient than lump-sum recycling. A strong double dividend, that is an increase in economic efficiency, can only occur with an inefficient pre-existing tax system. In our setting, there is also an increase in GDP (see Fig. 5, bottom) because the pre-existing income tax schedule creates an inefficient labor supply.

The tax system before the increase in the preference for environmental quality is described by the pre-existing income tax $\tau^0_{w,i}$, given by the model calibration described in Sect. 5.1, the pre-existing environmental tax τ^0_Z and the absence of lump-sum transfers (i.e. $L = 0$).

The increase in the preference for environmental quality leads to an increase in the optimal environmental tax level from τ^0_Z to τ_Z. The additional environmental tax revenue can be returned to the households through the following recycling mechanisms:

1. Non-linear income tax cuts: In this scenario the government endogenously determines the optimal income tax cut $\tau_{w,i} < 0$. Lump-sum transfers are zero, and the government's maximization problem then is

$$\max_{\tau_{w,i},\tau_Z} W \quad \text{s.t.} \quad \text{Eq. (12)} \quad \text{and} \quad G = \sum_{i=1}^{N} (\tau^0_{w,i} + \tau_{w,i})\phi_i w(T - l_i) + \tau_Z Z.$$

The auxiliary function H in the households' first-order conditions (see "Appendix" Eqs. 17–19) changes accordingly:

$$H(w, p_D, \tau^0_{w,i}, \tau_{w,i}) = ((1 - \tau^0_{w,i} - \tau_{w,i})\phi_i wT - p_D D_0).$$

2. Linear income tax cuts: The tax revenues are redistributed via linear income tax cuts. Lump-sum transfers are equal to zero and the equations are analogous to the case of non-linear income tax cuts only with $\tau_{w,i} = \tau_w < 0$.
3. Lump-sum transfers: we model household heterogeneity explicitly and uniform lump-sum transfers L to each income class are hence a realistic revenue-recycling mechanism. In this case the government maximization problem reads:

$$\max_{L,\tau_Z} W \quad \text{s.t.} \quad \text{Eq. (12)} \quad \text{and} \quad G = -NL + \sum_{i=1}^{N} \tau^0_{w,i}\phi_i w(T - l_i) + \tau_Z Z.$$

Again, the auxiliary function H in the households' first-order conditions (see "Appendix" Eqs. 17–19) changes accordingly:

$$H(w, p_D, \tau^0_{w,i}, L) = ((1 - \tau^0_{w,i})\phi_i wT + L - p_D D_0).$$

5.3 Distributional Consequences of Different Recycling Mechanisms

In this section, we compare three environmental tax revenue recycling scenarios, in which the government has a preference for environmental quality ξ greater than zero, to the case of $\xi = 0$. Furthermore, we compare the three scenarios in terms of their equity impacts and their implications for the tax system.

The main mechanism through which an environmental tax acts on the distribution remains unchanged: poor households cannot substitute clean for polluting consumption as freely as high-income households, due to our assumption of non-homothetic preferences.

The main results are: First, the Gini coefficient (see Fig. 5, middle left) is strongly reduced by non-linear income tax cuts, closely followed by uniform lump-sum transfers (i.e. both recycling mechanisms lead to a double dividend of redistribution). Linear income tax cuts, by contrast, increase the Gini coefficient slightly, compared to the initial scenario. It can be seen from the top left graph of Fig. 5 that rich households benefit relatively more from linear income tax cuts than poor households. The opposite is true for non-linear income tax cuts. Since rich households pay a higher total share of taxes, uniform lump-sum redistribution is

