Carbon Taxation and Inequality: Theory and Evidence from Denmark

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May 2020

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 1,000 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 computable general equilibrium model calibrated to the Danish economy to assess the long-run distributional effects of a carbon tax of 1,000 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.

Number of characters including spaces in main text $\approx$ 61,131, corresponding to 25.5 normal pages. Counted with `https://www.lettercount.com/`

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.

We are indebted to David Klenert for providing the GAMS code on which we based our model, to Sune Caspersen for helpful advice and data provision, to our advisor Peter Kjær Kruse-Andersen and seminar participants for helpful comments and suggestions.

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 tax on CO_2-equivalents is a cost-effective way to reduce greenhouse gas emissions (Mankiw, 2009), as it will lead to the most inexpensive reductions being carried out. We will refer to such a tax as a carbon tax throughout the paper. 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 Act 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 1,500 DKK per ton of CO_2e 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. The input-output is suitable for analyzing the short run impact of a carbon tax, as it builds directly on Danish production and consumption data. However, there is no substitution in neither firm's production inputs or households' consumption patterns, making it unsuitable for long-run analysis. By combining the the input-output model with a general equilibrium model we account for substitution in both production and consumption. Thus, applying both model frameworks we assess the impact in both the short and long run. Using the general equilibrium framework we further analyze redistribution schemes to offset the regressivity of a carbon tax reform. We find that both in the short and long run, carbon taxes have a regressive distributional profile. However, when the revenue is distributed either as lump sum transfers or through differentiated tax cuts, both inequality and carbon emissions fall. 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 Danish carbon tax reforms and conducts a literature review of the distributional effects of

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

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

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 computable 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.

1.2 A review on carbon tax reforms

1.2.1 A short history of the Danish carbon tax

In the light of a growing international agenda on sustainability, Denmark imposed the first carbon tax in 1992 as a part of a bigger green tax reform including other energy taxes (Wier et al., 2005). The tax was set to around 100 DKK per ton of carbon emitted in Danish production and from households' energy consumption. Businesses were at the time given a 50 percent tax rebate to secure their international competitiveness. Furthermore, the most energy intensive businesses were given reimbursements to the extent where the most energy intensive businesses got their carbon tax bill completely refunded (Wier et al., 2005), leaving them little incentive to actually lower carbon emissions. The carbon tax was not (and still is not) imposed directly on carbon emissions, but instead imposed per energy units of different fuels, which means that different fuels pay different tax rates per ton emitted (The Danish Ministry of Taxation, 2018).

The tax scheme has been revised continuously and recent calculations by the Danish Climate Council (2018) show that the carbon tax corresponds to around 170 DKK per ton of carbon emitted in 2018, where businesses already covered by the EU ETS are excluded from tax payment. The carbon tax is small compared to other energy taxes. For example, the carbon tax on coal is around 70 percent lower than the energy tax on coal measured per GJ. As the Danish Climate Council (2018) stresses, the biggest issue of the green tax system today is that the carbon tax is too small and not uniform across energy types and sectors. Thus, it does not provide a sufficient incentive to lower carbon emissions. This motivates their proposal to increase carbon taxation in Denmark to comply with the national reduction target of 70 pct. in the Danish Climate Act.

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 the findings in the field.

There is mixed evidence on the effect of carbon taxation on carbon emissions. 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 large tax credits.

The distributional impact of the carbon tax schemes 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 lifetime. Using this method he finds a 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 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 social benefit transfers, an income tax credit or a cut in the income tax rate. They use the SWITCH model, which is built on a national representative survey on households' income, taxes and benefits. 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.

Klenert et al. (2018b) similarly focus on redistributing the revenue from an environmental tax. 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 computable 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. They find that using the carbon tax revenue for reducing taxes (VAT) on food will increase GDP.

