Carbon Taxation and Inequality: Theory and Evidence from Denmark

Rasmus Lindø Kaslund   Julie Deding Nielsen

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Abstract

In this paper we examine the distributional impact of a carbon tax in Denmark. We find that a carbon tax is regressive but that a tax reform with redistribution through lump-sum transfers or differentiated income tax cuts can lead to a double dividend of redistribution, both lowering carbon emissions and inequality. We set up an input-output model of the Danish economy to assess the short-run distributional effect of the existing carbon tax in Denmark and a carbon tax of 1000 DKK/ton. We find that carbon taxes are highly regressive as share of disposable income but less so as share of expenditures. Furthermore, we set up a general equilibrium model calibrated to the Danish economy to assess the long-run distributional effects of a carbon tax of 1000 DKK/ton as well as different redistribution schemes. We find that a carbon tax has a smaller impact on Danish households in the long run, however the tax is still regressive. Furthermore, we find that recycling the revenue can offset this effect such that the reform as a whole decreases inequality.

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Introduction and conclusion was written in collaboration. Rasmus is responsible for sections 2.1, 2.3, 2.5.1, 2.5.2, 2.6, 3.2, 3.4, 3.5, 4.1, 5.1, 6.1. Julie is responsible for sections 2.2, 2.4, 2.5.3, 2.5.4, 3.1, 3.3, 3.6, 4.2 and 6.2.

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Contents

1 Introduction

1.1 Motivation

The awareness of climate change and calls for mitigation have increased heavily in the recent years. In Denmark, the pre-election debate in 2019 was heavily focused on environmental issues and it became obvious that the population desires political action to combat climate change. Many economists believe that a uniform carbon tax is a cost-effective way to reduce carbon emissions (Mankiw, 2009), as it will lead to the most inexpensive reductions being carried out. However, a common critique of carbon taxes is that they might increase inequality, which previous studies have shown (Wier et al., 2005; Callan et al., 2009). The Danish Minister for Climate, Energy and Utilities, Dan Jørgensen, expressed his concerns in the Danish newspaper Berlingske[1], responding to a proposal of higher carbon taxes: *'We need to complete the green transition (...) without compromising social balance or competitiveness.'* The same is stated in the Danish Climate Law of December 2019.[2] We understand social balance as entailing that the poor do not pay a relatively higher price for the green transition than the rich. Thus, assessing the regressivity of a carbon tax will be relevant for its public and political support in Denmark and abroad (Klenert et al., 2018a).

In March 2020, the Danish Climate Council (2020) came out in strong support of a carbon tax of 1500 DKK per ton of CO_2 emitted. A few weeks earlier, the think tank Kraka (2020) published a report with similar recommendation, including an analysis of the carbon tax incidence, which concluded that a carbon tax reform could be carried out without increasing inequality, if reducing already existing and regressive energy taxes.

In this paper, we examine the distributional effects of a carbon tax reform more closely, using both an input-output model as well as a general equilibrium model for the Danish economy. Combining the two models we assess the impact in both the short and long run. Furthermore, we analyze redistribution schemes to compensate for the regressivity of the tax. We find that both in the short and long run, carbon taxes have a regressive distributional profile, but that recycling the revenue can offset that, such that inequality actually decreases. We call this the double dividend of redistribution, as Klenert et al. (2018b).

The paper is structured in the following way: Section 1.2 reviews past carbon tax reforms and distributional effects of carbon taxation. Section 2 applies an input-output model of the Danish economy to assess the short-run distributional effects of a carbon tax. Section 3 applies a general equilibrium model calibrated to the Danish economy to analyze the long-run effects of a carbon tax on both distribution and redistribution. Section 4 presents the results of the general equilibrium analysis and combine these with the findings of the input-output analysis. Section 5 presents a robustness analysis of chosen model parameters, and section 6 discusses model limitations and potential biases of our results.

[1] Mangedobling af skat møder modstand, Berlingske.dk

[2] Klimaloven af 6. december 2019, kefm.dk

1.2 A review on carbon tax reforms

1.2.1 A short history of the Danish carbon tax

The first carbon tax was imposed in Denmark in 1992 as a part of a bigger environmental tax reform, as a result of an international sustainability agenda in the light of, amongst other events, the publishing of the Brundtland Report (Wier et al., 2005). The tax was set to 100 DKK per ton of carbon emitted in Danish production and from households' energy consumption. All businesses were however given a 50 percent tax rebate to secure their international competitiveness. Further, high energy intensive businesses were given further reimbursements to the extent where the most energy intensive businesses got their carbon tax bill completely refunded. Since 1992 there has been many modifications to the environmental tax system as a whole. The regulation on carbon continues to be a small part of the total amount of energy and pollution taxes collected by the Danish state (The Danish Ministry of Taxation, 2018). Further the carbon tax is imposed per energy units of different fuels, which means that different fuels pay different tax rates per ton emitted. According to calculations by Danish Climate Council (2018), however, the carbon tax corresponds to around 170 DKK per ton of carbon emitted in 2018, for businesses not already covered by the EU ETS.

1.2.2 Evaluations

Different empirical studies have examined the distributional consequences of a carbon tax as well as its effect on emissions. In this section we review different findings in the field.

There is mixed evidence on the effect of carbon taxation. Empirical evidence from Denmark based on the environmental tax schemes of the early nineties show that a carbon tax reduces emissions. The Danish Ministry of Finance (1999) finds that an extension in 1995 to the environmental tax reform from 1992 has reduced emissions. The scheme has further reduced emissions cost-effectively and without compromising international competitiveness. Bjørner and Jensen (2002) examine the tax scheme of 1992 using panel data on energy prices and consumption from 1993 to 1997. The study finds that the carbon tax scheme have contributed to a reduction in energy consumption of 10 percent during this period. However, Bjørner and Jensen (2002) also find that in the industries which received high tax credits in return for voluntary energy efficiency agreements, 9 percent of the energy reduction was due to the voluntary agreements. This indicates that the 10 percent effect of the carbon tax might be overestimated. Other studies have found that existing carbon tax schemes have not succeeded in reducing emissions (Lin and Li, 2011; Bruvoll and Larsen, 2004), which is most likely due to energy-intensive industries receiving tax credits.

The distributional impacts of the Danish carbon tax scheme has also been evaluated. A Danish study by Wier et al. (2005) finds that carbon taxes are regressive, especially the taxes imposed directly on household's energy consumption. They use data on actual Danish carbon tax payments, national consumer surveys and input-output tables. Since Wier et al. (2005) use actual carbon tax payments a few years after the tax was imposed, they nicely incorporate short-run substitution effects in their analysis. Poterba (1991) uses consumer survey data and short-run and long-run estimated price elasticities to measure the effects on income distribution. Furthermore he emphasizes that calculating the tax payment's share of households' total expenditure rather than disposable income gives a more accurate measure of the effect, since households' will smooth expenditure over their life-time. Using this method he finds a far smaller effect of the tax on income distribution, however still regressive.

The distributional impact of a carbon tax is also examined in Callan et al. (2009). They use Irish data consisting of national consumer surveys and input-output tables from 2004. Since there was not an actual carbon tax in Ireland, the authors have calculated the effects of a hypothetical tax of 20 EURO per ton of carbon emitted. They calculate only the effect of direct taxes on households and ignore indirect taxes through consumption of goods. Under these assumptions the authors find that a carbon tax is regressive, especially for rural households who use more personal transportation.

Callan et al. (2009) also study the effects of recycling the tax revenue through either an increase of 2 EURO per week in *all* social benefit transfers, an increase in the income tax credit by 104 EURO per year or a cut in the income tax rate of 20 percent. To calculate the effects they use the SWITCH model, which is built on a national representative survey on households' income, taxes and benefits, and is regularly used by the Irish Department of Finance. Using this method the authors find that if the revenue is used to increase social benefits combined with increases in income tax credits or cuts in income tax rates, households can become better off across the entire income distribution without exhausting the total carbon tax revenue (up to 80 percent of the tax revenue is recycled).

Klenert et al. (2018b) similarly focus on redistributing the revenue from an environmental tax scheme. They set up a theoretical framework in which revenue recycling is possible through either lump-sum transfers or income tax cuts. Their model is a general equilibrium model accounting for behavioural effects of firms and households and it is calibrated to US data. Simulating a baseline scenario and a number of tax scheme scenarios with different recycling options the authors find that a carbon tax is regressive but that recycling the revenue through lump-sum transfers can lead to a double dividend of redistribution. The usual double dividend occurs when a tax reform reduces emissions while increasing productivity, for instance by using the tax revenue to lower distortionary taxes (Goulder, 1995; Bovenberg, 1999). However Klenert et al. (2018b) find a 'double dividend of redistribution' in the form of reducing pollution while reducing inequality. Heerden et al. (2006) find evidence of a triple dividend, where pollution is reduced while increasing productivity and equality, using a detailed computable general equilibrium model with multiple households for South Africa. The environmental tax reform that assures the triple benefits consists of certain mixes of increased energy taxes and reduced food taxes.

More recently, Kraka (2020) analyzes a recycling scheme in a Danish context. The analysis uses the multi-sectoral CGE model REFORM combined with input-output tables, income statistics and consumer survey data to evaluate effects of an environmental tax reform. They find that implementing a uniform carbon tax which increases over time to reach 1250 DKK pr ton of carbon emitted in 2030 will not increase inequality if the revenue is used to cut other regressive energy taxes or is redistributed using lump-sum transfers. In their proposed tax reform, tax credits are given to industries like agriculture which are highly exposed to carbon leakage. This is both to protect Danish competitiveness and to ensure that reductions actually happen, since a full tax might induce firms to move the entire production to a country with less regulation.

