Green Growth Knowledge Platform (GGKP)
Third Annual Conference
Fiscal Policies and the Green Economy Transition: Generating Knowledge – Creating Impact
29-30 January, 2015
University of Venice, Venice, Italy

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The GGKP's Third Annual Conference is hosted in partnership with the University of Venice, The Energy and Resources Institute (TERI) and the United Nations Environment Programme (UNEP).

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The Distributional Incidence of Carbon Taxation: The Double Dividend of Redistribution

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January 20, 2015

Abstract

UNPUBLISHED MANUSCRIPT – DO NOT QUOTE

In this study we determine the distributional impacts of a carbon tax in combination with different revenue recycling schemes. Taking into account that households in developed countries need a certain level of polluting consumption in order to subsist, we obtain three main results: First, redistributing the revenues as proposed in the double dividend literature, i.e. through a uniform reduction in distorting taxes, leads to increased inequality and thus to a trade-off between environmental and equity objectives. Second, this trade-off can be avoided when the revenues are redistributed through a differential decrease in distorting taxes. Third, we show that the optimal level of a carbon tax depends on the redistribution mechanism: the more equity-enhancing the revenue recycling is, the higher the optimal carbon tax, and the higher total welfare. We thus obtain an additional welfare-enhancing effect through optimal redistribution which we call the redistribution dividend.

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1 Introduction and motivation

It is a well-established result in the literature, that using the revenues from a CO_2 tax to cut distorting taxes, does not only yield an environmental, but also an efficiency dividend, due to the reduction in distorting taxes. Hence, this tax swap is sometimes referred to as "double dividend" (Goulder, 1995; Bovenberg, 1999). When it comes to the distributional impacts of such a tax reform, previous literature often identifies a trade-off between equity and efficiency goals in the following sense: carbon tax revenues can *either* be used to reduce inequality, *or* to cut distorting taxes and thus enhance efficiency (Bovenberg, 1999).[1] Our results contradict with this view: we demonstrate that a well-designed policy can achieve both goals at the same time.

In this paper we extend a double dividend-type model to include a subsistence level of polluting consumption, a mechanism that is often quoted to be responsible for the regressive effect of carbon taxation.[2] We obtain two main results.

First, we compare different revenue recycling mechanisms for a fixed carbon tax level. The recycling mechanisms are uniform income tax cuts, uniform lump-sum transfers, and differential income tax cuts. We find that a uniform income tax cut, as it is described in the double dividend literature, can have inequality increasing effects and thus leads to a trade-off between efficiency and equity objectives. We show that this trade-off can be overcome if the tax revenues are recycled via differential income tax cuts: this recycling mechanism enhances total welfare and equity at the same time.

Second, we determine the optimal carbon tax rate under different revenue recycling schemes. We conclude that the mechanism for redistribution of the carbon tax revenues has a strong impact on the optimal tax level and on total welfare: welfare is maximal and the carbon tax is at its highest level when the revenue is used for differential income tax rebates. The lowest tax in combination with the lowest welfare levels is obtained when the tax revenue is used to finance uniform income tax rebates. Uniform lump-sum transfers are somewhere in between in both variables.

Carbon pricing is usually considered to have a regressive effect. The main driver of this effect is that carbon taxation increases the prices of carbon-intensive goods such as heating, food and energy. These price increases affect low-income households more strongly, since they spend a large part of their income on carbon intensive goods (Grainger and Kolstad, 2010; Fullerton et al., 2010; Fullerton, 2011; Combet et al., 2010).[3]

[1] Or in the sense of Parry and Williams III (2010) and Rausch et al. (2011), that the most efficient revenue recycling is regressive, while a more progressive recycling scheme is less efficient.

[2] E.g. Grainger and Kolstad (2010); Fullerton et al. (2010); Fullerton (2011); Combet et al. (2010).

[3] There is additional literature on further channels, through which carbon taxation influences the distribution; Fullerton (2011) provides a good overview of these mechanisms.