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 1,250 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 which are exposed to carbon leakage, such as agriculture. 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 industries and households. Following the method of Wier et al. (2005) we set up an input-output model of the Danish economy, which is built on a Leontief production structure. We analyze both the current carbon taxation in Denmark using data on tax payments as well as a hypothetical carbon tax of 1,000 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. The input-output model assumes a Leontief-type production structure, with no substitution possibilities for firms in their intermediate good use. A core assumption of input-output models is that consumers absorb the entire tax burden and that there is not taken substitution or income effects into account, making the carbon tax payments ceteris paribus measures. The results can thus be interpreted as the tax burden in the very short run. 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].

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

[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.

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

[6]Data on carbon intensities of different energy types was also provided by Sune Caspersen.

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, 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 and electricity.

2.4 Indirect taxes

We calculate the indirect carbon tax payment for households in quintile i using the formula:

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

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 the average household in each quintile of the income distribution spends on different consumption goods.

2.5 Analysis

We calculate the distributional impact of two different tax schemes: First we consider the distributional impact of the current carbon tax in Denmark, partly to replicate the results of Wier et al. (2005) with newer data, partly to have a baseline which we will compare with the tax reform where all emissions are taxed with a flat rate of 1,000 DKK/ton carbon emitted.

2.5.1 Current tax scheme

To calculate the current 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 total 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. We proceed to assume that all carbon tax-related fuel use is linked to either transport or heating and electricity.

Table 2: Calculation of the current 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.

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

[7]See PWC: Guide to CO2-taxes

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

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

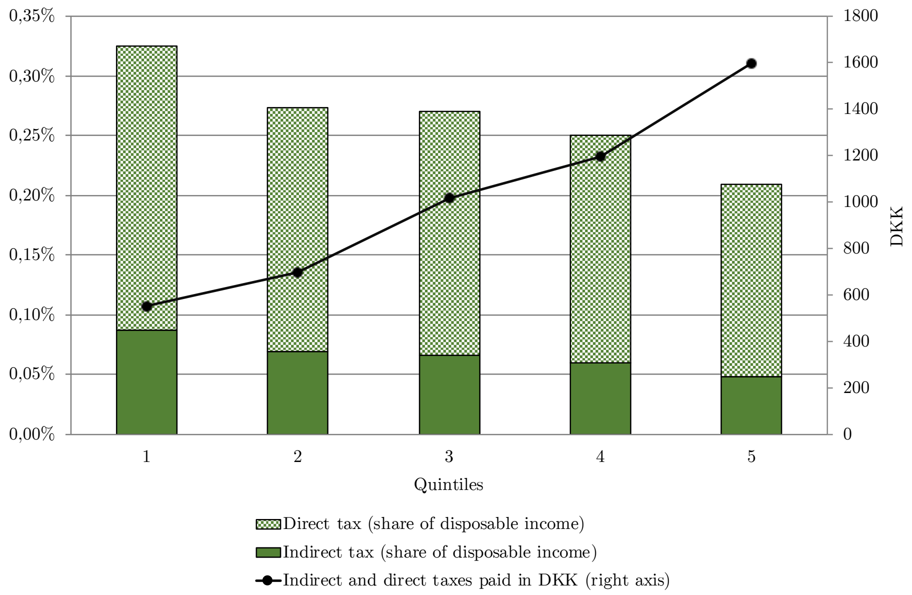
with industry $k = 1, 2, ..., 117$ and Tax_{rev}^i denoting the calculated tax revenue for industry k, based on its share of energy tax revenue. Then, indirect taxes are calculated as in equation (2.3).

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 represents 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. 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 1,598 DKK. The fraction of income spend on carbon taxes is indeed quite small, which is in line with the results of Wier et al. (2005). The results indicate that in the short run, current Danish carbon taxes are regressive, at least when using disposable income as the denominator.

