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Abstract

A major obstacle for introducing carbon pricing are its distributional implications: climate policy is believed to be regressive. We illuminate the role of carbon-intensive subsistence consumption for the prospect of making carbon pricing progressive. The distributional impacts of a carbon tax reform depend on the revenue recycling options: we prove that lump-sum transfers proportional to income and linear income tax cuts make the reform regressive and that this is due only to subsistence consumption. By contrast, returning the revenue as *uniform* lump-sum transfers renders the carbon tax reform progressive.

JEL classification: D3, D60, E62, H22, H23

Keywords: carbon tax reform, distribution, revenue recycling, inequality, non-homothetic preferences

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1 Introduction

Mitigating climate change requires substantial reductions in carbon emissions, which would best be achieved by carbon pricing. An important obstacle to introducing carbon pricing are distributional concerns: Pricing emissions in developed countries is often believed to harm the poorest part of the population due to the higher share of their income that is spent on carbon-intensive goods.

Grainger and Kolstad (2010) show for the case of the U.S., that for most carbon-intensive goods such as electricity, heating and food, subsistence levels exist and that a price increase in these goods is the main driver behind the regressivity of carbon taxes. This mechanism, to our knowledge, has not received enough attention in the literature on the distributional implications of carbon pricing.

Analyzing the distributional effects of a carbon tax reform while accounting for a subsistence level of carbon-intensive goods is the purpose of the present note. We use a stylized analytical model that features two consumption goods, one of which is assumed to be carbon-intensive.[1] Households differ only in their productivity and must consume a minimal amount of the carbon-intensive good to survive, which is modeled by means of a Stone-Geary utility function. In this note we are only concerned with the short-term distributional effects of a carbon tax reform, i.e. how setting a price on carbon impacts inequality[2], which we believe to be decisive for political decision-making.

We find three main results. First, when the tax revenue is returned to the households via linear income tax cuts, or proportional to their productivity, the overall effect of the tax reform is regressive. Second, for the case of uniform lump-sum recycling, the overall effect of the tax reform is progressive. Finally we show that when setting the subsistence level of carbon-intensive consumption to zero, regressive policies appear distribution-neutral.

Previous literature either relies on large numerical models (Rausch et al., 2010, 2011) or on rather specific modeling assumptions (Chiroleu-Assouline and Fodha, 2011, 2014; Fullerton and Monti, 2013). In fact, there seems to be some disagreement in the theoretical literature on the extent to which the regressivity of a carbon tax can be reduced by the recycling of its revenues: Fullerton and Monti (2013) show, that in a model with household heterogeneity in skills, "returning all of the revenue to low-skilled workers is still not enough to offset higher product prices." On the other hand, Chiroleu-Assouline and Fodha (2011, 2014) show in a model with a more

[1]For a more detailed numerical treatment that accounts for both the household and the firm side in an optimal taxation framework see Klenert et al. (2015).

[2]This permits us to abstract from major factors usually discussed in the context of climate policy, such as environmental damages, structural change and international cooperation.

complex household heterogeneity structure, but less detail in pollution, that "whatever the degree of regressivity of the environmental tax alone, it is possible to design a recycling mechanism that renders the tax reform more Pareto efficient, by simultaneously decreasing the wage tax and increasing its progressivity."[3] Both studies mention a subsistence level of polluting consumption as at least partially responsible for the regressivity of a carbon tax, but refrain from modeling it.

Our results instead rely on this empirically verified mechanism of the interaction between carbon taxation and inequality. Our findings are very robust, since the only driver of our results is the assumption of a subsistence level of carbon-intensive consumption.

This assumption is supported by a large body of literature that agrees that lower income households spend a larger percentage of their income on carbon-intensive goods, notably heating, electricity and food, than higher income households: While Grainger and Kolstad (2010) demonstrate this for the case of the U.S., Flues and Thomas (2015) confirm that taxes on heating fuels and electricity are regressive over a set of 21 OECD countries. Wier et al. (2001) study the case of Denmark and also comprehensively survey studies of other countries. This spending behavior is often mentioned as one of the main reasons for climate policy being regressive[4] (Grainger and Kolstad, 2010; Fullerton, 2011; Combet et al., 2010), but has received little attention so far in the theoretical literature.