Wier et al. (2001) study the relative CO_2 emissions of different household types for the case of Denmark. They come to two important conclusions. First, CO_2 intensities vary strongly between consumption goods, with food and transport being very CO_2 intensive, and services and financial transfers being on the other end of the scale. Second, low-income cohorts mainly consume carbon-intensive necessities, while high-income cohorts spend a large part of their income on "luxury" items that have a higher service component. This explains regressive nature of CO_2 taxes. Wier et al. (2001) compare their study to similar studies of the U.S. (Herendeen and Tanaka, 1976; Herendeen et al., 1981), New Zealand (Peet et al., 1985), the Netherlands (Vringer and Blok, 1995; Biesiot and Noorman, 1999), Germany(Weber and Fahl, 1993), Norway (Herendeen, 1978) and Australia (Lenzen, 1998), and find that the two results above also hold for these countries. In a more recent analysis of the U.S. economy, Grainger and Kolstad (2010) confirm that there are certain carbon-intensive necessities on which poorer households spend a larger fraction of their income (see Table 1 in their article).
Even though there seems to be some consensus on the importance of this mechanism for the assessment of the distributional incidence of carbon taxation, to our knowledge it has not been explicitly modeled so far in this context.[4]
We propose a general equilibrium framework in which the existence of a subsistence level of polluting consumption is explicitly modeled: heterogeneous households can choose between a clean consumption good and a polluting consumption good, of which they have to consume a minimum amount. This is modeled by means of a Stone-Geary utility function (Geary, 1950; Stone, 1954). Two firms produce the goods with pollution and labor as production inputs. The households differ in their share of income. A fixed government budget has to be financed either by an income tax or a tax on the polluting production input. Excess revenue is returned to the households in different ways.[5]

To name a few: Parry (2004) investigates the difference between auctioning and grandfathering of pollution permits on the distribution. In a more recent contribution, Karp and Rezai (2014) find that current asset owners benefit from climate policy if the environment is modeled as a stock, since future avoided damages are capitalized in current asset prices.

[4]One notable exception is Jacobs and Van der Ploeg (2010): the authors model a government that has environmental quality and intra generational equity as an objective, and find that with non-homothetic (i.e. Stone Geary) preferences, the carbon tax is set below the Pigouvian level. Using an overlapping-generations approach, they identify a trade-off between future and current generations. Our study contrasts to theirs due to our choice of a utilitarian social planner without equity constraints and due to our static setting.

[5]The government in our setting aggregates utility of income N-tiles into a social welfare function. Most papers in the double dividend literature take total consumption as the government objective and analyze distributional issues ex post or not at all. In our model by contrast, the government can endogenously optimize the trade-off between efficiency (that is total consumption) and equity (that is the distribution of consumption). We

It is important to note, that our study addresses political concerns about the distributional effects of carbon taxation only in developed countries in the short-run: there is evidence that a CO_2 tax might have a less regressive or even a progressive effect in developing countries (Sterner, 2011). Since we do not explicitly model possibilities for complete decarbonization of the economy, the model is only valid in the short-run.
In this study we make six important points: first, we provide a micro-foundation for the regressive impact of a carbon tax on the uses side by explicitly modeling a subsistence level of polluting consumption. We demonstrate that this assumption is the driver of our results. Second, we demonstrate that a uniform tax cut, as it is modeled in the double dividend literature, enhances inequality, which leads to a trade-off between equity and efficiency. Third, this trade-off can be overcome when carbon taxes are recycled via differential income tax cuts. Fourth, we demonstrate that the optimal carbon tax level depends on the recycling mechanism: the more equity-enhancing the recycling scheme is, the higher the optimal carbon tax becomes.[6] It follows that the highest welfare level is obtained with differential income tax cuts, while uniform income tax cuts perform worst, both in terms of equity and welfare. Fifth, even though it is still equity-enhancing, lump-sum recycling performs worse than differential income tax cuts in equity and welfare terms, but it still is an improvement over uniform income tax cuts. It therefore is a viable second-best option if, for some reasons, differential income tax cuts are not feasible. Finally, we point out that inequality in income can be a misleading indicator for inequality in welfare when there is a subsistence level of consumption in one of the goods.