2 Input-output model

In this section, we examine the short-run distributional impact of a uniform carbon tax on Danish firms and households, following the method of Wier et al. (2005). We analyze both an approximation of the current carbon taxation in Denmark, as well as a hypothetical carbon tax of 1000 DKK/ton of carbon.

2.1 Method

To measure the tax burden for households with different incomes, we divide the tax payment into households' direct and indirect tax payments following Wier et al. (2005). Households' direct tax payments are through direct purchases of gas, electricity and fuel, and their indirect tax payments are through purchases of goods and services, for which carbon is emitted in the production process. For the indirect tax payments we set up an input-output model using input-output tables and household budget survey data for the danish economy. A core assumption of input-output models is that consumers carry the entire tax burden and that there are not taken substitution or income effects into account, making the carbon tax payments ceteris paribus measures. For the direct tax payments we use data on households' energy consumption combined with carbon intensities of different energy sources.

2.2 Data

We use data from Statistics Denmark (2020) from 2016 on carbon emissions for 117 different sectors, households' direct energy consumption, input-output tables of 117 sectors and 43 different types of goods, households' consumption of the 43 goods and households disposable incomes. Further we use carbon-intensities of different energy sources collected by Sune (AE). Below is a detailed description of each dataset.

The carbon emissions data from the DRIVHUS table comprises the total emissions of carbon-equivalents from 117 sectors of the Danish economy measured in tons.[3] Emissions from biomass are excluded, as biomass consumption is considered carbon-neutral.[4].

[3]To calculate CO2-equivalents methane emissions are multiplied by a factor 25 and nitrous oxide with a factor 298. Throughout the paper, we refer to CO_2-equivalents as simply carbon

[4]Biomass is considered carbon neutral in the calculation of Danish emissions on which the 70 % reduction target is based, see Danish Climate Council: report on biomass.

The input-output tables stem from table NI01. The first input-output table consists of a 117×117 matrix, corresponding to the 117-categorization of Danish production sectors. The table describes intersectoral inputs and outputs, hence the name. The unit of measurement is DKK, running prices. The second input-output table is a 117×43 matrix that measures the share input units from each one of the 117 sectors there is used to produce each one of 43 different types of goods in the Danish economy. We will in the analysis leave out the categories prostitution and illegal drugs, as the reported consumption of those goods and services are 0 in the survey. Thus, we end up having 41 different type of goods.

The household budget survey describes the consumption of the same 43 different consumption goods categories by approximately 2200 representatively selected households. The consumption data is combined with disposable income data.[5]

From the table ENE2HA we obtain data on households energy consumption, measured in GJ. We combine with data on carbon-intensities of different energy sources.[6]

2.3 Direct taxes

The direct carbon tax payments from households in quintile i are calculated from the following formula,

$$Tax_i^{direct} = \frac{CO_2^{tra} \cdot \tau}{H} \cdot \frac{c_i^{tra}}{c_{avg}^{tra}} + \frac{CO_2^{heat} \cdot \tau}{H} \cdot \frac{c_i^{heat}}{c_{avg}^{heat}} \tag{2.1}$$

where CO_2^{tra} and CO_2^{heat} denote total carbon emissions from Transport and Heating and Electricity, respectively, and τ is the carbon tax rate. The nominator in the fractions in these terms reflect the total tax revenue from households. H is the number of households in Denmark in 2016, which we obtain from table FAM55N from Statistics Denmark (2020) . Thus, the fraction $\frac{CO_2^{tra} \cdot \tau}{H}$ is the average household carbon tax payment from transport. The fraction $\frac{c_i^{tra}}{c_{avg}^{tra}}$ indicates the ratio of consumption of transport of households in quintile i to average transportation consumption.

We calculate carbon emissions from households for different energy types

$$CO_{2,e} = \sum_{e=1}^{46} E_e \cdot \frac{CO_2}{E_e} \tag{2.2}$$

where $CO_{2,e}$ denotes total carbon emissions from Danish households in tons of a given energy type. E_e is the consumption of energy type $e \in (1, 2, 3, ..., 46)$ measured in GJ, from table ENE2HA. $\frac{CO_2}{E_e}$ denotes the carbon-intensity of energy type e, measured in tons CO2/GJ.

From this calculation of household emissions decomposed on energy types, we ascribe all of the transport fuel-related energy use to emissions from transport,

[5] Consumption and income data was kindly provided to us by Sune Caspersen from Arbejderbevægelsens Erhvervsråd.

[6] Data on carbon intensities was collected and kindly provided to by Sune Caspersen as well.

and the rest to emissions from heating. The direct household carbon emissions are presented in table 1.

Table 1: Direct household emissions

Total CO_2	11.126 Mt
Transport	6.589 Mt
Heating and electricity	4.537 Mt

Notes: Total household emissions are calculated as described in (2.2). Emissions from transport fuels are ascribed to transport, the rest is ascribed to heating.

2.4 Indirect taxes

We calculate the indirect carbon tax payment by household i, where $i \in (1, ..., 5)$ denotes income groups divided into quintiles:

$$Tax_i^{indirect} = T(I - A)^{-1} Cc_i, \tag{2.3}$$

where T is a (1×117) vector of taxes paid per unit of Danish production in nominal prices. T is constructed by multiplying data on carbon emissions for the 117 sectors with a carbon tax rate τ. Then we divide by the total production Y_k in that sector to get the carbon tax payment for each production unit, where $k \in (1, ..., 117)$. Thus, we calculate each entry in T according to the formula:

$$T_k = \frac{CO2_k}{Y_k} \cdot \tau_k \tag{2.4}$$

$(I - A)^{-1}$ is the symmetric Leontief matrix, which measures the input-output intensity between each of the 117 sectors of the economy. I is the identity matrix and A is the intensity matrix calculated from the (117×117) input-output table by dividing each output-column by the total production in each sector. C is a (117×41) matrix describing the composition of the consumption commodities for 41 different product types. That is, the share of consumption in each product category that comes from production in each sector. We proceed assuming that the carbon intensity is identical for goods produced domestically and abroad (Fremstad and Paul, 2019), since we can not distinguish imported and domestically produced goods in the consumer survey data. To get a final measure of the total carbon tax payment for each household from purchases of goods and services, we multiply with c_i, which is a (41×5) consumption matrix, containing how much each household spends on different consumption goods.

2.5 Analysis

We calculate the distributional impact of two different tax schemes: First we consider a realistic tax scheme that seeks to capture the distributional impact of the current carbon tax in Denmark. Then we consider a tax reform, where all emissions are taxed with a flat rate of 1000 DKK/ton carbon emitted.

Table 2: Calculation of the realistic carbon tax

	Energy taxes paid (mDKK)	Share of energy taxes	Carbon taxes paid (mDKK)
Total	45673	1	3577
Households	25236	0.55	1976
Industries	20437	0.45	1601

Notes: Energy taxes are taken from Statistics Denmark, table MRS1. Total carbon taxes are taken from table MREG21. Carbon taxes paid from households and industries are then calculated as the share of energy taxes times total carbon taxes.

2.5.1 Realistic tax scheme

To calculate the actual carbon tax for different industries in Denmark, we take as starting point the total carbon tax revenue in Denmark, which in 2016 was 3.58 bn. DKK according to Statistics Denmark (2020), table MREG21. The carbon tax is linked to the consumption of fossil fuels, see Danish Ministry of Taxation (2018). For example, gasoline is subject to a carbon tax of 0.42 DKK/litre. Furthermore, these taxes are subject to a range of exemptions.[7] Thus, to calculate the direct and indirect tax burden on households, we assume that the carbon tax is distributed between households and industries the same way as all energy taxes are, as we only have access to data on energy taxes on the industry and household level. It seems a fair assumption, since carbon taxes are linked to the consumption of fossil fuels, which are also subject to other energy taxes.

As can bee seen from Table 2, we assume that households pay 55 pct. of carbon taxes, corresponding to 1.98 bn. DKK, and industries the rest, corresponding to 1.60 bn. DKK. We then calculate direct taxes on households by altering equation (2.1), such that

$$Tax_i^{direct} = \frac{Tax_{rev}^{trans}}{H} \cdot \frac{c_i^{tra}}{c_{avg}^{tra}} + \frac{Tax_{rev}^{heat}}{H} \cdot \frac{c_i^{heat}}{c_{avg}^{heat}}, \tag{2.5}$$

where $Tax_{rev}^{trans}$is calculated as the share of total carbon emissions stemming from transport, multiplied by total carbon emissions from households, as in section 2.3. Tax_{rev}^{heat} is calculated as the rest of the 1.97 bn. DKK carbon tax revenue paid directly by households.