2 The model

We use a two sector model in which N households are distinguished by their productivity. Households are required to consume a minimum amount of the polluting good, which we model by means of a Stone-Geary utility function. Since we only look at the near term, in which structural change in the energy system is negligible, we use a static model. Furthermore we assume that the prices of clean and polluting goods are fixed.

Households: There are N households in the economy which are distinguished only by their productivity ϕ_i. Each household is endowed with the production factor T. A share l_i of the production factor is used at home and can be interpreted as leisure, for the remaining share $(T - l_i)$ the household receives a rental rate r, so the households' incomes are given by

$$I_i = \phi_i r(T - l_i)(1 - \tau_w^0 + \tau_w), \tag{1}$$

[3]The numerical analyses by Rausch et al. (2010, 2011) yield an even stronger result: under certain conditions the carbon tax itself has a progressive effect. The progressive effects on the sources side (changes in factor prices) offset the regressive effects on the uses side (higher product prices). In the present small analytical model, we only consider the distributional impacts on the uses side.

[4]This might not be the case for developing countries, see Sterner (2011).

where τ_w^0 denotes the income tax before the carbon tax reform and τ_w is a potential (linear) income tax reduction financed by carbon tax revenues. We normalize the households' productivities such that $\sum_{i=1}^{N} \phi_i = 1$.

Households derive utility from the consumption of clean goods C_i, polluting goods D_i and leisure l_i. They have the same non-homothetic preferences and maximize the following utility function

$$U(C_i, D_i, l_i) = C_i^{\alpha}(D_i - D_0)^{\beta} l_i^{\gamma}, \tag{2}$$

with α, β and $\gamma > 0$. Households are assumed to need a minimal level D_0 of polluting consumption. The utility function is not defined for $D_i < D_0, \quad \forall i = 1 \dots N$. The budget equation for each household is given by

$$C_i \cdot p_C + D_i \cdot p_D \cdot (1+\tau) = I_i + L_i, \tag{3}$$

with τ denoting a tax on the consumption of polluting goods and L_i a lump-sum transfer. We assume the prices of the commodities to be constant.

Maximizing the utility function (2) with respect to the budget equation (3), yields the first order conditions of the households. Those can be reformed to obtain explicit expressions for each household's consumption of each commodity (the derivations can be found in Appendix A):

$$C_i = \frac{\alpha}{(\alpha+\beta+\gamma)} \frac{1}{p_C} \left(\phi_i r T(1 - \tau_w^0 + \tau_w) + L_i - D_0 p_D (1+\tau)\right), \tag{4}$$

$$D_i = \frac{\beta}{(\alpha+\beta+\gamma)} \frac{1}{p_D(1+\tau)} \left(\phi_i r T(1 - \tau_w^0 + \tau_w) + L_i - D_0 p_D (1+\tau)\right) + D_0, \tag{5}$$

$$l_i = \frac{\gamma}{(\alpha+\beta+\gamma)} \frac{1}{\phi_i r(1 - \tau_w^0 + \tau_w)} \left(\phi_i r T(1 - \tau_w^0 + \tau_w) + L_i - D_0 p_D (1+\tau)\right). \tag{6}$$

Despite a substitution elasticity of one in the utility function, leisure is not fixed (as in the Cobb-Douglas case) but influenced by the level of subsistence consumption, taxes and transfers.

The model is only well-defined when all households are able to pay at least for their minimum consumption D_0, so

$$I_i + L_i \geq D_0 p_D (1+\tau) \quad \text{for all } i. \tag{7}$$

Government: The government has a fixed spending requirement G, which is financed by the (pre-existing) income tax τ_w^0. Additional revenue can either be returned to the households via lump-sum transfers L_i or reductions in the income tax τ_w. The government's budget constraint thus reads as:[5]

$$G + \sum_{i=1}^{N} L_i + \sum_{i=1}^{N} \phi_i r(T - l_i)\tau_w = \tau \cdot D \cdot p_D + \sum_{i=1}^{N} \phi_i r(T - l_i)\tau_w^0. \tag{8}$$

3 Results

We analyze the distributional implications of three possible carbon tax reforms: First, the carbon tax revenues are returned to the households' via lump-sum transfers proportional to their productivity. Second, linear income tax reductions are used as a means of revenue recycling. Third, each household receives the same uniform lump-sum transfer.

Section 3.1 contains the main analytical results: We show in Proposition 1, that in the first and second scenario inequality is increased. In the third scenario inequality is reduced (Proposition 2). Finally we demonstrate in Proposition 3 that recycling the revenues as in the first and second scenario is neutral, when the subsistence level of polluting consumption equals zero.