2 Literature

There is empirical evidence that the direct incidence of a carbon tax is regressive, as Wier et al. (2005) demonstrate for the case of Denmark. Poterba (1991) and Hassett and Metcalf (2009) show that the same holds for fuel taxes in the U.S.[7] A good overview of the literature on fuel taxes and in-

therefore link the literature on efficient carbon tax recycling with the literature on optimal income taxation. This link is not only nice to have but essential, since Aigner (2014) demonstrated that the two problems cannot be solved in isolation.

[6]The mechanism behind this effect is that in the case of an equity-enhancing carbon tax reform, the lowest income cohorts' consumption of both goods is increased. Due to their higher marginal utility of consumption, total welfare increases more strongly, and the trade-off between environmental damages and consumption benefits leads to a higher optimal carbon tax (i.e. the economy can afford a higher carbon tax). This mechanism also works in the other direction for a regressive tax reform.

[7]Note that carbon as well as fuel taxation might not not have the same effect in developing countries: Shah and Larsen (1992) show that in Pakistan a carbon tax could be mildly progressive, Yusuf and Resosudarmo (2007) look at the case of Indonesia and Sterner (2011) also mentions examples of cases in which fuel taxation has almost no

equality is given in Sterner (2011).
However, a crucial issue of carbon taxation is neglected in these studies: the use of the tax revenues. Bento et al. (2005, 2009) empirically show that the distributional impacts of a fuel tax U.S. critically depend on the revenue recycling. Metcalf (1999) uses data from the 1994 Consumer Expenditure Survey (CES) and finds the pure incidence of a carbon tax to be regressive, but proposes payroll tax rebates which could neutralize this regressivity. West and Williams (2004) analyze different recycling scenarios of a fuel tax by using more recent CES data. They find that for labor tax rebates the efficiency can be increased while regressivity is reduced, but not neutralized. Further empirical studies agree that the regressivity of a carbon tax can be reduced or neutralized with intelligent revenue recycling (Parry et al., 2005; Metcalf et al., 2008). An extensive review of this literature can be found in Bento (2013).
The theoretical literature agrees on that the initial regressivity of a carbon tax can in some cases, be reduced by the recycling of its revenues, but varies on the extent.
It is important to distinguish between the impacts of a carbon tax on the uses (differential burden from difference in consumption patterns), and on the sources side (factor prices can react differently): Rausch et al. (2010) find that under certain circumstances, the progressive impacts of a carbon tax on the sources side exceed the regressive impacts on the uses side, which in sum leads to a mildly progressive effect even without recycling of the revenues. Rausch et al. (2011) extend their 2010 analysis and find that when recycling is taken into account the tax reform can always be made progressive. In their model, however, this comes at the cost of efficiency: the authors thus conclude that there is a trade-off between equity and efficiency goals.
Fullerton and Heutel (2007) describe the effects of carbon taxation on the different factor prices: they depend critically on the substitutability of capital, labor, and emissions. In a follow-up paper, Fullerton and Heutel (2010) show that the incidence of a carbon tax on the uses side is regressive, the incidence on the sources side can be progressive, U-shaped, or regressive, depending on the parameters. Accounting for household heterogeneity, Fullerton and Monti (2013) show that even when accounting for potential progressivity on the uses side, the burden a carbon tax places on the lowest income cohort can never be offset completely.[8]
Chiroleu-Assouline and Fodha (2011, 2014) consider a research question that is related to ours: they analyze the equity and efficiency effects of a carbon tax in a small stylized model. Agents in their model provide labor inelas-

regressive or even a progressive effect. This might be partially due to the continued use of biomass as a primary fuel of the very poor, who are not able to afford taxable fuels (Pachauri, 2004). The incidence of a fuel tax would then mostly fall on the middle and upper class households.

[8]But it can at least be reduced to a certain extent.

tically, so the pre-existing labor income tax is not distortive, which makes the model not directly comparable to other models of the double dividend literature, in which income taxation is required to have a distortionary effect.