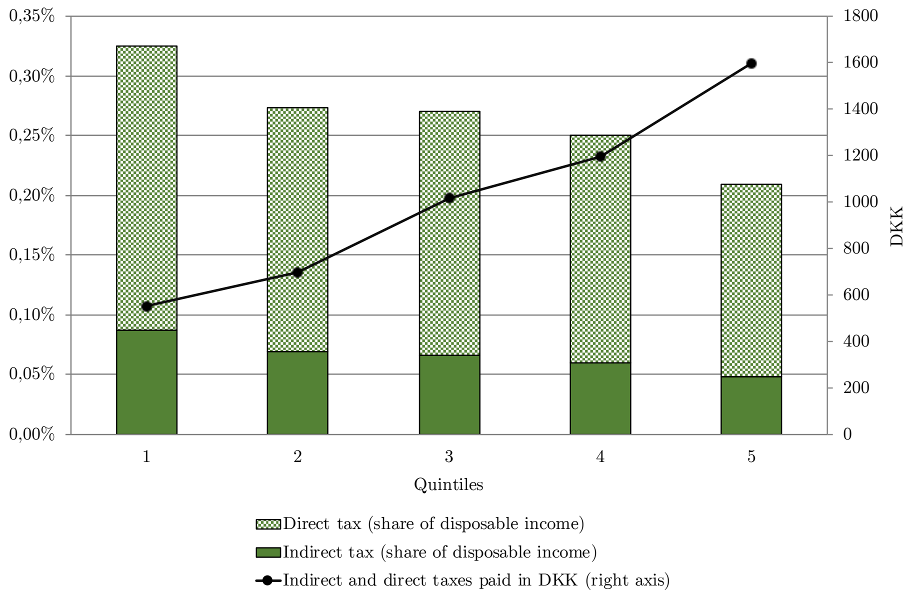
To calculate the carbon taxes per unit of production, we alter equation (2.4) such that each entry in the (1×117) vector T is calculated as

$$T_k = \frac{Tax_{rev}^k}{Y_k} \tag{2.6}$$

with industry $k = 1, 2, ..., 117$ and Tax_{rev}^i denoting the calculated tax revenue for industry k, based on its share of energy tax revenue. Then, indirect taxes are calculated as in equation (2.3).

[7]See PWC: Guide to CO2-taxes

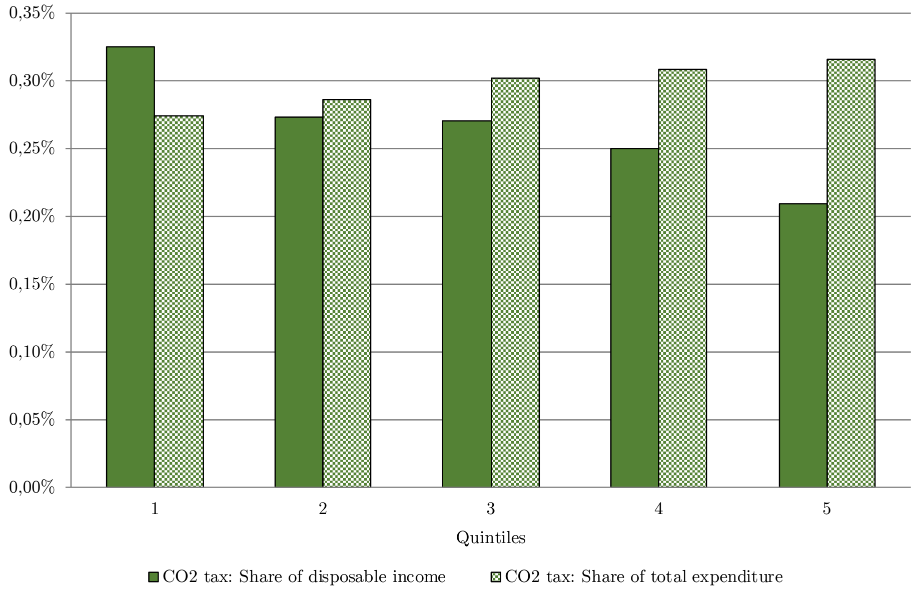
Figure 1: Direct and indirect tax payments by income deciles



2.5.2 Results

The distributional impact of the carbon tax in Denmark can be examined by looking at tax payments as a share of disposable income. Using disposable income as a base for measuring distributional effects is based on the fact that disposable income indicates consumption possibilities in the present and near-future. Thus, the regressivity measured can be thought of as the 'short-run'-regressivity, see Figure 1. We see that tax payments are increasing in nominal terms across income quintiles, but decreasing as a percentage of disposable income, indicating a regressive tax. We also note that approximately 3/4 of total carbon taxes are paid directly by households, and 1/4 indirectly through taxation of industries. The lowest quintile pays 553 DKK in carbon taxes, while the highest quintile pays 1598 DKK. It may not be preferable to use annual disposable income as the denominator when considering regressivity, for two reasons (Wier et al., 2005). First, the tax is essentially a consumption tax, making total consumption a relevant denominator. Second, households are often assumed to smooth consumption over time, and we indeed see that the lowest quintile has higher total expenditure than disposable income, thus negative savings. As households tend to earn most during middle age, the lower quintiles may be comprised of students and retirees, but may have a higher lifetime income. Thus, using expenditure as the denominator may be a better approximation for lifetime income of the different quintiles. Measuring regressivity of a tax relative to expenditure may

Figure 2: Total carbon tax payments, share of income and expenditure



Notes: Total carbon tax payments are the sum of direct and indirect tax payments.

therefore be more indicative of the long-run regressivity (Caspersen, 2020).

We see from Figure 2 that the Danish carbon tax distribution is actually slightly progressive across expenditure quintiles. The lowest quintile pays .27 pct. of total expenditure, while the highest quintile pays .32 pct. of total expenditure. It is a general result of the literature that carbon taxes are less regressive when total expenditure is used as the base (Wier et al., 2005).

2.5.3 Tax reform

In this section, we analyze a tax reform where all Danish carbon emissions are taxed at a rate of 1000 DKK/ton. The Danish Climate Council (2020) has proposed a carbon tax gradually increasing to 1500 DKK/ton in 2030, Kraka (2020) has proposed a tax of 1250 DKK/ton, and the Danish Economic Council has also spoken in favor of a carbon tax.[8] We choose to set our tax rate to 1000 DKK, as it is a nice, round number, and also closer to the level of Sweden and Switzerland, who have the highest carbon taxes in Europe (Klenert et al., 2018a). We choose not to set it as high as 1500 DKK as there already exist a number of energy taxes in Denmark. In the tax proposals of Danish Climate Council (2020) and Kraka (2020) a reduction of these energy taxes are included. Thus imposing a 1500 DKK tax on

[8]Vismænd ser CO2-afgifter som den rigtige vej, Børsen

top of energy taxes would surely overestimate the impact of a potential carbon tax reform in Denmark.

Implementing the tax reform in our input-output model simply corresponds to setting $\tau = 1000$ DKK/ton in sections 2.3 and 2.4.

2.5.4 Results

In the realistic case, average carbon taxes were 41 DKK/ton.[9] Now, as we impose a 1000 DKK/ton tax, the impact on consumers rises, unsurprisingly. The lowest quintile will pay roughly 8906 DKK in carbon taxes yearly, while the highest quintile will pay 19906 DKK. From Figure 3 we see that the 1000 DKK carbon tax is more steeply regressive compared to the current Danish carbon tax. We also note that indirect taxes now account for the lion's share of the tax burden on the consumers, with direct taxes being relatively small. This is due to the fact that in the realistic tax scheme, households pay 55 pct. of total carbon taxes while emitting less than 10 pct. of total emissions. In this tax scheme, the polluter pays-principle applies, and everyone are taxed according to their emissions at the 1000 DKK/ton-rate, meaning that industries will pay significantly more. The tax burden is then passed onto consumers.

Using total expenditure as the base for measuring regressivity, we still see a substantial reduction in regressivity, however, the incidence is still slightly regressive, see Figure 4.

We conclude that carbon taxes are clearly regressive when using disposable income as the base, but less so when using total expenditure. This means that in the short run, carbon taxes will clearly be regressive, but only slightly over the life cycle.

[9] Calculated as total revenue (3.5 bn DKK) divided by total carbon emissions, including emissions from international shipping and air transport. If we exclude those emissions, the average carbon tax is 71 DKK/ton.

Figure 3: Direct and indirect tax payments by income deciles

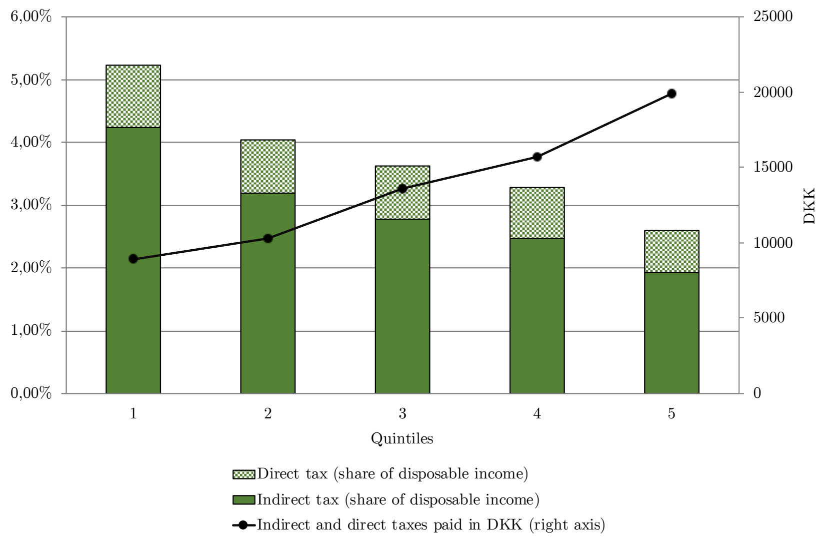
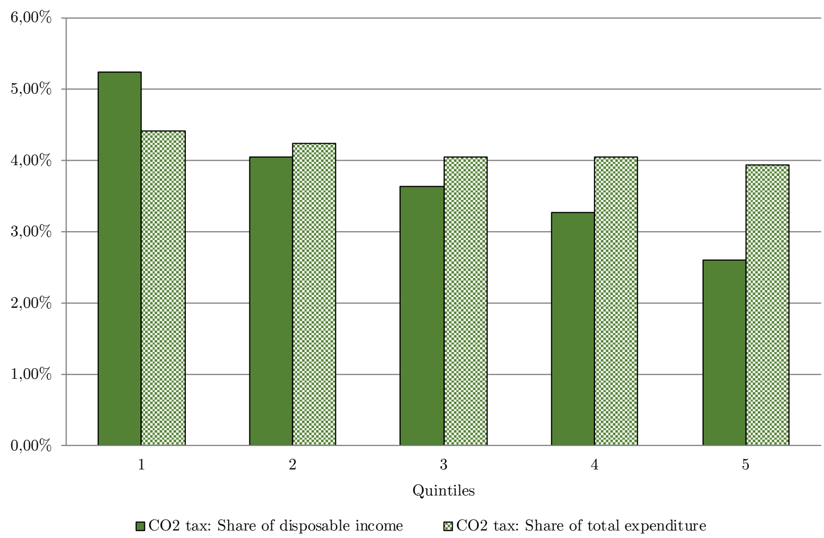


Figure 4: Total carbon tax payments, share of income and expenditure



Notes: Total carbon tax payments are the sum of direct and indirect tax payments. The figures show the impact of 1000 DKK/ton carbon tax.