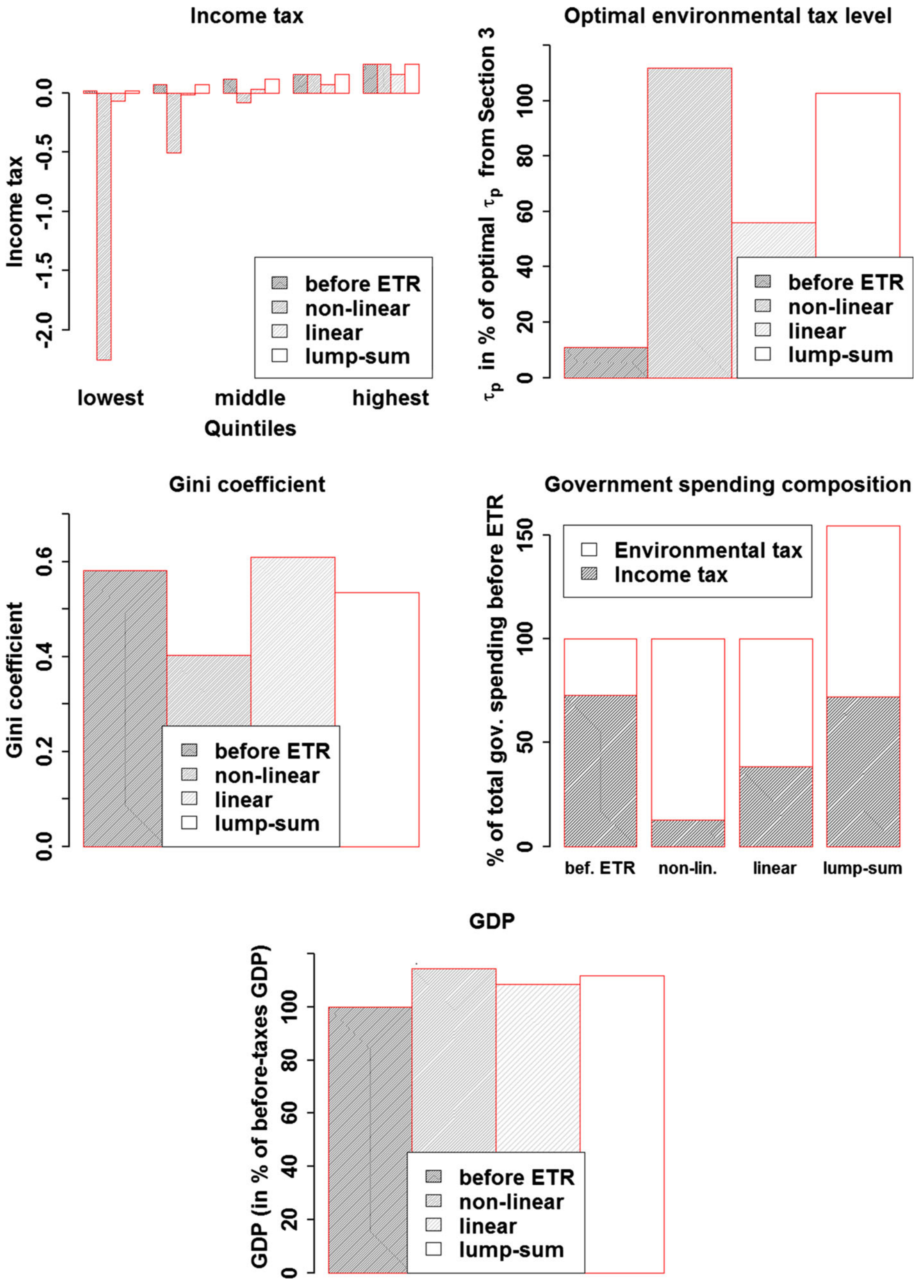

Fig. 5 Effect a greening of the government's preferences for environmental quality on income taxes, optimal environmental tax levels, the Gini coefficient, the composition of government spending and GDP. The case of non-optimal pre-existing income taxes. We compare three designs of an environmental tax reform

also progressive. Second, the optimal environmental tax depends on the way the tax revenues are returned to the households. In the top right graph of Fig. 5 we see a correlation between the progressivity of the recycling mechanism and the optimal level of the environmental tax: more progressive recycling leads to higher optimal environmental taxes. Third, we additionally obtain an environmental double dividend in the sense of Goulder (1995) and Bovenberg (1999): Setting the environmental tax at its optimal level yields revenues which are used to optimally adjust the inefficient initial income tax schedule, which increases the GDP (see Fig. 5, bottom).

6 Conclusion

We analyze the effects of an optimal environmental tax reform when environmental taxation is regressive. Specifically, we quantify the distributional impacts and changes in the optimal tax structure induced by an optimal environmental tax reform. For this purpose it is necessary to combine key elements from several literature strands: Mirrleesian income taxation in the presence of an externality (as in Cremer et al. 1998 and Jacobs and De Mooij 2015), comparing different design options for environmental tax reforms (as in Kaplow 2012) and determining the distributional impacts of an environmental tax reform when accounting for price effects, outside the optimum (as in Fullerton and Heutel 2007, 2010).

An environmental tax reform has distributional impacts both on the household side and on the firm side. Assessing the distributional impacts of such a reform hence requires accounting for all these effects. Our model therefore combines a household side as in a traditional optimal taxation model with an optimizing firm side as in models that focus exclusively on price effects outside the optimum. Our study is the first to analyze the distributional effects of optimal environmental tax reforms in a setting which combines both firm-side and household-side distributional effects.