Aigner (2014) demonstrates that matters of optimal environmental taxation and equity are mutually dependent and cannot be treated in an optimal way by setting a carbon and an income tax separately. He proposes transfers as the preferred option for alleviating the regressive effects of carbon taxes. We agree with the author that the optimal level of the environmental tax depends on the revenue recycling scheme, but rather recommend differential income tax rebates instead of transfers as the preferred revenue recycling option.

We add to this literature in the following sense: first, we introduce a subsistence level of polluting consumption. This provides a micro-foundation for the regressivity of carbon taxes (on the uses side) and makes the mechanisms at work more transparent. Second, in contrast to most studies on the topic, we find that equity and efficiency are not necessarily two conflicting goals, when it comes to the recycling of carbon tax revenues. Third, we determine the optimal carbon tax reform by letting a government optimize the households' utility while taking disutility from pollution into account. We find that the more equity-enhancing the revenue recycling is, the higher total welfare and the higher the optimal carbon tax.

3 The model

We use a two sector model in which N households are distinguished by their productivity. Only the government is able to see damages from pollution, the households are unable to anticipate them. Within this model we assess the distributional effects of a carbon tax in combination with different revenue recycling schemes.

Firm: There are two representative firms, one produces a clean consumption good "C", the other produces a dirty consumption good "D". Both firms use labor T_j and pollution Z_j, with j $\in \{C, D\}$, as production inputs.[9]:

$$F_C(T_C, Z_C) = A_C T_C^{\gamma} Z_C^{1-\gamma} \tag{1}$$

$$F_D(T_D, Z_D) = A_D T_D^{\epsilon} Z_D^{1-\epsilon}, \tag{2}$$

where

$$T_C + T_D = \sum_{i=1}^{n} \phi(i)(T - l_i). \tag{3}$$

[9]We model pollution in this way, along the lines of Fullerton and Heutel (2007). See also Copeland and Taylor (1994), Appendix A for a justification of this approach.

The sum of labor used in the clean and dirty production, $T_C + T_D$, must equal the sum of the total time endowment T over all households, minus total leisure l_i, times the productivity/income share of household i, $\phi(i)$. Maximizing profits of both firms yields four first-order conditions:

$$w = \frac{\partial F_C(T_C, Z_C)}{\partial T_C} = \gamma A_C T_C^{\gamma-1} Z_C^{1-\gamma} p_C, \tag{4}$$

$$\tau_Z = \frac{\partial F_C(T_C, Z_C)}{\partial Z_C} = (1-\gamma) A_C T_C^{\gamma} Z_C^{-\gamma} p_C, \tag{5}$$

$$w = \frac{\partial F_D(T_D, Z_D)}{\partial T_D} = \epsilon A_D T_D^{\epsilon-1} Z_D^{1-\epsilon} p_D, \tag{6}$$

$$\tau_Z = \frac{\partial F_D(T_D, Z_D)}{\partial Z_D} = (1-\epsilon) A_D T_D^{\epsilon} Z_D^{-\epsilon} p_D. \tag{7}$$

In these equations, w is the wage rate, τ_Z is the tax on the polluting input Z set by the government and p_D and p_C stand for the prices of the dirty and the clean good.

Households: Households are distinguished only in their productivity/share of total factor income ϕ_i (so $\sum_{i=1}^{n} \phi_i = 1$). There are N households, ordered from 1 for lowest to N for highest income. 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 income of

$$I_i = \phi_i w (T - l_i). \tag{8}$$

All households have the same preferences and maximize the following utility function

$$U(C_i, D_i, l_i) = C_i^{\alpha} (D_i - D_0)^{\beta} l_i^{\delta}. \tag{9}$$

We model the fact that in order to survive, households need a minimal level of dirty good consumption D_0, with a Stone-Geary utility function (Geary, 1950; Stone, 1954).This utility function is not defined for $D_i < D_0$ so a household's budget has to fulfill

$$(1 - \tau_{w,i}) I_{\min} + L_i \geq p_D D_0 \tag{10}$$

in order to subsist. L_i are lump-sum returns of tax revenues and $\tau_{w,i}$ is a tax on income.