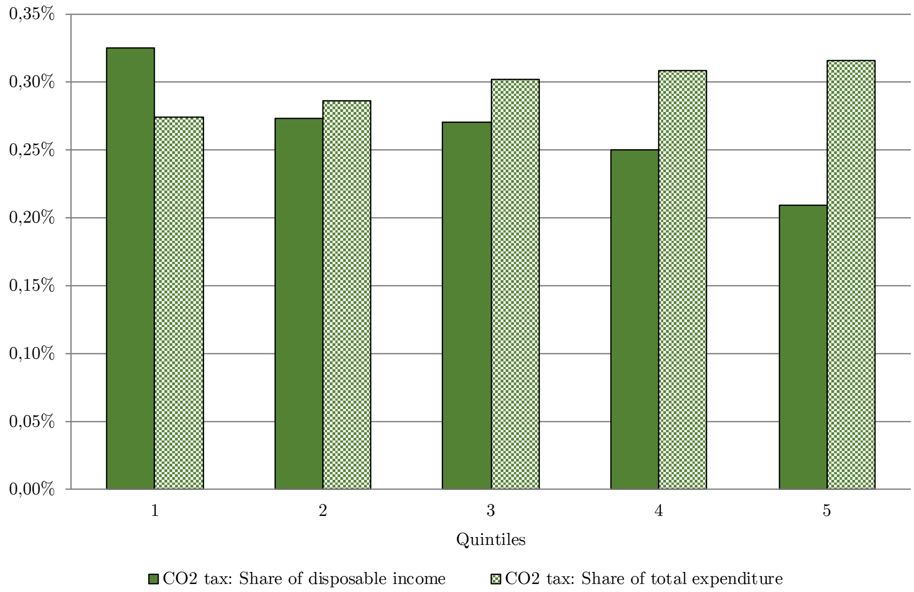
Figure 1: Direct and indirect tax payments by income quintiles



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 therefore be more indicative of the long-run regressivity (Caspersen, 2020). However, there are people who do not change position in the income distribution, and for those, total expenditure will not be a good proxy for lifetime income. Furthermore, the lack of substitution in our input-output model is not a realistic assumption for the longer run. Thus, the long-run impact on inequality is quite complicated, and expenditure should at most be interpreted as an indicator of life-time income.

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). Thus, the current Danish carbon tax might not be regressive in a lifetime perspective using total expenditure as an approximation of lifetime income.

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.

2.5.3 Tax reform

In this section, we analyze a tax reform where all Danish carbon emissions are taxed at a rate of 1,000 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 1,000 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 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 $\tau = 1,000$ DKK/ton in sections 2.3 and 2.4.

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

2.5.4 Results

Under the current carbon tax scheme, we found average carbon taxes to be 41 DKK/ton.[9] Now, as we impose a 1,000 DKK/ton tax, the impact on consumers rises, unsurprisingly. The lowest quintile will pay roughly 8,906 DKK in carbon taxes yearly, while the highest quintile will pay 19,906 DKK. From Figure 3 we see that the 1,000 DKK/ton 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 consumers, with direct taxes being relatively small. This is due to the fact that in the current tax scheme, households pay 55 pct. of total carbon taxes while emitting less than 10 pct. of total emissions. In the hypothetical tax scheme, the polluter pays-principle applies, and everyone are taxed according to their emissions at the 1,000 DKK/ton-rate, meaning that industries will pay significantly more. The tax burden is then entirely passed onto consumers, due to the Leontief production structure of the model.

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 indicates that in the short run, carbon taxes will clearly be regressive, but probably less so in the longer run.

[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. We find a lower tax rate than The Danish Ministry of Taxation (2018), who calculate the tax payment for those who actually pay the tax, while we calculate the average tax payment for all sectors.