2.6 Limitations of the input-output model

It is important to note that the input-output analysis has some limitations. We implicitly assume, as Wier et al. (2005), that carbon tax levies are fully transmitted into prices. This is not a hugely restrictive assumption in our analysis of the realistic tax scheme, where firms and consumers have already responded to the carbon tax, as Denmark started imposing those in 1993 (Wier et al., 2005, p. 243). However, the assumption is somewhat critical in the case of the 1000 DKK/ton tax, which is a quite significant tax increase. Producers and consumers will be expected to substitute towards less polluting goods, which is the purpose of the tax. Thus, there is most likely an upward bias in our estimates of the impact of a 1000 DKK/ton carbon tax, as we essentially assume that no substitution is made at neither the firm or consumer level. We will make an effort to account for these behavioral effects by analyzing a tax scheme by simulating a general model of the Danish economy in section 3.

Accounting for differences in carbon intensities between domestically produced and foreign goods would require a large amount of data on foreignly produced goods and a Leontief-matrix for the entire world economy, which is outside the scope of this paper.

3 A general equilibrium model

In this section we will analyze the implementation of a 1000 DKK/ton carbon tax reform by applying a general equilibrium model to the Danish economy. The purpose is to measure the distributional effects of the tax, where we will be able to take behavioral effects of firms and households into account. Further, the purpose is to analyze different redistribution schemes to compensate for the regressivity of the carbon tax.

Our model is a 41-sector general equilibrium model with Mirleesian income taxation, an extension of the two-sector model in Klenert et al. (2018b). Our 41 sectors correspond to the 43 consumption categories in the Danish Household Budget Survey, less the categories prostitution and illegal drugs where consumption is 0 according to the survey. Furthermore, imposing environmental taxes on these sectors could prove difficult. We model 5 households which are differentiated by their productivity.

3.1 Firms

There are 41 firms in our model, each producing a unique good denoted $g \in (1, ..., 41)$. There are two inputs to production, 'labor', denoted T_g, which is bought from the households, and carbon emissions, denoted Z_g. T_g as production input should be interpreted as the fixed amount of both labor, capital and other traditional inputs. For simplicity we do not differentiate between these production inputs, as our main interest is the impact of carbon taxation. Thus we refer to the input T_g as labor. Modeling pollution as a production input stems from Copeland and

Taylor (1994), where output is given by the CES production function $F_g(T_g, Z_g)$:

$$F_g(T_g, Z_g) = \begin{cases} (\epsilon_g T_g^r + (1-\epsilon_g) Z_g^r)^{(\frac{1}{r})}, & \text{if } Z_g \leq xT_g \\ 0, & \text{if } Z_g > xT_g, \end{cases} \tag{3.1}$$

where $\sigma = 1/(1-r)$ is the elasticity of substitution between labor and emissions, and ϵ_g is labor share parameter in sector g. The additional inequality with $x > 0$ in the production function implies that firms will allocate some labor to carbon emissions abatement, following Appendix A of Copeland and Taylor (1994). The intuition is that the maximum amount of carbon emissions is where firms do not abate at all, and firms cannot substitute towards the carbon emissions input above that level. This means that pollution and output is bounded above for a given labor input. The firms sell their good at price p_g. It pays w to labor T_g and τ_P to pollution Z_g, which is a per unit tax collected by the government. Profit maximisation yields

$$w = \frac{\partial F_g(T_g, Z_g)}{\partial T_g} \tag{3.2}$$

and

$$\tau_P = \frac{\partial F_g(T_g, Z_g)}{\partial Z_g}. \tag{3.3}$$

The details of the first order conditions of firms are given in the appendix, section 8.1. It should be noted that $\tau_P = 0$ is sub-optimal, as firm will always conduct some abatement, as a consequence of the inequality in (3.1). Therefore, τ_P will be positive even as carbon emissions do not affect social welfare. Total carbon emissions in the economy are given by

$$Z = \sum_{g=1}^{41} Z_g. \tag{3.4}$$

3.2 Households

Households are distinguished by their productivity ϕ_i, where $i \in (1, 2, .., 5)$. They each have a time endowment T, which they can spend on leisure l_i or labor to production. Each household has after tax income I_i, where $\tau_{w,i}$ is the tax on income for each household:

$$I_i = (1 - \tau_{w,i})\phi_i w(T - l_i). \tag{3.5}$$

Households maximize a Stone-Geary utility function, which models non-homothetic preferences, with $X_{g,0}$ denoting a minimal level of consumption of good g. Note that household utility is not affected by carbon pollution, in contrast to Klenert et al. (2018b).[10] We consider this a realistic utility function in a Danish setting, as the

[10]In Klenert et al. (2018b) environmental preferences are modeled as $(E_0 - \xi(Z)^\theta)$, where E_0 is a baseline level of pollution, ξ is an environmental preference parameter and θ is an environmental damage parameter. The optimal pollution tax is found by adding this function to the utility maximisation problem.

externalities of carbon emissions are global and Denmark will, at least not to a first approximation, be seriously exposed to damages therefrom.

The utility function is given by

$$V_i = U(X_i, l_i) = \prod_{g=1}^{41}[(X_{g,i} - X_{g,0})^{\alpha_g}]l_i^{\gamma}, \tag{3.6}$$

where γ is the leisure utility share and α_g is the consumption utility share for consumption of good g. $\sum_g \alpha_g < 1$ reflects decreasing marginal utility to consumption. Note that marginal utility of consumption of good X_g tends to infinity as $X_g \to X_{g,0}$ Each household has the following budget constraint, where L denotes a uniform lump-sum transfer:

$$\sum_{g=1}^{41}(p_g X_{g,i}) = I_i + L. \tag{3.7}$$

Utility maximization with respect to the budget constraint yields the following 40 first order conditions.

$$(\frac{\partial U_i}{\partial X_{g,i}})/(\frac{\partial U_i}{\partial X_{g+1,i}}) = \frac{p_g}{p_{g+1}}, \quad g \in (1, 2, ..., 40) \tag{3.8}$$

as well as a first order condition for good 41 and leisure

$$(\frac{\partial U_i}{\partial X_{41,i}})/(\frac{\partial U_i}{\partial l_i}) = \frac{p_{41}}{(1 - \tau_{w,i})\phi_i w}. \tag{3.9}$$

An elaboration of the households' FOC's can be found in section 8.1.

3.3 Government

The Government acts as a Stackelberg leader, where firms and households take the government's actions as given and the government anticipates all future actions of firms and households. We let the government impose a fixed tax on pollution, τ_P, which we calibrate such that it corresponds to a 1000 DKK uniform carbon tax (see section 3.5.1). The government maximizes social welfare W, defined as the sum of the utilities of agents:

$$W = \sum_{i=1}^{5} V(X_i, l_i). \tag{3.10}$$

Income taxes and carbon taxes finance government spending and lump sum transfers:

$$G + 5L = \sum_{i=1}^{5} \tau_{w,i}\phi_i w(T - l_i) + \tau_P Z. \tag{3.11}$$

The Mirrleesian approach (Mirrlees, 1971) assumes that the government cannot observe the individual agents' productivity levels, making it possible for agents to pretend to have lower productivity than they do. Thus, we apply the following restriction

$$U_i^j \leq U_i \quad \text{for all} \quad j \neq i, \quad U_i^j = U(X_i, T - \frac{I_j}{1 - \tau_{w,j}\phi_i w}), \tag{3.12}$$

where U_i^j is the utility of household i pretending to be household j. When the government sets income taxes, it must take into account both inequality concerns, due to diminishing marginal utility of consumption, and the individual agents' incentive to pretend to be a lower-productivity household.

Finally, we have the general equilibrium for the labor market

$$\sum_{g=1}^{41} T_g = \sum_{i=1}^{5} \phi_i (T - l_i), \tag{3.13}$$

and the general equilibrium for the goods markets

$$p_g \sum_{i=1}^{5} X_{g,i} + \frac{1}{41} G = F_g p_g, \quad g \in (1, 2, ..., 41) \tag{3.14}$$

We follow Klenert et al. (2018b) and make a somewhat unrealistic assumption that the government consumes equal shares of all goods. We set the wage w, that is the price paid to the labor input of production, as the numeraire.