In Section 3.1 we consider the utility ratios of two of the households as a measure of the distributional impacts of the carbon tax reform. For a more refined inequality measure see Section 3.2, in which we demonstrate numerically that (for the parameters given in Appendix B) the analytical results derived in Propositions 1 and 2 also hold when the Gini coefficient in utility is used as a measure of inequality.

3.1 Analytical results

The ratio U_i/U_j is derived by inserting the expressions (4)–(6) into the households' utility function (2) and then dividing the utility of household i by the utility of household j:

$$\begin{aligned} \frac{U_i}{U_j} &= \frac{C_i^\alpha (D_i - D_0)^\beta l_i^\gamma}{C_j^\alpha (D_j - D_0)^\beta l_j^\gamma} \\ &= \left(\frac{\phi_j}{\phi_i}\right)^\gamma \left(\frac{(\phi_i r T(1 - \tau_w^0 + \tau_w) + L_i - D_0 p_D(1+\tau))}{(\phi_j r T(1 - \tau_w^0 + \tau_w) + L_j - D_0 p_D(1+\tau))}\right)^{(\alpha+\beta+\gamma)} \end{aligned} \tag{9}$$

We choose the following notation: $(U_i/U_j)^{\text{BT}}$ is the ratio of utilities before taxes, $(U_i/U_j)^{\text{AT-U}}$ is the ratio of utilities after taxes with uniform lump-sum recycling of the revenues, $(U_i/U_j)^{\text{AT-P}}$ is the case of a tax with the revenues recycled proportional to each household's productivity ϕ_i and $(U_i/U_j)^{\text{AT-DD}}$ is the case of a tax with the revenues recycled via linear income tax reductions:

[5] The government is only represented through this budget constraint, it hence does not optimize.

$$\left(\frac{U_i}{U_j}\right)^{\text{BT}} = \left(\frac{\phi_j}{\phi_i}\right)^{\gamma} \left(\frac{\phi_i r T(1-\tau_w^0) - D_0 p_D}{\phi_j r T(1-\tau_w^0) - D_0 p_D}\right)^{(\alpha+\beta+\gamma)}, \tag{10}$$

$$\left(\frac{U_i}{U_j}\right)^{\text{AT-U}} = \left(\frac{\phi_j}{\phi_i}\right)^{\gamma} \left(\frac{\phi_i r T(1-\tau_w^0) + \tau D p_D \frac{1}{N} - D_0 p_D(1+\tau)}{\phi_j r T(1-\tau_w^0) + \tau D p_D \frac{1}{N} - D_0 p_D(1+\tau)}\right)^{(\alpha+\beta+\gamma)}, \tag{11}$$

$$\left(\frac{U_i}{U_j}\right)^{\text{AT-P}} = \left(\frac{\phi_j}{\phi_i}\right)^{\gamma} \left(\frac{\phi_i (r T(1-\tau_w^0) + \tau p_D D) - D_0 p_D(1+\tau)}{\phi_j (r T(1-\tau_w^0) + \tau p_D D) - D_0 p_D(1+\tau)}\right)^{(\alpha+\beta+\gamma)}, \tag{12}$$

$$\left(\frac{U_i}{U_j}\right)^{\text{AT-DD}} = \left(\frac{\phi_j}{\phi_i}\right)^{\gamma} \left(\frac{\phi_i r T(1-\tau_w^0 + \tau_w) - D_0 p_D(1+\tau)}{\phi_j r T(1-\tau_w^0 + \tau_w) - D_0 p_D(1+\tau)}\right)^{(\alpha+\beta+\gamma)}. \tag{13}$$

Proposition 1. *The incidence of a tax on the polluting good is regressive, if*

(a) the revenues are recycled proportional to each household's productivity ϕ_i *(i.e.* $L_i = \phi_i \tau p_D D$ *and* $\tau_w = 0$*).*

(b) the revenues are recycled via linear income tax cuts τ_w *(i.e.* $\tau_w r \sum_{i=1}^{N} \phi_i (T - l_i) = \tau p_D D$ *and* $L_i = 0$*).*[6]

Proof. For the proof of part (a), it suffices to demonstrate that $(U_i/U_j)^{\text{AT-P}} < (U_i/U_j)^{\text{BT}}$ for $\phi_j > \phi_i$.