Figure 3: Direct and indirect tax payments by income quintiles

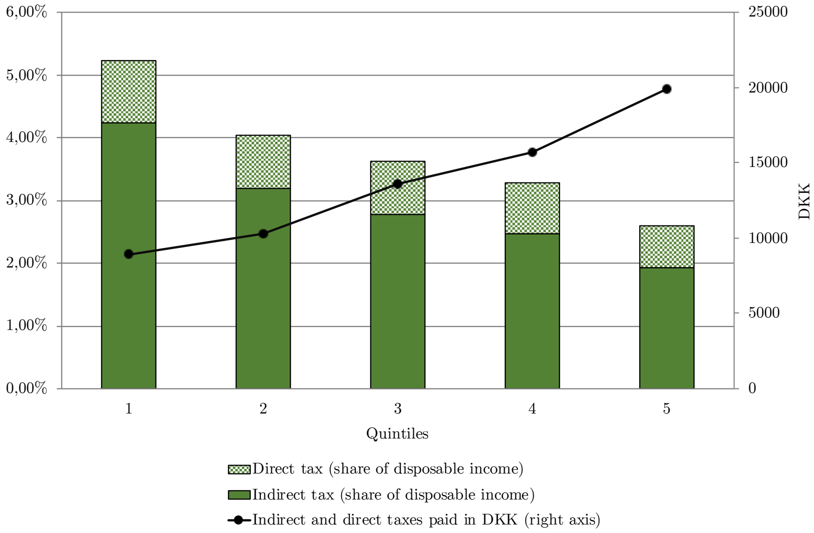
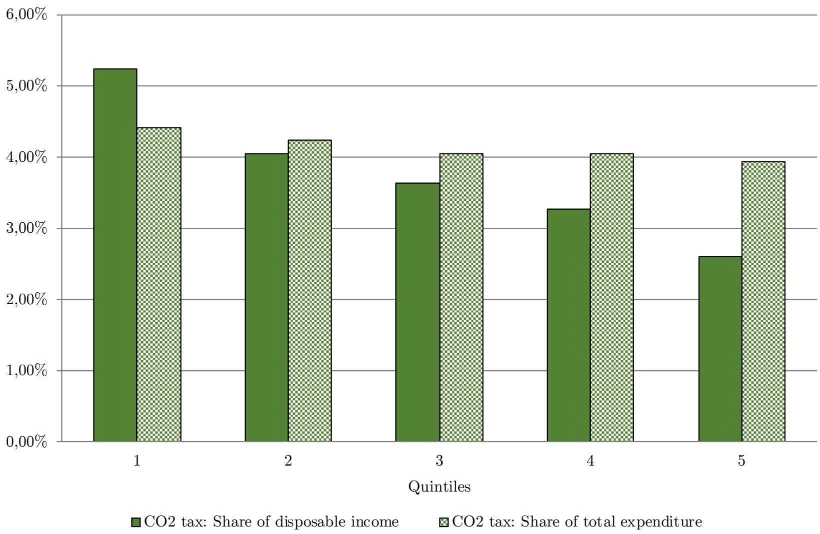


Figure 4: Total carbon tax payments, share of income and expenditure



Notes: Total carbon tax payments are the sum of direct and indirect tax payments. The figures show the impact of 1,000 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 current tax scheme, where firms and consumers have already responded to the carbon tax, as Denmark started imposing those in 1992 (Wier et al., 2005, p. 243). However, the assumption is somewhat critical in the case of the 1,000 DKK/ton tax, which is a quite significant tax increase. Producers and consumers will be expected to substitute towards less polluting intermediate and final goods, which is the purpose of the tax. Furthermore, some of the tax burden will probably be passed onto businesses and their owners, which are typically found in the upper part of the income distribution. Thus, there is most likely an upward bias in our estimates of the regressivity of a 1,000 DKK/ton carbon tax, as we essentially assume that no substitution is made at neither the firm or consumer level. We seek to account for these behavioral effects by simulating a tax scheme within 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 1,000 DKK/ton carbon tax reform by applying a computable general equilibrium model to the Danish economy. First we solve for a baseline equilibrium, representing status quo, and then we impose tax reforms and solve for the counterfactual equilibria. The purpose is to measure the distributional effects of the tax, taking into account the behavioral effects of firms and households. With this model, we can analyze the impact of a carbon tax reform in the long run, where prices change and firms and households react, which was not the case in our input-output model. Furthermore, we assess 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 reported consumption is zero[10]. We model 5 households who correspond to quintiles of the danish income distribution. The average income in each quintile is interpreted as the given household's productivity. The calibration of the model is described in section 3.4.