The budget equation for each household is given by

$$C_i \cdot p_C + D_i \cdot p_D = (1 - \tau_{w,i}) I_i + L_i. \tag{11}$$

By maximizing the utility function with respect to the budget equation, we obtain the following first-order conditions:

$$\alpha C_i^{\alpha-1}(D_i - D_0)^{\beta} l_i^{\delta} = \lambda_i p_C, \tag{12}$$
$$\beta C_i^{\alpha}(D_i - D_0)^{\beta-1} l_i^{\delta} = \lambda_i p_D, \tag{13}$$
$$\delta C_i^{\alpha}(D_i - D_0)^{\beta} l_i^{\delta-1} = \lambda_i (1 - \tau_{w,i}) \phi_i w, \tag{14}$$

where λ_i is the co-state variable of the Lagrangian.

Government The government maximizes total welfare W, i.e. the sum of all agents' utilities minus disutility from pollution used in production, represented by the factor $\xi(Z_C + Z_D)^{\theta}$:

$$W(C_i, D_i, l_i, Z_C, Z_D) = \sum_{i=1}^{N} U(C_i, D_i, l_i) - \xi(Z_C + Z_D)^{\theta}. \tag{15}$$

All taxes and transfers have to add up to finance total government consumption of clean and polluting goods ($p_C C_G + p_D D_G$), which is held constant:

$$\text{const.} = p_C C_G + p_D D_G = \sum_{i=1}^{N} L_i + \tau_{w,i} I_i + \tau_Z (Z_C + Z_D). \tag{16}$$

We assume that the government consumes the same proportion of clean to polluting goods as the households, so that the effect of government consumption on the relative prices is neutral.

$$\frac{C_G}{D_G} = \frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} D_i}. \tag{17}$$

3.1 General Equilibrium

The system is in equilibrium when the following resource constraints hold:

$$\sum_{i=1}^{n} C_i + C_G = F_C, \tag{18}$$

and

$$\sum_{i=1}^{n} D_i + D_G = F_D. \tag{19}$$

We set the price w of the production input labor as the numeraire, which yields all other prices in relation to this price.

3.2 Scenarios

We analyze a variety of scenarios which can be structured into two subgroups: scenarios with an exogenous carbon tax and scenarios where the carbon tax is set endogenously.

3.2.1 A: Exogenous carbon tax

For all these scenarios the carbon tax is set exogenously ($\tau_Z = \text{const.}$), only the recycling scheme for the carbon tax revenues is varied. In order to find C_i, D_i, p_C, p_D, T_C, T_D, l_i, λ_i Z_C and Z_D we look at the general equilibrium by letting GAMS[10] solve the system of equations, defined by Equations 3, 4 – 7, 11, 12 – 14, 16,17, 18 and 19. The different revenue recycling scenarios for an exogenously set carbon tax are:

1. Differential income tax cuts: we additionally maximize Equation 15, so the government is free to redistribute additional carbon tax revenue by lowering $\tau_{w,i}$ for each household individually. No lump-sum transfers (i.e. $L_i = 0$ in Equations 11 and 16).

2. Uniform income tax cuts: additional revenue is used for a uniform income tax cut ($\tau_{w,i} = \tau_w$). No lump-sum transfers (i.e. $L_i = 0$ in Equations 11 and 16).

3. Lump-sum transfers: additional revenue is returned to the households in a uniform lump-sum fashion (i.e. $L_i > 0$ in Equations 11 and 16).

3.2.2 B: Endogenous carbon tax

In these scenarios the government has the additional degree of freedom of setting the carbon tax level to internalize pollution damages. In the different sub-scenarios it is constrained in the way it recycles the carbon tax revenues. We use GAMS to maximize Equation 15, subject to Equations 3, 4 – 7, 11, 12 – 14, 16,17, 18 and 19.