3.4 Calibration to a Danish setting

We calibrate the model to a Danish setting using data from Statistics Denmark (2018).[11] We measure household i's productivity level as the share of total income of quintile $i \in (1, 2, ..., 5)$ in Denmark. We use income tax payments for each quintile to calculate the income tax rate for each household in the model, which we denote the pre-calibrated tax rates $\tau_{w,i}^0$. The productivity levels and income tax rates for each quintile are given in Table 3.

Table 3: Calibration of model parameters

Quintile i	1	2	3	4	5
ϕ_i	0.055	0.118	0.167	0.229	0.431
$\tau_{w,i}^0$	0.200	0.244	0.279	0.308	0.360

Government spending in Denmark in 2016 was 24.9 pct. of GDP.[12] Government spending in the model is set at $G = 5$, corresponding to roughly 25 pct. of the GDP in our baseline model specification. This and and other parameter values are listed in Table 4. The elasticity of substitution, σ, is set at 0.5, which is somewhere between the elasticity of substitution in a Cobb-Douglas production function (where $\sigma = 1$)

[11] Statistics Denmark were so kind to send us the data used in this article.
[12] See table NAN1 in Statistics Denmark (2020).

and Leontief production (where $\sigma = 0$). Thus, in our model, carbon emissions and labor are imperfect substitutes. We conduct a sensitivity analysis of σ in section 5.1. The leisure share in utility, γ, and the abatement threshold, x, follow the parameter values in Klenert et al. (2018b).

Table 4: Calibration of model parameters

Parameter	Description	Value
γ	Leisure share in utility	0.2
σ	Elasticity of subs. between labour and pollution	0.5
G	Government spending	5
x	Abatement threshold	1

To calibrate α_g we set it equal to the share of each good in total Danish consumption, weighted such that the sum of the shares equals 0.8. Thus, with $\gamma = 0.2$ the components in the utility function sum to 1.

To calibrate ϵ_g we have used a similar method as for calculating the indirect carbon taxes in the input-output model by applying the following equation:

$$D(I - A)^{-1}C = \epsilon, \tag{3.15}$$

where D is a (1×117) matrix with carbon tax payments measured as the carbon intensity for each sector times the cost of carbon emission, inspired by the calibration in Fullerton and Heutel (2011). In Denmark there exists a modest carbon tax of around 170 DKK/ton (Danish Climate Council, 2018). The idea is that firms will have taken the cost of carbon into account, and shifted away from carbon emissions in production until the marginal cost of doing so was equal to the tax. Thus the current emission level of a production sector is considered optimal given a 170 DKK carbon tax. C is the (117×41) matrix as described in the section on indirect carbon taxes 2.4. ϵ is a (1×41) vector with carbon emissions factor share parameters for the production of the 41 goods.

In Table 5 we show the calibrated parameter values for α_g and ϵ_g as well as $X_{0,g}$ for 10 selected goods, which are all among the 15 most consumed. For most goods, we assume that no minimum consumption is required in the utility function. However, for food, water, electricity, gas and heating and transport services, which all have a relatively high ϵ_g and which we value as somewhat essential goods, we set a positive $X_{0,g}$. We consider these as conservative values. It could be discussed whether other consumption categories should have a minimum consumption level as well. We conduct a sensitivity analysis of minimum levels of consumption in section 5.2.

3.5 Solving the model

In our baseline simulation of the model, we let the government set τ_P as they see fit. We let the government balance the budget by adjusting lump-sum transfers, as the income tax revenue is larger than the government spending requirement. As Klenert

Table 5: Parameters for selected goods

g	Description	α_g	ϵ_g	$X_{0,g}$
1	Food	0.065	0.989	0.05
5	Clothing	0.021	0.997	0.00
7	Rent	0.087	0.999	0.00
8	Calculated rent of own dwelling	0.139	0.999	0.00
10	Water	0.019	0.990	0.01
11	Electricity, gas and heating	0.029	0.962	0.02
22	Personal transport	0.041	0.994	0.00
23	Transport services	0.019	0.989	0.01
34	Restaurants and cafés	0.046	0.994	0.00
40	Financial services	0.045	0.999	0.00

et al. (2018b), we maximize social welfare given by equation (3.10) with respect to the government's budget (3.11), the Mirrleesian incentive constraints (3.12), resource constraints (3.13) and (3.14) and the first order conditions of firms and households (3.3) (3.4) and (3.7), (3.8), (3.9) by varying τ_P and L. The variables T_g, Z_g, p_g, l_i and $X_{g,i}$ are determined for $g = 1, 2, ..., 41$ and $i = 1, 2, ..., 5$. We use algebraic modelling software GAMS and nonlinear programming algorithm CONOPT[13] to solve our model numerically.

3.5.1 Calibration of the carbon tax

In our input-output-analysis, we concluded that the introduction of a 1000 DKK/ton carbon tax would mean that the poorest consumers pay 4.4 pct. of their expenditure in carbon tax payments. We calibrate τ_P such that the resulting price changes reflect a similar change in percentage of total consumption in the model for the poorest household. To do this calibration, we lower the input factor of substitution to $\sigma = 0.1$ and the preference for leisure $\gamma = 0.001$, to more closely mimic the input-output model, where there is no substitution between work/leisure or between production inputs. We find that setting the pollution tax to $\tau_P = 0.3$ results in price increases such that the poorest agents pay 4.4 pct. more for their pre-tax reform basket of goods. We interpret this tax reform as being comparable with a 1000 DKK carbon tax in Denmark. It should be noted, that in the baseline scenario before the tax reform, the carbon tax $\tau_p = 0.04$ is small but positive. This is a consequence of the assumption that firms allocate some of their labor to pollution abatement, see eq. (3.1).

3.6 A carbon tax reform and recycling schemes

We impose a carbon tax reform consisting of a tax on the carbon emissions input in production and consider different recycling schemes for the tax revenue. The tax is imposed exogenously on producers, which is different to other economic environ-

[13] See `https://www.gams.com/latest/docs/S_CONOPT.html`

mental tax models (here amongst Klenert et al. (2018b)) that aim at determining an optimal environmental tax given societal preferences. Our focus is on the distributional effects of a carbon tax and not weather the tax is optimal in the sense of reflecting social costs.

Increasing the carbon tax τ_P will result in higher tax revenue for the government. The government has a minimum required fixed spending in the model, thus for the government's budget to clear and resource constraints to hold, the extra revenue must either be spent on goods or redistributed. We analyze 4 different tax reforms, 1) a carbon tax reform with no redistribution, 2) redistribution through differentiated income tax cuts, 3) redistribution through uniform tax cuts and 4) redistribution through lump-sum transfers. We do not consider combinations of lump-sum transfers and tax cuts, as they yield the same results as differentiated tax cuts alone.

3.6.1 No redistribution

We simulate a tax reform scenario, where the government cannot redistribute the revenue and must spend it on non-utility yielding goods and services. Thus, we move away from the assumption of fixed government spending, and instead set a lower bound such that $G \geq 5$. Through this tax reform, we estimate the distributional impact of the tax reform without redistribution to have a case comparable with that of section 2. Where the input-output analysis measures the distributional effects on households' expenditure with no possibility to substitute away from the tax, representing the short run, the general equilibrium model simulation measures distributional effects in the longer run, where firms can substitute between production inputs and households can substitute between consumption of different goods and between labor and leisure.

In this scenario, we alter equation (3.11) such that

$$G + 5L = \sum_{i=1}^{5} \tau_{w,i}\phi_i w(T - l_i) + \tau_P Z, \tag{3.16}$$

where $G = 5 + G_{res}$. G_{res} is the residual spending of extra tax income from the fixed τ_P. Lump sum transfers are fixed at the level from the baseline calibration $L = 0.233$. Agents optimize their leisure-labor decisions and consumption given the pre-calibrated income tax rates (see 3.4) and lump sum transfers, and firms optimize production given the carbon tax and labor inputs.

3.6.2 Differentiated tax cuts

The differentiated tax cuts are modeled as below, where $\tau_{w,i}^0$ denotes pre-calibrated income tax rates and $\tau_{w,i} \leq 0$ is the income tax cuts, differentiated by households. The households' budget constraints will change according to the change in tax rate, which will affect the household first order conditions. This is outlined in appendix (8). The government now maximizes the following problem:

$$\max_{\tau_{w,i}} W \text{ s.t. Eq. (3.7) and } G + 5L = \sum_{i=1}^{n} (\tau_{w,i}^0 + \tau_{w,i})\phi_i w(T - l_i) + \tau_P Z \tag{3.17}$$

L is fixed at the level from the baseline calibration.

3.6.3 Uniform tax cuts

This recycling scheme with uniform tax cuts is modeled as above, but wit $\tau_{w,i} = \tau_w \leq 0$. L is still fixed at the level from the baseline calibration.

3.6.4 Lump sum transfers

This recycling scheme allows for lump-sum transfers of uniform size L, but no tax cuts. One way to transfer lump-sums to households in a real life setting is through a cut in the total amount of taxes payed by households. This is the case of the green check imposed by the Danish government in 2010 to compensate low income households after a tax reform that increased a number of energy and environmental taxes Danish Ministry of Taxation (2019). The green check is income-dependent (it is not given to high income households), whereas transfers in this model are given to all households. Again, households' first order conditions change, which is outlined in 8. The government solves the following problem:

$$\max_{L} W \text{ s.t. Eq. 3.7 and } G + 5L = \sum_{i=1}^{5} \tau_{w,i}^{0} \phi_i w(T - l_i) + \tau_P Z \tag{3.18}$$

4 Results

In this section, we present the results of our general equilibrium model analysis. First, we integrate our model with our input-output analysis, to analyze the short run and long run effects of a carbon tax. Then we show how our model can lead to a double dividend of redistribution.