Our theoretical foundation is simple such that we can interpret on firms' and households' behavior after a tax reform. The downside of our simplistic model is that we have to make a number of unrealistic assumptions and aggregations. We

[10]We do not consider this a critical exclusion, as the carbon footprint of these sectors is probably negligble, and imposing environmental taxes on them might prove difficult.

model a static, closed economy with a simplified public sector and taxation system. Limits to the model will be discussed in 6.

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 simply labor. Modeling pollution as a production input stems from Copeland and Taylor (1994). Output is given by the CES production function $F_g(T_g, Z_g)$:

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

where $\sigma = 1/(1-r)$ is the elasticity of substitution between labor and emissions, and ϵ_g is the labor share parameter in sector g. The additional inequality with $x > 0$ (exogenously given) 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 details of the production function is given in section A.1. 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

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

and

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

The details of the first order conditions of firms are given in the appendix, section A.2. 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 emissions, in contrast to Klenert et al. (2018b).[11] We consider this a realistic utility function in a Danish setting, as the externalities of carbon emissions are global and Denmark will, at least not to a first approximation, be seriously exposed to damages therefrom. Thus, we ignore the mechanism that Danish climate policy will have an actual effect on Danish climate damage on the margin, which seems plausible considering the Danish share of the global emissions level.

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 A.2.

[11] 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.

3.3 Government

The government's actions are taken as given by firms and households and the government can anticipate all future actions of firms and households, thus it acts as a Stackelberg leader (Von Stackelberg, 2010). We let the government impose a fixed tax on pollution, τ_P, which we calibrate such that it corresponds to a 1,000 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 that ensures that households will not obtain higher utility from pretending to have lower productivity:

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

where U_i^j is the utility of household i pretending to be household j. Thus, when the government sets income taxes, it must take into account both inequality concerns, due to diminishing marginal utility of consumption, and the restriction on 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).[12] Each household i corresponds to the average household in each quintile of the Danish income distribution. We measure household i's productivity level ϕ_i as the share of total income of quintile $i \in (1, 2, ..., 5)$ in Denmark, following Klenert et al. (2018b). Thus households are assumed to earn an income corresponding to their productivity level. To calibrate the income tax rate for each household we use income tax payments for each quintile. The pre-calibrated income tax rates, which we denote $\tau^0_{w,i}$, is then simply the average tax payment payed by the households in each quintile divided by the average income for households in the same quintile. 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
$\tau^0_{w,i}$	0.200	0.244	0.279	0.308	0.360

Government spending in Denmark in 2016 was 24.9 pct. of GDP.[13] 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 $\sigma = 1$) 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). The latter implicates that the amount of emissions cannot exceed the labor input for each good.

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 use data on carbon intensities, applying a similar method as for calculating the indirect carbon taxes in the input-output model. Since ϵ_g is the (composite) labor share in production, we calculate it from the carbon emissions

[12] Statistics Denmark were so kind to send us the data used in this article.

[13] See table NAN1 in Statistics Denmark (2020).

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

share in production being $1 - \epsilon_g$, which is calculated by the formula:

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

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. Further C is the (117×41) matrix as described in the section on indirect carbon taxes 2.4. 1 is a (1×41) vector with a 1 in each entry, $1 - \epsilon$ is a (1×41) vector with carbon emissions factor shares for the production of the 41 goods, and ϵ is the (1×41) vector with labor factor shares.

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 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 the algebraic modeling software GAMS and nonlinear programming algorithm CONOPT[14] to solve our model numerically.

3.5.1 Calibration of the carbon tax

To calibrate the carbon tax we take our model solutions for total GDP ($\sum_g F_g p_g$) and total emissions (Z) from our baseline simulation and translate them into real world units (DKK and tons of carbon) using data on value added (NABP117) and total emissions (DRIVHUS) from Statistics Denmark (2020). We find that a 1,000 DKK/ton carbon tax corresponds to a level of $\tau_p = 0.16$ in our model.