By introducing the auxiliary variables A and B we further simplify Equation (12) to

$$\left(\frac{U_i}{U_j}\right)^{\text{AT-P}} = \left(\frac{\phi_j}{\phi_i}\right)^{\gamma} \left(\frac{\phi_i (A+B) - D_0 p_D(1+\tau)}{\phi_j (A+B) - D_0 p_D(1+\tau)}\right)^{(\alpha+\beta+\gamma)}, \tag{14}$$

with $A = rT(1-\tau_w^0)$ and $B = \tau p_D D$. We can ignore the prefactor $(\phi_j/\phi_i)^\gamma$ and the exponent $(\alpha+\beta+\gamma)$ for the moment since they cancel out when

[6] This result can be seen as related to the so called double dividend debate (Goulder, 1995; Bovenberg, 1999). In the traditional double dividend literature it is argued that using carbon tax revenues for rebates in a pre-existing income tax system does not only reduce pollution but also enhances efficiency. Proposition 1 (b) would thus imply that reaping a possible double dividend via linear income tax cuts might come at the cost of increased inequality.

two utility ratios are compared. We furthermore reform the term $\phi_k(A+B)$, with k in $[i,j]$, such that it is of the form $\phi_k A(1+B/A)$:

$$\left(\frac{\phi_i A(1+\frac{B}{A}) - D_0 p_D(1+\tau)}{\phi_j A(1+\frac{B}{A}) - D_0 p_D(1+\tau)}\right). \tag{15}$$

In both the numerator and the denominator of this expression a positive and a negative term remain. The positive term can be increased by increasing B/A, which has an increasing effect on the utility ratio (and thus a decreasing effect on inequality). Similarly, the negative term $(-D_0 p_D)$ can be increased by increasing τ, which decreases the utility ratio (and thus increases inequality). We can infer from this expression directly that the distributional effect of a carbon tax reform is neutral if $B/A = \tau$, since in that case the term $(1+\tau)$ would cancel out and we would get that $(U_i/U_j)^{\text{AT-P}} = (U_i/U_j)^{\text{BT}}$. The distributional effect of a tax reform is regressive (progressive), if $B/A < \tau$ $(B/A > \tau)$. It thus remains to show that $B/A < \tau$. By inserting the expressions for A and B we get

$$\frac{B}{A} = \frac{\tau p_D D}{rT(1-\tau_w^0)} < \tau. \tag{16}$$

By reforming this inequality we get:

$$\underbrace{p_D D}_{\text{total spending on polluting goods (before tax reform)}} < \underbrace{rT(1-\tau_w^0)}_{\text{total income w/o leisure term (before tax reform)}}. \tag{17}$$

Since by assumption ϕ_i is strictly smaller than ϕ_j, households with $j > 1$ always consume a positive amount of leisure and of the clean good. Total spending on polluting goods hence must be lower than total income (when no leisure is consumed) and the inequality above always holds. This implies that $(U_i/U_j)^{\text{AT-P}} < (U_i/U_j)^{\text{BT}}$, which closes the proof of part (a).

The proof of part (b) is analogous to that of part (a) with $B = rT\tau_w$. What remains to show is that B/A is smaller than τ. By inserting the expressions for A and B we get:

$$\frac{B}{A} = \frac{\tau_w}{(1-\tau_w^0)} < \tau. \tag{18}$$

For revenue recycling through income tax cuts the sum of all income tax rebates equals the total carbon revenue: $\tau_w r \sum_{i=1}^N \phi_i(T-l_i) = \tau p_D D$. We use this relationship to eliminate τ_w from Equation (18) and get:

$$\frac{B}{A} = \frac{\tau p_D D}{(1-\tau_w^0) r \sum_{i=1}^N \phi_i(T-l_i)} < \tau. \tag{19}$$

By reforming this expression we get:

$$\underbrace{p_D D}_{\text{total spending on polluting goods (before tax reform)}} < \underbrace{(1-\tau_w^0) r \sum_{i=1}^{N} \phi_i (T - l_i)}_{\text{total income (before tax reform)}} . \tag{20}$$

For the same reason as in the proof of part (a) this inequality holds. □

Proposition 2. *The tax reform becomes progressive for uniform lump-sum redistribution of the revenues (that is $L_i = L = \tau p_D D/N$ for $i = 1, \ldots, N$ and $\tau_w = 0$).*