1. Differential income tax cuts: the government is free to redistribute additional carbon tax revenue by lowering $\tau_{w,i}$ for each household individually. No lump-sum transfers (i.e. $L_i = 0$ in Equations 11 and 16).

2. Uniform income tax cuts: additional revenue is used for a uniform income tax cut ($\tau_{w,i} = \tau_w$). No lump-sum transfers (i.e. $L_i = 0$ in Equations 11 and 16).

3. Lump-sum transfers: additional revenue is returned to the households in a uniform lump-sum fashion (i.e. $L_i > 0$ in Equations 11 and 16).

3.3 Calibration

For a first numerical assessment we set $N = 5$. The income quintiles are then calibrated to U.S. data from the year 2011 and are displayed in Table 1.

[10]General Algebraic Modeling System (GAMS). For more information see the documentation by Rosenthal (2014).

Quintile	1	2	3	4	5
Income Share	3.2	8.4	14.3	23.0	51.1

Table 1: Preliminary calibration of the households' productivities to the U.S. income distribution. (Data source: U.S. Census Bureau, "Income, Poverty and Health Insurance Coverage in the U.S. 2011")

4 Results

In this section the main results of the numerical simulations are summed up. We compare three recycling mechanisms for carbon tax revenue in terms of their equity and efficiency implications.
We start with an exogenously set tax in Section 4.1, to derive first intuitions about the model's behavior. In this section it already becomes clear, that a uniform income tax cut is the mechanism that performs the worst in equity and efficiency terms, while a differential income tax cut performs best in both variables. In Section 4.1.1 it is shown that the Gini coefficient in income, in our model, is a problematic measure of (unobservable) utility. We thus use the Gini coefficient in utility as a more meaningful inequality measure in our simulations. We verify in Section 4.1.2 that it is our assumption of a subsistence level that drives the results.
In Section 4.2 the optimal policy is determined: we find that the highest levels of welfare can be reached with the most equity-enhancing revenue recycling scheme, namely the differential income tax cuts. In addition we find that the optimal carbon tax level depends on the revenue recycling mechanism: the more equal the recycling scheme is, the higher the optimal carbon tax level becomes.
Both, in Sections 4.1 and 4.2, lump-sum recycling outperforms uniform income tax cuts (i.e. the classic double dividend recycling). We conclude that if for some reasons differential income tax cuts are not feasible, lump-sum recycling of the revenues is still a better recycling option than uniform income tax cuts.

4.1 Exogenous carbon tax

In this section a tax τ_Z on the polluting production input (Z_C, Z_D) is set exogenously. We compare different scenarios for recycling the tax revenues in terms of their implications for inequality and welfare: a uniform income tax cut similar to that proposed in the double dividend literature, uniform lump-sum transfers and differential income tax cuts. These are the scenarios A1 – A3, outlined in detail in Section 3.2.
We find that differential income tax cuts perform best, both in terms of welfare and equity. A uniform income tax cut performs worst in both indicators

and the uniform lump-sum transfers are somewhere in between. These results are displayed in Figure 1. The Gini coefficient in utility G^U is used as an indicator of equity.[11]

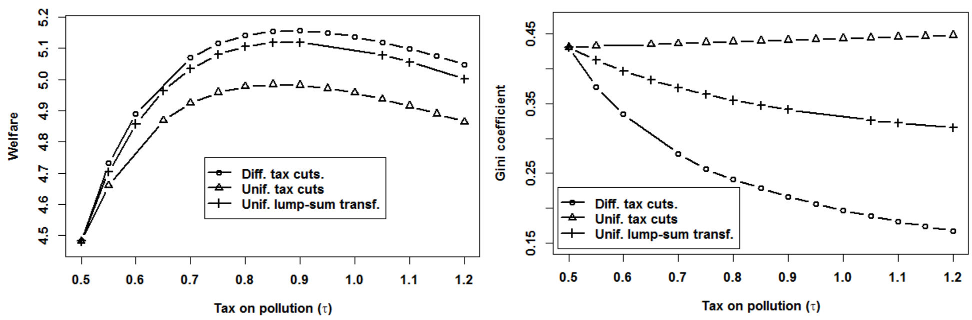

Figure 1: Effects of an exogenously varied carbon tax on welfare (left figure) and its distribution (right figure).