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 environmental 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.

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

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 households' first order conditions. This is outlined in appendix (A.2). 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 A.2. 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 1,000 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

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

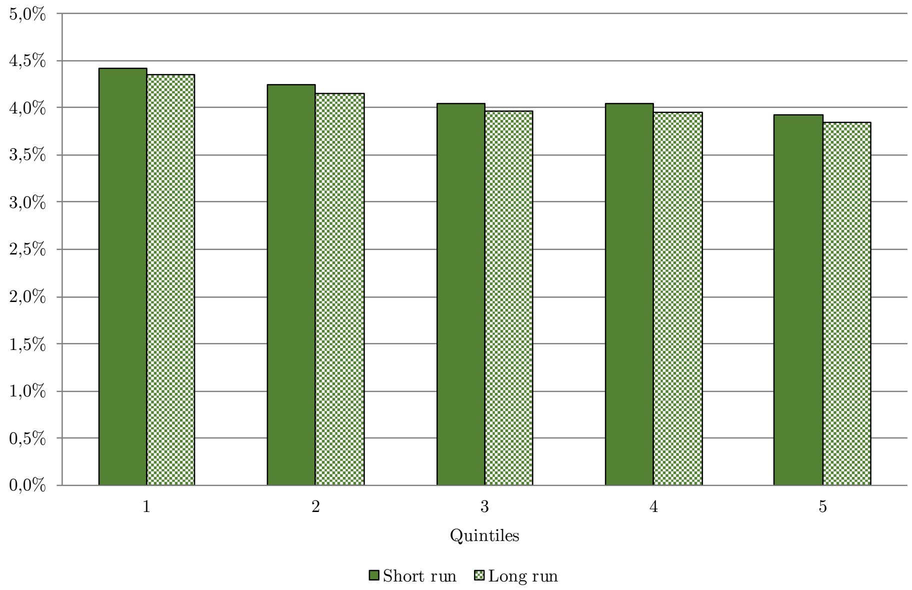
where i denotes the representative agent for quintiles 1 to 5, and g denotes the 41 consumption goods. Then, direct and indirect taxes are calculated exactly as in section 2, but with long-run quantities. We calculate the indirect tax payments in the long run by replacing c_i with $c_{LR,i}$ in (2.3). 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 1.1 pct., but total pollution falls a rather significant 49.8 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	18.65	-1.1%
Agg. emission intensity	0.31	0.15	-49.8%
Agg. labor intensity	1.01	1.02	1.2%
Gov. spending (nominal)	5	5.24	4.8%
Real total consumption	13.96	13.63	-2.3%

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 $\tau_P = 0.16$, which corresponds to a 1,000 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 five cases, one before a carbon tax reform and four different redistribution schemes after the tax reform, which are described in section 3.6.

From Figure 6 we see that the Gini coefficient is slightly increasing after imposing the carbon tax. This is due to poorer households not being able to 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 slightly.

From Figure 7, 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.