We analyze two different scenarios: first, a scenario in which the tax system before the environmental tax reform is optimal from a non-environmental point of view. Second, a scenario in which the tax system before the environmental tax reform is calibrated to U.S. data (and inequality is suboptimally high) and in which the government is constrained to different revenue recycling options. We show that, in the first scenario, the regressive effect of the environmental tax can be largely or even completely offset by the revenue recycling (depending on the available revenue recycling mechanisms). In the second scenario, we show that inequality can be reduced significantly if the environmental tax revenue is recycled either lump-sum, or through a progressive income tax reform. Furthermore, we demonstrate that more progressive recycling leads to higher optimal environmental taxes. Whenever an environmental tax reform reduces inequality a *double dividend of redistribution* occurs.

These findings have important political consequences: an environmental tax reform can reduce inequality below initial levels by simple measures such as recycling the revenue as per-capita cash transfers. Even higher distributional gains can be achieved by an environmental tax-financed (budget-neutral) progressive reform of the income tax system. However, this policy might be less feasible politically.

Possible extensions include performing a similar analysis in an intertemporal setting, accounting for structural changes in the economy, and taking the difference in factor ownership of the income quintiles into account. Furthermore, since an equitable income distribution might also be seen as a public good (Thurow 1971), it may be worthwhile to endogenize public consumption (as in Bovenberg and van der Ploeg 1994, 1996) and to analyze possible trade-offs between these two public goods.

Acknowledgments The authors thank three anonymous reviewers for their encouraging and helpful comments. We further thank Ulrike Kornek and Jan Siegmeier, as well as the participants of the 2015 GGKP, the 2015 EAERE and the 2016 Tinbergen Institute conferences for insightful discussions.

Appendix: First-Order Conditions of Households and Firms

Households By combining the households' first-order conditions with their budget equation, the following explicit demand functions can be derived:

$$C_i = \frac{\alpha}{p_C(\alpha+\beta+\gamma)} H(w, p_D, \tau_{w,i}, L), \tag{17}$$

$$D_i = \frac{\beta}{p_D(\alpha+\beta+\gamma)} H(w, p_D, \tau_{w,i}, L) + D_0 \tag{18}$$

$$l_i = \frac{\gamma}{(\alpha+\beta+\gamma)(1-\tau_{w,i})\phi_i w} H(w, p_D, \tau_{w,i}, L), \tag{19}$$

with

$$H(w, p_D, \tau_{w,i}, L) = ((1-\tau_{w,i})\phi_i w T + L - p_D D_0). \tag{20}$$

Firms Maximizing profits of both firms yields four first-order conditions:

$$w = \frac{\partial F_j(T_j, Z_j)}{\partial T_j} = \epsilon_j T_j^{(r-1)} F_j^{(1-r)} p_j, \tag{21}$$

$$\tau_Z = \frac{\partial F_C(T_C, Z_C)}{\partial Z_C} = (1-\epsilon_j) Z_j^{(r-1)} F_j^{(1-r)} p_j, \tag{22}$$

with $j \in \{C, D\}$.

References

Ballard CL, Goddeeris JH, Kim SK (2005) Non-homothetic preferences and the non-environmental effects of environmental taxes. Int Tax Public Finance 12:115–130

Bento AM (2013) Equity impacts of environmental policy. Annu Rev Resour Econ 5(1):181–196

Bento AM, Goulder LH, Henry E, Jacobsen MR, Haefen RHV (2005) Distributional and efficiency impacts of gasoline taxes : an econometrically based multi-market study. Am Econ Rev 95(2):282–287

Berg A, Ostry JD, Zettelmeyer J (2012) What makes growth sustained? J Dev Econ 98(2):149–166

Bovenberg AL (1999) Green Tax reforms and the double dividend: an updated reader's guide. Int Tax Public Finance 6:421–443

Bovenberg AL, van der Ploeg F (1994) Environmental policy, public finance and the labour market in a second-best world. J Public Econ 55(3):349–390

Bovenberg AL, van der Ploeg F (1996) Optimal taxation, public goods and environmental policy with involuntary unemployment. J Public Econ 62:59–83

CBO (2013) The distribution of household income and federal taxes, 2010. Congress of the United States—Congressional Budget Office 4613 (December)

Chiroleu-Assouline M, Fodha M (2014) From regressive pollution taxes to progressive environmental tax reforms. Eur Econ Rev 69:126–142

Combet E, Ghersi F, Hourcade J-C, Théry D (2010) Carbon tax and equity the importance of policy design. In: Dias Soares C, Milne J, Ashiabor H, Deketelaere K (eds) Critical issues in environmental taxation, vol. VIII. Oxford University Press, Oxford, pp 277–295