4.1 The short and long run impact of a carbon tax

To analyze the short run and long run impact of a 1000 DKK carbon tax, we combine our input-output results with our general equilibrium model results. We take the changes in quantities consumed in the model as a result of the tax reform with no redistribution ($\%\Delta X_{g,i}$), and multiply those onto the empirical consumption from section 2, which we call short run consumption, $c_{SR,g,i}$, to obtain the long-run consumption

$$c_{LR,g,i} = c_{SR,g,i}(1 + \%\Delta X_{g,i}), \tag{4.1}$$

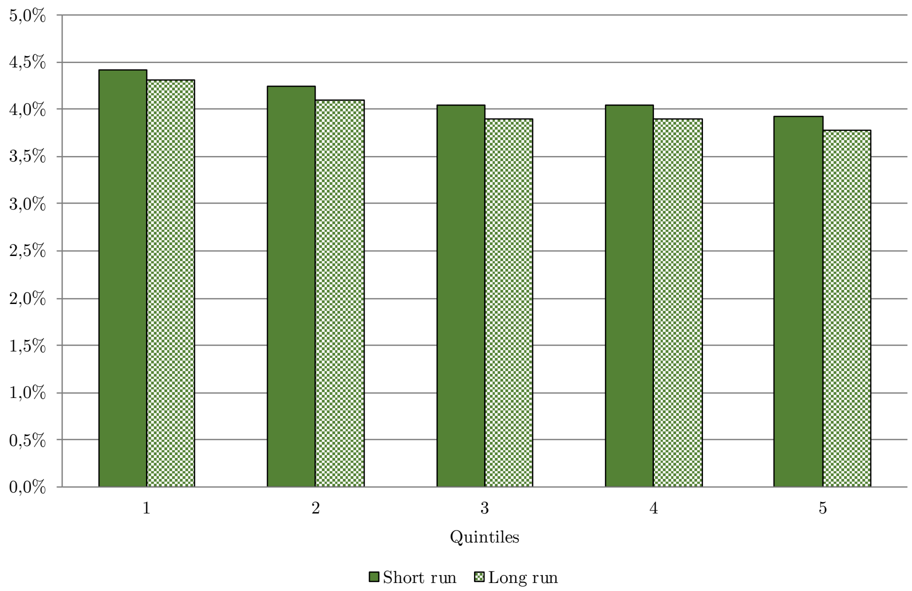
where i denotes the representative agent for quintiles 1 to 5, and g denotes the 41 consumption goods. Then, direct and indirect taxes are calculated exactly as in section 2, but with long-run quantities. We calculate the indirect tax payments in the long run by replacing c_i with $c_{LR,i}$ in (2.3). Direct taxes are calculated by replacing c_i^{tra} and c_i^{heat} as with their long-run equivalents. The average consumption quantities, c_{avg}^{tra} and c_{avg}^{heat} change accordingly.

Total real expenditure falls in our model for all quintiles. Thus, we similarly compute long-run total expenditure as

$$c_{LR,i}^{Tot} = c_{SR,i}^{Tot}(1 + \%\Delta X_i^{Tot}), \tag{4.2}$$

where superscript *tot* denotes the sum of consumption of all goods. In Figure 5, total tax payments are denominated with total expenditure in the short and long run, respectively.

Figure 5: Carbon tax payments in the short run and long run (w/ substitution), as share of total pre-tax reform expenditure.



Notes: Total carbon tax payments are the sum of direct and indirect tax payments.

Both total tax payments and total expenditure fall in the long run for all quintiles. Tax payments fall a little more than total expenditure, as agents substitute towards less polluting goods, and thus the impact as share of total expenditure falls. The overall distribution of the tax has roughly the same profile, but is a little bit more regressive, as poorer agents do not have the same possibilities for substitution as richer agents, due to the minimum consumption requirements for certain polluting goods. In Table 6, the impact on selected variables in our model are described. Real GDP falls 2 pct., but total pollution falls a rather significant 64 pct, as firms substitute towards labor input. Government spending increases as total tax revenue rises.

Table 6: Change in variables from a tax reform with no redistribution

Variable	Before tax reform	After tax reform	Change
Real GDP	18.86	18.49	-2%
Agg. emission intensity	0.31	0.11	-64%
Agg. labor intensity	1.01	1.03	2%
Gov. spending (nominal)	5	5.41	8%
Real total consumption	13.96	13.40	-4%

Notes: Aggregate emission intensity is calcualted as $\frac{\sum_g^{41}(Z_g)}{Real\ GDP}$ and aggregate labor intensity is calculated as $\frac{\sum_g^{41}(T_g)}{Real\ GDP}$.

4.2 Different redistribution schemes

In this subsection we consider whether a carbon tax can give rise to a double dividend of redistribution - that is both reduce carbon emissions and inequality. We impose a carbon tax of $\tau_P = 0.3$, which roughly corresponds to a 1000 DKK carbon tax, following section 3.5.1. The overall conclusion is that the imposure of a carbon tax in itself will increase inequality, but after redistribution of the revenue, inequality will decrease.

To evaluate the distributional effects of each tax scheme we calculate the gini-coefficient of utility as a measure of equity for each scheme. Thus we take into account the utility of leisure and not just consumption.

We consider 5 cases, 1 before a carbon tax reform and 4 different redistribution schemes after the tax reform, which are described in section 3.6.

From panel (b) of Figure 6 we see that the Gini coefficient is slightly increasing after imposing the carbon tax. This is due to poorer households not being to able substitute less polluting goods as easily as richer households, due to the non-homothetic Stone-Geary preferences. However, as the revenue is distributed back to households either through differentiated tax cuts or lump-sum transfers, inequality declines. With uniform tax cuts, inequality rises.

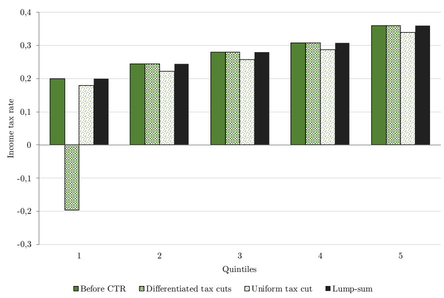
From panel (a), we see that when we allow for differentiated tax cuts, only the lowest quintile gets a tax cut, such that the tax rate turns negative. The other quintiles do not receive a tax reduction. In fact it would be optimal in our model setting to increase income taxes for all other quintiles, but we have restricted the tax reform such that income tax rates cannot increase.

From panel (c), we see that after the carbon tax reform a larger share of government income comes from the carbon tax. When we do not allow for redistribution of the tax revenue, government spending (plus lump-sum transfers) naturally increases. Our results are very similar to those of (Klenert et al., 2018b, section 5), except on one point: We do not observe an increase in GDP after the carbon tax reform. They ascribe their increase in GDP after their tax reform to the pre-existing tax system being sub-optimal. However, we note that in this model, there is a trade-off between equality and efficiency: To increase GDP, high-income households should not be deterred too much from working through high income taxes, as they can substitute towards leisure. Furthermore, the Mirrlees incentive compatibility constraint described in 3.12 puts limits to the restructuring of the tax schedule. Total pollution falls 64 pct. after the carbon tax reform in all redistribution schemes.

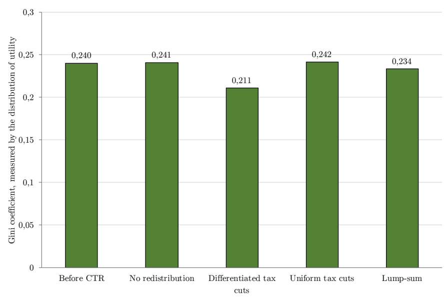
We conclude that it is possible in our model to decrease both carbon emissions and inequality, thus obtaining a double dividend of redistribution. However, we do not obtain a triple dividend (Heerden et al., 2006) as Klenert et al. (2018b) do, as GDP in our model falls.