4.1.1 Utility vs. income as a measure of inequality

For some cases, the Gini coefficient in income can lead to false conclusions about the distributional impact of a tax reform. An example is displayed in Figure 2: Here, the Gini coefficients in utility (black) and income (blue) are compared. The right figure magnifies the lines for the case of uniform income tax cuts. The Gini coefficient in utility increases, while the Gini coefficient in income decreases. In this case, income is a misleading indicator: even though the income of a poor household might increase due to the recycling of tax revenues, this increase can be more than offset by an increase in the prices of dirty goods. Since poor households are forced to spend a larger fraction of their income on those goods, they end up with less consumption and less welfare. The Gini coefficient in utility is thus the correct indicator for inequality in our model.

4.1.2 Stone-Geary vs. homothetic preferences

In this subsection we set the minimum consumption level to zero, i.e. the agents' preferences are homothetic again. In Figure 3 we compare the Gini coefficients with and without a subsistence level of polluting consumption for the case of uniform income tax cuts: it can be seen directly that uniform income tax cuts appear distribution-neutral when the subsistence level of polluting consumption is set to 0. Both, the Gini coefficient in utility and

[11] We explain in Section 4.1.1 why we for some cases the Gini coefficient in income is not sufficient and why we have to use the Gini coefficient in welfare as an alternative measure.

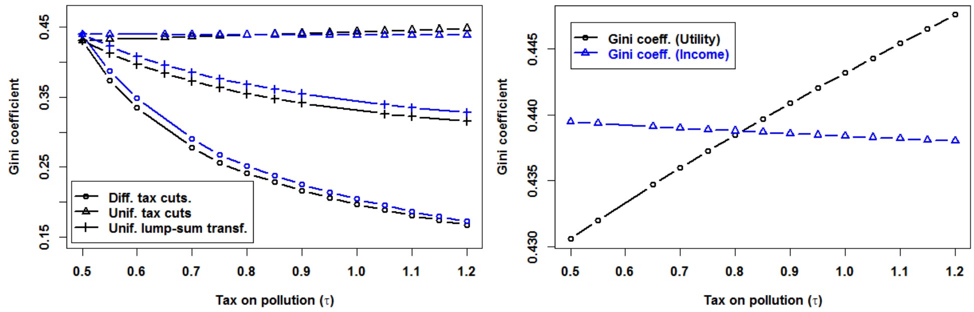

Figure 2: Comparison of the Gini coefficients in utility (black) and income (blue). On the right side the line for the case of uniform income tax cuts as a recycling measure, is magnified.

income appear neutral, when $D_0 = 0$. This exercise demonstrates the importance of the assumption of a subsistence level of polluting consumption for obtaining our results.

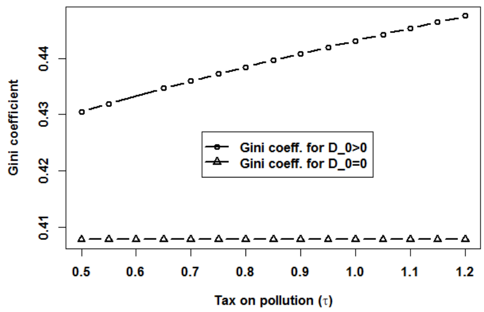

Figure 3: The Gini coefficient in utility in dependence of the carbon tax: for the case of a subsistence level of polluting consumption bigger than zero, it increases with increasing τ_Z. For $D_0 = 0$ the Gini coefficient is independent of τ_Z.

4.2 Results for endogenous carbon taxation

In this section we let a social planner determine the optimal rate of carbon taxation by numerically maximizing total welfare (Equation 15). We then compare the scenarios B1 – B3 in terms of their implications for the optimal level of carbon taxation and for total welfare. These scenarios are outlined in detail in Section 3.2.