Copeland BR, Taylor MS (1994) North-south trade and the environment. Q J Econ 109(3):755–787

Cremer H, Gahvari F (2001) Second-best taxation of emissions and polluting goods. J Public Econ 80:169–197

Cremer H, Gahvari F, Ladoux N (1998) Externalities and optimal taxation. J Public Econ 70:343–364

DeNavas-Walt C, Proctor BD, Smith JC (2012) Income, poverty, and health insurance coverage in the United States: 2011. U.S. Census Bureau, Current Population Reports, pp 60–243

Dissou Y, Siddiqui MS (2014) Can carbon taxes be progressive? Energy Econ 42:88–100
Ekins P (1999) European environmental taxes and charges: recent experience, issues and trends. Ecol Econ 31:39–62
Engel E (1857) Die Productions-und Consumtionsverhältnisse des Königreichs Sachsen. Zeitschrift des sächsischen Statistischen Bureaus des Innern 8 and 9, 1–54
Flues F, Thomas A (2015) The distributional effects of energy taxes: preliminary report. OECD Taxation Working Papers (23)
Fullerton D, Heutel G (2007) The general equilibrium incidence of environmental taxes. J Public Econ 91:571–591
Fullerton D, Heutel G (2010) Analytical general equilibrium effects of energy policy on output and factor prices. B E J Econ Anal Policy 10(2):1–24
Fullerton D, Hong I, Metcalf GE (2001) A tax on output of the polluting industry is not a tax on pollution. The importance of hitting the target. In: Carraro C, Metcalf GE (eds) Behavioral and distributional effects of environmental policy. University of Chicago Press, Chicago, pp 13–44
Fullerton D, Metcalf GE (2001) Environmental controls, scarcity rents, and pre-existing distortions. J Public Econ 80:249–267
Fullerton D, Monti H (2013) Can pollution tax rebates protect low-wage earners? J Environ Econ Manag 66(3):539–553
Goulder LH (1995) Environmental taxation and the double dividend: a reader's guide. Int Tax Public Finance 2(2):157–183
Goulder LH, Parry IW, Williams RC III, Burtraw D (1999) The cost-effectiveness of alternative instruments for environmental protection in a second-best setting. J Public Econ 72:329–360
Grainger CA, Kolstad CD (2010) Who pays a price on carbon? Environ Resour Econ 46(3):359–376
Jacobs B, De Mooij RA (2015) Pigou meets Mirrlees: on the irrelevance of tax distortions for the second-best Pigouvian tax. J Environ Econ Manag 71:90–108
Jacobs B, van der Ploeg F (2010) Precautionary climate change policies and optimal redistribution. OxCarre Research Paper 49
Kaplow L (2004) On the (ir)relevance of distribution and labor supply distortion to government policy. J Econ Perspect 18(4):159–175
Kaplow L (2012) Optimal control of externalities in the presence of income taxation. Int Econ Rev 53(2):487–509
Klenert D, Mattauch L (2016) How to make a carbon tax reform progressive: the role of subsistence consumption. Econ Lett 138:100–103
Kumhof M, Rancière R, Winant P (2015) Inequality, leverage, and crises. Am Econ Rev 105(3):1217–1245
Levinson A, O'Brien J (2015) Environmental Engel curves. NBER Working Paper Series 20914
Ligthart JE, van der Ploeg F (1999) Environmental policy, public goods and the marginal cost of public funds. Environ Resour Econ 13:187–207
Marrero GA, Rodríguez JG (2013) Inequality of opportunity and growth. J Dev Econ 104:107–122
Mirrlees J (1971) An exploration in the theory of optimum income taxation. Rev Econ Stud 38(2):175–208
OECD (2011) Divided we stand: why inequality keeps rising. OECD Publishing, Paris
Piketty T (2014) Capital in the twenty-first century. Harvard University Press, Cambridge
Rosenthal RE (2014) GAMS a user's guide. GAMS Development Corporation, Washington
Sandmo A (1975) Optimal taxation in the presence of externalities. Swed J Econ 77(1):86–98
Sterner T (2011) Fuel taxes and the poor: the distributional effects of gasoline taxation and their implications for climate policy. RFF Press, New York
Thurow LC (1971) The income distribution as a pure public good. Q J Econ 85(2):327–336
Wier M, Birr-Pedersen K, Jacobsen HK, Klok J (2005) Are CO_2 taxes regressive? Evidence from the Danish experience. Ecol Econ 52(2):239–251