Figure 6: Effects of the carbon tax reform

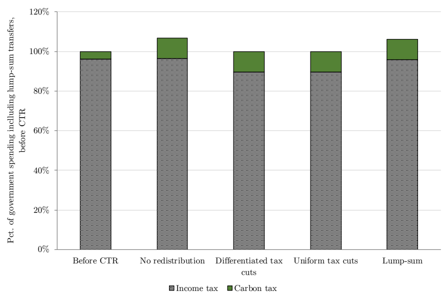
(a) Income tax



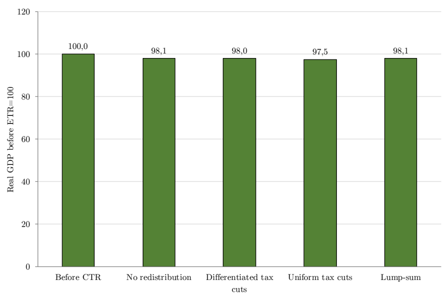
(b) Gini coefficient



(c) Goverment spending composition



(d) GDP



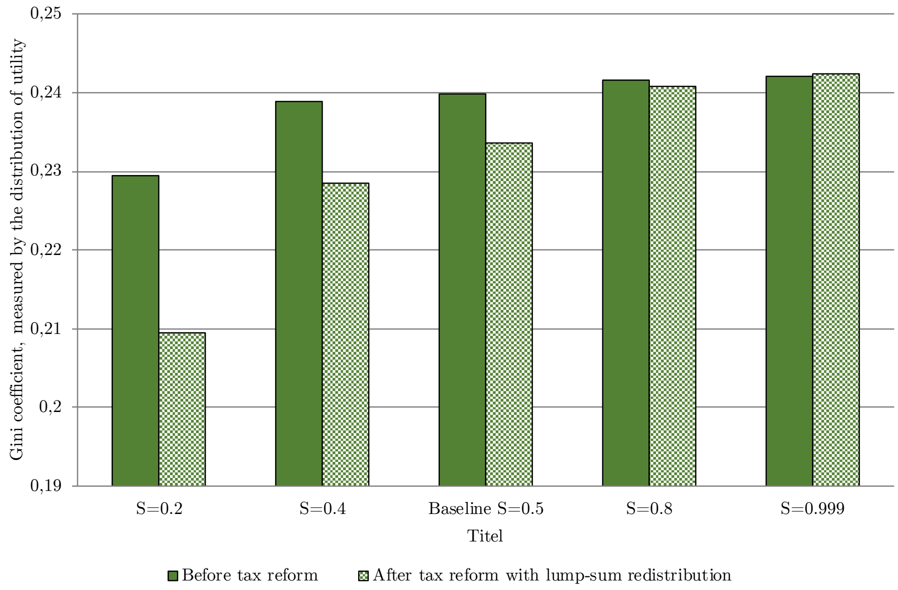
5 Robustness

In this section, we carry out robustness checks of selected parameters in the model.

5.1 The role of the elasticity of substitution

In this section we will explore the role of different values of the elasticity of substitution between the inputs in production. To evaluate the role of σ we calculate the Gini coefficient before and after an environmental tax reform for different values of σ between 0 and 1. We use the tax scheme with lump-sum transfers as our 'preferred' redistribution scheme. When σ increases, the Gini coefficient increases as illustrated in Figure 7. This is because a higher elasticity leads firms to substitute towards labor, leading to households reducing leisure. Since households have different labor productivity, richer households will benefit relatively more from this shift in time allocation, which will increase inequality. Furthermore, the difference in inequality after a tax reform with redistribution through lump-sum transfers will decrease as σ increases. This is because the higher the σ, the less inelastic is the demand for carbon emissions input, which means less carbon tax revenue available for redistribution. Thus, when σ is close 1, the distributional effects of carbon tax reform are small.

Figure 7: Robustness check of the elasticity of substitution



Notes: S indicates the level of σ.

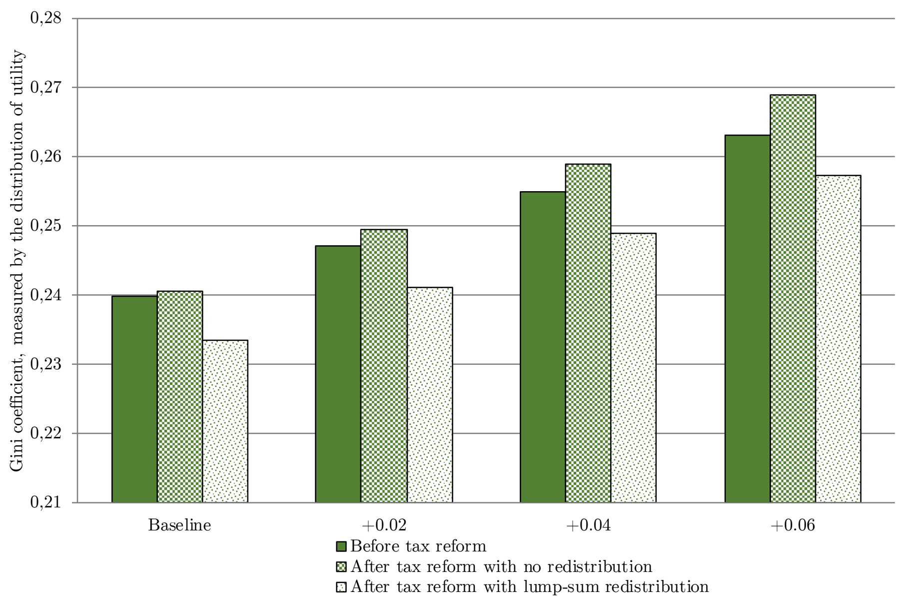
5.2 The role of non-homothetic preferences

In this model we have assumed non-homothetic preferences by imposing a minimum consumption level of certain high carbon-intensive goods: food, water-supply, electricity and heating and transportation. We interpret this as a subsistence level of consumption of the mentioned goods. The assumption of non-homothetic preferences are to a high extent creating the regressivity of a carbon tax (Klenert et al., 2018b), since with homothetic preferences, low income households would just substitute away from carbon-intensive goods. However, it is unrealistic to assume that households can do without some level of food, water, electricity and transportation, to get to work e.g. In this section we examine the role of the size of minimum consumption levels imposed in the model.

In our model calibration we chose reasonably low values of minimum consumption of these good, see Table 5. In Figure 8 we show the effect on inequality when increasing the minimum consumption levels $X_{g,0}$ presented in Table 5 by amounts of 0.02, 0.04 and 0.06 for those 4 goods. In our baseline case before the carbon tax reform, the poorest household have a consumption of food of 0.12 and of electricity of 0.05, for scale. We compare the baseline scenario with a tax reform with no distribution, to illustrate the effect of non-homothetic preferences on regressivity of the carbon tax reform without compensation, and with a tax reform with lump-sum transfers.

As the figure illustrates, higher minimum consumption levels increase inequality in all cases. Changing the minimum consumption levels does not have any impact on the direction of the results: imposing a carbon tax without attempts to compensate will increase inequality, and imposing a carbon and tax redistributing using lump-sum transfers will decrease inequality. However, the magnitude of the results are increasing in the minimum consumption levels. The inequality rises relatively more in the case without redistribution, and inequality falls relatively more, when the revenue is recycled. This is due to the more inelastic demand for these relatively carbon-intensive goods, which both increases the direct distributional impact of the carbon tax, as poorer households cannot substitute away, but also increases the carbon tax revenue available for redistribution.

Figure 8: Robustness check of the minimum consumption levels X_0



Notes: Baseline indicates the levels of $X_{0,g}$ from Table 5. +0.02 indicates a 0.02 increase from this level..

6 Discussion

6.1 Limitations and potential biases

There are several potential biases in our model regarding the analysis of a carbon tax reform in Danish context.

Our model describes a closed economy, which is obviously not the case of the Danish economy. A common concern of opponents of uniform carbon tax on Danish production is that it will cause carbon leakage, where firms move production outside Denmark. Our model cannot account for this, and it isn't possible for consumers to substitute towards cheaper foreign goods. The overall impact of a carbon tax reform in a closed economy, without any border carbon adjustment, the distribution and magnitude impact would most likely be smaller. However, if border carbon adjustment policies are implemented, consumers cannot substitute towards goods produced in economies with less restrictive environmental regulation in that regard, and our model could be interpreted as an approximation of that case.

We model 41 goods and sectors, which is based on the 43 consumption categories in the Danish Budget Survey less prostitution and illegal drugs. We then proceed to assume a single share parameter ϵ_g of the pollution input in the production of all 41 goods. This is of course a simplifying assumption, since each consumption category consists of a large number of different goods and services. This assumption is potentially quite restrictive, as we assume that producers cannot shift their production frontiers. For example, consider the production of electricity and fuel, which is the most carbon-intensive sector in our model. By the end of this century, Danish Energy Agency (2010) expects the lion's share of Danish electricity needs to be covered by renewables, which will decrease the 'input' of carbon emissions in that sector. Furthermore, consumers cannot substitute towards less carbon-intensive goods intra-category. For example in the consumption of food in the model, it is not possible to substitute between beef and vegetables. Overall, substitution possibilities towards less polluting production and consumption is probably underestimated in our model, leading to an upward bias in the distributional impact of a carbon tax reform.

The calibration of levels $X_{g,0}$ lacks empirical basis. While probably few people would oppose the idea that there are certain minimum expenditure thresholds on e.g. food and heating, the exact levels of those could be discussed. We assume some quite conservative threshold levels in our baseline calibration. As we saw in section 5.2, increasing these threshold levels leads to higher level and distributional impacts of a carbon tax reform. Thus, this could be a downward bias in our baseline calibration.

Our modeling of the public sector could also be more elaborate. The assumption that the government spends equal amounts on all goods in the economy is obviously quite unrealistic. The model could be improved by modelling public expenditure to mostly be spend on health, schooling and social services. Furthermore, the tax system is heavily simplified, as we only include income taxes in our model calibration, and thus ignore the VAT as well as other taxes. At the same time, we ignore the significant transfer payments in Denmark, which amounts to almost a quarter of

GDP. We do have some transfers in our model, as we let positive lump sum transfers balance the government budget, but they are of course not a complete description of the Danish system. However, we do not believe that our simplification of the public sector significantly affects our conclusions regarding the distributional impact of a carbon tax reform.

Overall, there are potential biases both upwards and downwards. However, given our quite restrictive assumption on substitution possibilities, we believe that the regressivity of is most likely to suffer from upward bias: A carbon tax reform in Denmark will most likely not be any more regressive than it is in our analysis.