Proof. A carbon tax reform with uniform lump-sum recycling of the revenues simply adds the constant terms $-D_0 p_D \tau < 0$ (decreased utility due to the tax on subsistence consumption) and $\tau p_D D/N > 0$ (increased utility due to the revenue recycling) to the numerator and the denominator of the expression on the right side of Equation (10). Summing up these two terms yields:

$$\tau p_D D/N - D_0 p_D \tau = p_D \tau (D/N - D_0) > 0, \tag{21}$$

This expression is strictly bigger than zero since we assume that τ, $p_D > 0$ and $\phi_i < \phi_j$. Therefore all agents with $j > 1$ have a level of polluting consumption that is higher than the subsistence level D_0, so the average level of polluting consumption, D/N, is always higher than the subsistence level D_0. It remains to show that adding a positive constant to the numerator and the denominator of a fraction that is smaller than one, increases this fraction. For that purpose we use the following elementary inequality:

$$m < s \Rightarrow \frac{m}{s} < \frac{m+t}{s+t}, \quad \text{for} \quad t > 0 \quad \text{and} \quad m, s > 0.$$

Let $m = \phi_i r T(1-\tau_w^0) - D_0 p_D$, $s = \phi_j r T(1-\tau_w^0) - D_0 p_D$ and $t = -D_0 p_D \tau + \tau D p_D/N$. For $i < j$, $\phi_i < \phi_j$ and thus $m < s$. From Equation (21) follows that $t > 0$ and we also know that $m, s > 0$. It then follows directly that $(U_i/U_j)^{\text{BT}} = (U_i/U_j)^{\text{AT-U}}$, which means that the tax reform is progressive. □

Proposition 3. *For a subsistence level of polluting consumption of zero ($D_0 = 0$), the revenue recycling mechanisms examined in Proposition 1, are distribution-neutral, i.e. Proposition 1, does not hold anymore.*

Proposition 3 demonstrates that it is only our assumption of a subsistence level of polluting consumption that drives the results of Proposition 1. The result presented in Proposition 2, that uniform lump-sum recycling reduces inequality, is independent of the level of D_0.

Proof. By setting $D_0 = 0$ in Equations (10) and (12) we obtain

$$\begin{aligned}\left(\frac{U_i}{U_j}\right)^{\mathrm{BT}} &= \left(\frac{\phi_j}{\phi_i}\right)^{\gamma}\left(\frac{\phi_i rT(1-\tau_w^0)}{\phi_j rT(1-\tau_w^0)}\right)^{(\alpha+\beta+\gamma)} = \left(\frac{\phi_j}{\phi_i}\right)^{\gamma}\left(\frac{\phi_i}{\phi_j}\right)^{(\alpha+\beta+\gamma)} \\ &= \left(\frac{\phi_j}{\phi_i}\right)^{\gamma}\left(\frac{\phi_i(rT(1-\tau_w^0)+\tau p_D D)}{\phi_j(rT(1-\tau_w^0)+\tau p_D D)}\right)^{(\alpha+\beta+\gamma)} = \left(\frac{U_i}{U_j}\right)^{\mathrm{AT\text{-}P}}.\end{aligned}$$

The same reasoning applies to the result derived in Proposition 1 b. □

3.2 Verifying the results for the Gini coefficient

It is well known that the utility ratio, used for analytical convenience in the previous subsection, is not an optimal measure of regressivity, as discussed in Ray (1997), for instance. In this subsection we subject our propositions about the distributional effects of carbon tax reform options to a robustness check: the above model is solved numerically to calculate the Gini coefficient in utility. We verify that (U_i/U_j) is a meaningful indicator of inequality, at least for the parameters given in Appendix B. We consider the same revenue recycling options as in as in Propositions 1 and 2.