The major insight in this section is that the level of the optimal carbon tax depends on the recycling of its revenues: optimal, and thus progressive, redistribution (i.e. differential income tax cuts) yields the highest welfare levels with the highest carbon tax. On the contrary, the most regressive recycling scheme (i.e. uniform income tax cuts) leads to the lowest welfare levels using a lower carbon tax. Recycling the revenues in a more progressive way thus leads to enhanced efficiency, on top of the efficiency gains through reduced pollution. We call this effect the double dividend of redistribution. Additionally we find that, if for some reason the government cannot redistribute optimally, a uniform lump-sum transfer is still a more viable recycling option than uniform income tax cuts. The results are summed up in Table 2; Figure 1 shows the welfare levels for different recycling schemes in dependence of the carbon tax rate.

Recycling scheme	W	τ_z	G^U
1. Differential income tax cuts	5.16	0.885	0.22
2. Uniform lump-sum transfers	5.12	0.879	0.34
3. Uniform income tax cuts	4.98	0.859	0.44

Table 2: Three CO_2 tax revenue recycling schemes are compared. The government sets the tax at the optimal level but is constrained in the cases 2 and 3 in its recycling options. In case 1 the government is given the additional degree of freedom to set the level of the income tax for each household individually.

5 Conclusion

In the current article we develop a model to assess the distributional impact of a carbon tax, and the recycling of its revenues. Our model accounts for the fact that in developed countries, low-income households spend a larger fraction of their income on carbon intensive goods than high-income households.[12]

We compare different recycling mechanisms for the carbon tax revenues and show, that a carbon tax reform can be progressive or regressive, depending on the recycling mechanism: differential income tax cuts[13] is the most efficient and the most equity-enhancing recycling instrument. This result demonstrates that in contrast to most of the literature, there is no evidence of an equity efficiency trade-off in our model (for the case of revenue recycling via differential income tax cuts).

On the other hand, a uniform income tax cut, as often proposed in the double dividend literature, performs worst in terms of efficiency and also has a regressive effect. Lump-sum recycling of the revenues renders the tax reform

[12] Otherwise, the model is very similar to models used in the double dividend literature (Goulder, 1995; Bovenberg, 1999).

[13] i.e. the government is able to distinguish between the households when setting the tax level.

progressive, and is somewhere in the middle between the other two policies in terms of efficiency.

Moreover we determine the optimal carbon tax level for the three different recycling schemes and show, that the optimal carbon tax level depends on the recycling scheme: the more equity-enhancing the recycling scheme is, the higher total welfare becomes. The highest level of welfare is reached with differential income tax cuts and the highest carbon tax. Lump-sum transfers are somewhere in-between and uniform income tax cuts yield the lowest welfare levels at the lowest carbon tax level, due to their regressive nature.

The intuition behind this result is that in the case of a progressive carbon tax reform, the lowest income cohorts' consumption of both goods is increased. Due to their higher marginal utility of consumption, total welfare increases more strongly, so the trade-off between environmental damages and consumption benefits leads to a higher optimal carbon tax (i.e. the economy can afford higher carbon taxes). The opposite occurs for a regressive tax reform.[14]

If, for some reason, differential cuts in income taxes are not feasible, uniform lump-sum recycling of carbon tax revenues would be the preferred option, since it is superior to uniform income tax cuts. Interestingly, Switzerland seems to mainly rely on uniform lump-sum recycling of the carbon tax revenues, which, according to a study by Imhof (2012), has a progressive effect at a reasonable efficiency cost.

Acknowledgments

The authors thank Linus Mattauch and Ulrike Kornek for insightful discussions.

[14]The lowest income cohorts' consumption of clean goods is strongly reduced, due to its necessity to consume the (now very expensive) polluting good. The higher income cohorts have a lower marginal utility of consumption than the low income cohorts and thus total welfare is lower than in the case of progressive revenue recycling, so the trade-off between environmental damages and consumption benefits leads to a lower optimal carbon tax (i.e. the economy cannot afford a carbon tax as high as with progressive revenue recycling).

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