7 Conclusion

We analyze the impact of a carbon tax reform in Denmark both empirically and theoretically. First, we consider the distribution of the tax incidence of both the current carbon tax and a 1000 DKK tax through an input-output model for the Danish economy, inspired by Wier et al. (2005). We find that the distribution of the tax incidence is highly regressive as a share of disposable income, but less so as a share of total expenditure. As a carbon tax reform in Denmark is likely to be offset by decreases in various energy taxes, the magnitude of the tax incidence will most likely be smaller, and so will the distributional impact, as energy taxes in general are regressive (Jacobsen et al., 2001).

Second, we analyze a carbon tax reform through the lens of a general equilibrium model, inspired by Klenert et al. (2018b), but altered and calibrated to a Danish setting. We analyze both the direct impact of a carbon tax increase as well as different revenue recycling schemes. When allowing for agents and firms to substitute away from carbon-intensive goods and production, the impact of a carbon tax reform decreases, but less so for poorer agents, thus in the longer run, a carbon tax is still regressive. Furthermore, we find that under certain recycling schemes, namely lump sum transfers and differentiated tax cuts, a carbon tax reform can decrease inequality, resulting in a double dividend of redistribution of carbon taxation.

These findings have important political implications. Our analysis concludes that on its own, a carbon tax is regressive, as some opponents of carbon taxation argue. However, we show that even with simple lump sum redistribution of the tax revenue, inequality can be decreased. As Denmark already has a green check to compensate low income household for energy taxes, the same could quite easily be applied to offset the regressivity of increased carbon taxation.

Possible extensions to our analysis include extending to an intertemporal setting, accounting e.g. for technical and structural change in production, opening the economy and incorporating potential carbon leakage issues or endogenizing consumer preferences. It might also be beneficial to incorporate a more realistic description of the Danish tax system and public spending.

8 Appendix

8.1 First-order conditions

The detailed combined first order conditions of households as stated in 3.5 to 3.9 are given by:

$$\frac{\alpha_g}{\alpha_{g+1}} \frac{(X_{g+1,i} - X0_{g+1})}{(X_{g,i} + X0_g)} = \frac{p_g}{p_{g+1}} \tag{8.1}$$

with $g \in (1, ..., 40)$ and $i \in (1, .., 5)$. And for the following with $g \in (1, ..., 41)$:

$$\frac{\alpha_{41}}{\gamma} \frac{l_i}{(X_{41,i} + X0_{41})} = \frac{p_{41}}{w\phi_i(1 - \tau_{w,i})} \tag{8.2}$$

$$\sum_{g=1}^{41} (p_g X_{g,i}) = (1 - \tau_{w,i})\phi_i w(T - l_i) + L \tag{8.3}$$

This gives us a total of 60 first order conditions for households.

For the recycling schemes the first order conditions will change according to the limits of the specific recycling scheme. Below is stated the two last first order conditions for the three different recycling schemes, where $\tau^0_{w,i}$ denotes the pre-calibrated tax rates, $\tau_{w,i}$ denoted differentiated tax cuts, τ_w denotes linear tax cuts and L denotes lump-sum transfers. kk

FOC's with differentiated tax cuts:

$$\frac{\alpha_{41}}{\gamma} \frac{l_i}{(X_{41,i} + X0_{41})} = \frac{p_{41}}{w\phi_i(1 - \tau_{w,i} - \tau^0_{w,i} - \tau_w)} \tag{8.4}$$

$$\sum_{g=1}^{41} (p_g X_{g,i}) = (1 - \tau^0_{w,i} - \tau_{w,i})\phi_i w(T - l_i) \tag{8.5}$$

FOC's with linear tax cuts:

$$\frac{\alpha_{41}}{\gamma} \frac{l_i}{(X_{41,i} + X0_{41})} = \frac{p_{41}}{w\phi_i(1 - \tau^0_{w,i} - \tau_w)} \tag{8.6}$$

$$\sum_{g=1}^{41} (p_g X_{g,i}) = (1 - \tau^0_{w,i} - \tau_w)\phi_i w(T - l_i) \tag{8.7}$$

FOC's with lump-sum transfers:

$$\frac{\alpha_{41}}{\gamma} \frac{l_i}{(X_{41,i} + X0_{41})} = \frac{p_{41}}{w\phi_i(1 - \tau^0_{w,i})} \tag{8.8}$$

$$\sum_{g=1}^{41} (p_g X_{g,i}) = (1 - \tau^0_{w,i} - \tau_w)\phi_i w(T - l_i) + L \tag{8.9}$$

The detailed 82 first order conditions of firms as stated in 3.3 and 3.4 are given by:

$$w = \frac{\partial F_g(T_g, Z_g)}{\partial T_g} = \epsilon_g T_g^{(r-1)} F_g^{(1-r)} p_g \tag{8.10}$$

$$\tau_P = \frac{\partial F_g(T_g, Z_g)}{\partial Z_g} = (1-\epsilon_g) Z_g^{(r-1)} F_g^{(1-r)} p_g \tag{8.11}$$

Bibliography

Bjørner, T. B. and Jensen, H. H. (2002). Energy taxes, voluntary agreements and investment subsidies—a micro-panel analysis of the effect on danish industrial companies' energy demand. *Resource and energy economics*, 24(3):229–249.

Bovenberg, A. L. (1999). Green tax reforms and the double dividend: an updated reader's guide. *International tax and public finance*, 6(3):421–443.

Bruvoll, A. and Larsen, B. M. (2004). Greenhouse gas emissions in norway: do carbon taxes work? *Energy policy*, 32(4):493–505.

Callan, T., Lyons, S., Scott, S., Tol, R. S., and Verde, S. (2009). The distributional implications of a carbon tax in ireland. *Energy Policy*, 37(2):407–412.

Caspersen, S. (2020). Fordelingsvirkninger af en afgift på co2e-udledninger på kort sigt. pages 3–4.

Copeland, B. R. and Taylor, M. S. (1994). North-south trade and the environment. *The quarterly journal of Economics*, 109(3):755–787.

Danish Climate Council (2018). Fremtidens grønne afgifter på energiområdet. Link.

Danish Climate Council (2020). Kendte veje og nye spor til 70 procents reduktion. `https://www.skm.dk/skattetal/satser/satser-og-beloebsgraenser/co2-afgiftsloven`.

Danish Energy Agency (2010). Basisfremskrivning 2019. `https://ens.dk/service/fremskrivninger-analyser-modeller/basisfremskrivninger`. Accessed: May 5, 2020.

Danish Ministry of Finance (1999). Evaluering af grønne afgifter og erhvervene.

Danish Ministry of Taxation (2018). Co2-afgiftsloven. `https://www.skm.dk/skattetal/satser/satser-og-beloebsgraenser/co2-afgiftsloven`. Accessed: May 5, 2020.

Danish Ministry of Taxation (2019). Grøn check - en historisk oversigt. `https://www.skm.dk/skattetal/statistik/tidsserieoversigter/groen-check-en-historisk-oversigt`. Accessed: May 5, 2020.

Fremstad, A. and Paul, M. (2019). The impact of a carbon tax on inequality. *Ecological Economics*, 163:88–97.

Fullerton, D. and Heutel, G. (2011). Analytical general equilibrium effects of energy policy on output and factor prices. *The BE Journal of Economic Analysis & Policy*, 10(2).

Goulder, L. H. (1995). Environmental taxation and the double dividend: a reader's guide. *International tax and public finance*, 2(2):157–183.

Heerden, J. V., Gerlagh, R., Blignaut, J., Horridge, M., Hess, S., Mabugu, R., and Mabugu, M. (2006). Searching for triple dividends in south africa: Fighting co2 pollution and poverty while promoting growth. *The Energy Journal*, 27(2):113–141.

Jacobsen, H. K., Birr-Pedersen, K., and Wier, M. (2001). Fordelingsvirkninger af energi-og miljøafgifter.

Klenert, D., Mattauch, L., Combet, E., Edenhofer, O., Hepburn, C., Rafaty, R., and Stern, N. (2018a). Making carbon pricing work for citizens. *Nature Climate Change*, 8(8):669–677.

Klenert, D., Schwerhoff, G., Edenhofer, O., and Mattauch, L. (2018b). Environmental taxation, inequality and engel's law: The double dividend of redistribution. *Environmental and Resource Economics*, 71(3):605–624.

Kraka (2020). Small great nation: En klimareform der leverer de magiske 70 pct.

Lin, B. and Li, X. (2011). The effect of carbon tax on per capita co2 emissions. *Energy policy*, 39(9):5137–5146.

Mankiw, N. G. (2009). Smart taxes: An open invitation to join the pigou club. *Eastern Economic Journal*, 35(1):14–23.

Mirrlees, J. A. (1971). An exploration in the theory of optimum income taxation. *The review of economic studies*, 38(2):175–208.

Poterba, J. M. (1991). Is the gasoline tax regressive? *Tax policy and the economy*, 5:145–164.

Statistics Denmark (2018). Flertallet betaler mindre end en tredjedel af deres indkomst i indkomstskat. `https://www.dst.dk/da/Statistik/bagtal/2018/2018-04-09-flertallet-betaler-mindre-end-en-tredjedel-i-indkomstskat`. Accessed: May 5, 2020.

Statistics Denmark (2020). Statistics denmark - statbank.dk. `https://statbank.dk/`.

The Danish Ministry of Taxation (2018). Afgifts- og tilskudsanalysen på energiområdet, delanalyse 1: Udviklingen i afgifts- og tilskudsgrundlag.

Wier, M., Birr-Pedersen, K., Jacobsen, H. K., and Klok, J. (2005). Are co_2 taxes regressive? evidence from the danish experience. *Ecological Economics 52*, 52:239–251.