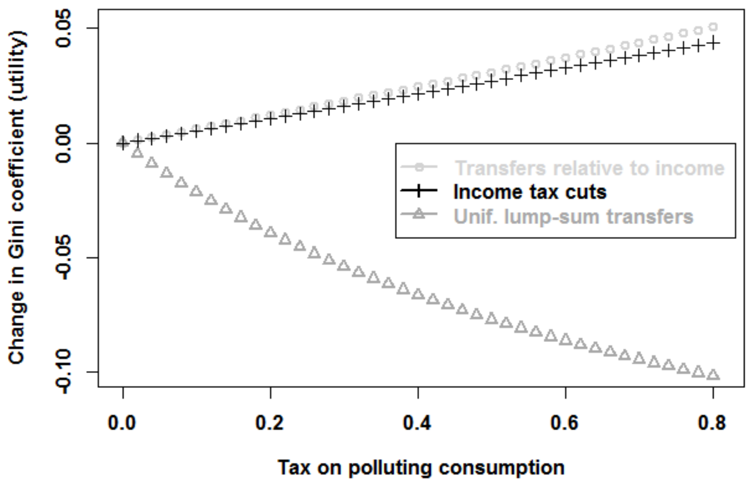

Figure 1: The change in the Gini coefficient (in utility) for different carbon revenue recycling mechanisms. For obtaining a numerical solution we use the algebraic modeling software GAMS (Rosenthal, 2014). The parameters used for creating Figure 1 are given in Appendix B.

We find that Propositions 1 and 2 remain valid when the Gini coefficient in utility is used as an indicator of inequality (for the parameters given in Appendix B), as can be seen in Figure 1.

4 Conclusion

In this note we demonstrate conceptually that carbon-intensive subsistence consumption is key to understand the distributional effects of a carbon tax reform. Our analysis confirms that the existence of a subsistence level of polluting consumption is a strong driver of the regressivity of carbon taxation. This holds for both, the case that revenues are recycled lump-sum, proportional to the households' productivities, and for the case of recycling via linear income tax cuts. By contrast, we prove that the overall effect of a carbon tax reform can be made progressive by recycling the revenues as *uniform* lump-sum transfers. No additional assumptions are required to obtain our analytical results, which makes the mechanisms at work transparent and our modeling strategy very robust.

An example of a carbon tax combined with lump-sum rebates can be found in Switzerland. Here carbon tax revenues are (at least partially) recycled in a uniform lump-sum fashion, in the form of a reduction in health insurance contributions (see for example Federal Office for the Environment 2015).

At least two interesting extensions of our framework are possible, but go beyond the scope of this article: First, considering not only linear but also non-linear income tax reductions and taxing emissions instead of output, preferably in a general equilibrium setting that accounts for price effects on the sources (firm) side. We treat this case in a further study with a numerical model (see Klenert et al. 2015). Second, studying the dynamics of different revenue recycling mechanisms when technological change is endogenous and a decarbonization of the economy is possible.

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Appendices

A Derivation of the equations for C_i and D_i

By maximizing Equation 2 subject to budget constraint 3 we obtain the two First Order Conditions:

$$\alpha C^{(\alpha-1)}(D_i - D_0)^{\beta} l_i^{\gamma} = \lambda_i p_C, \tag{A.1}$$

$$\beta C^{\alpha}(D_i - D_0)^{(\beta-1)} l_i^{\gamma} = \lambda_i p_D(1+\tau), \tag{A.2}$$

$$\gamma C^{\alpha}(D_i - D_0)^{\beta} l_i^{\gamma-1} = \phi_i r(1 - \tau_w^0 + \tau_w). \tag{A.3}$$

By eliminating λ_i we get:

$$\frac{(D_i - D_0)}{C_i} = \frac{\beta}{\alpha}\frac{p_C}{p_D(1+\tau)}, \tag{A.4}$$

$$\frac{l_i}{C_i} = \frac{\gamma}{\alpha}\frac{p_C}{\phi_i r(1 - \tau_w^0 + \tau_w)}. \tag{A.5}$$

Together with Equation 3, explicit expressions for C_i and D_i can obtained (see Equations (4), (5) and (6)).

B Parameters for calculating the Gini coefficient

For the numerical simulations we set $N = 5$. The individual productivities are calibrated as in Table 1. The remaining parameters are given in Table

Quintile	1	2	3	4	5
Productivity (ϕ_i)	0.032	0.084	0.143	0.23	0.511

Table 1: Household productivities are calibrated to match data from the U.S. Census Bureau on the income shares of different quintiles (DeNavas-Walt et al., 2012).

2.

α	clean consumption share in utility	0.5
β	polluting cons. share in utility	0.28
γ	leisure share in utility	0.15
D_0	subsistence level poll. consumption	0.15
p_C, p_D	price of clean/polluting consumption	1
G	government consumption	2.551
τ_w^0	pre-existing income tax	30 %

Table 2: Calibration of the model parameters

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