Figure 6: Gini coefficients in different redistribution schemes

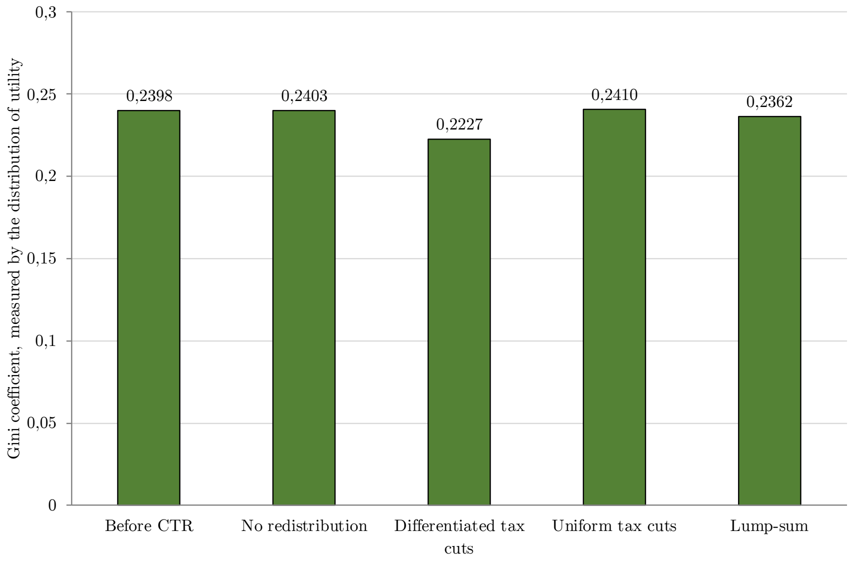
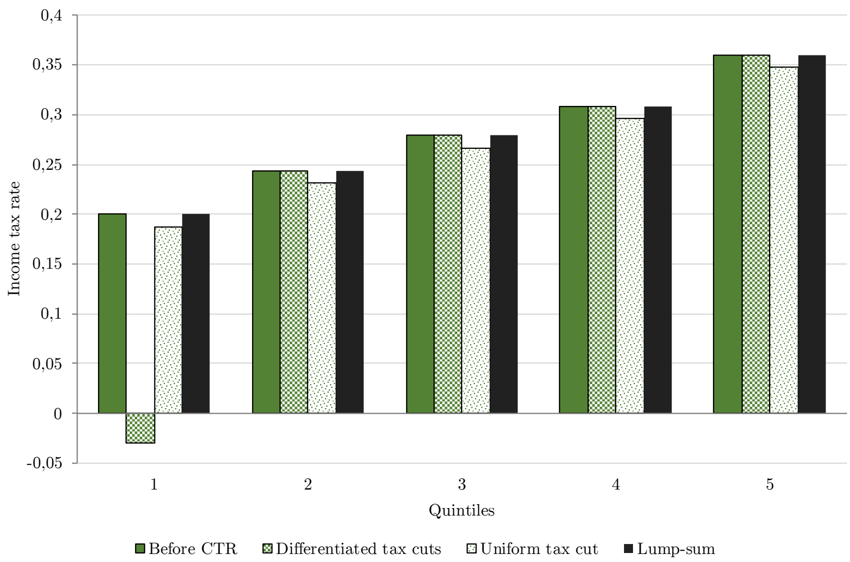


Figure 7: Income taxes in different redistribution schemes

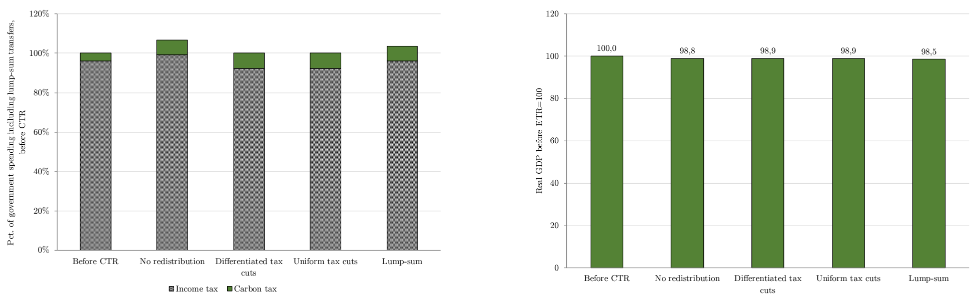


From panel (a) of Figure 8, we see that after the carbon tax reform a larger share of government income comes from the carbon tax. When we do not allow for redistribution of the tax revenue, government spending (plus lump-sum transfers) naturally increases. Our results are very similar to those of (Klenert 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 equation (3.12) puts limits to the restructuring of the tax schedule. Total pollution falls 49.8 pct. after the carbon tax reform in all redistribution schemes.

Figure 8: Effects of the carbon tax reform on GDP and government spending

(a) Goverment spending composition

(b) GDP



We conclude that it is possible in our model to decrease both carbon emissions and inequality, 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.

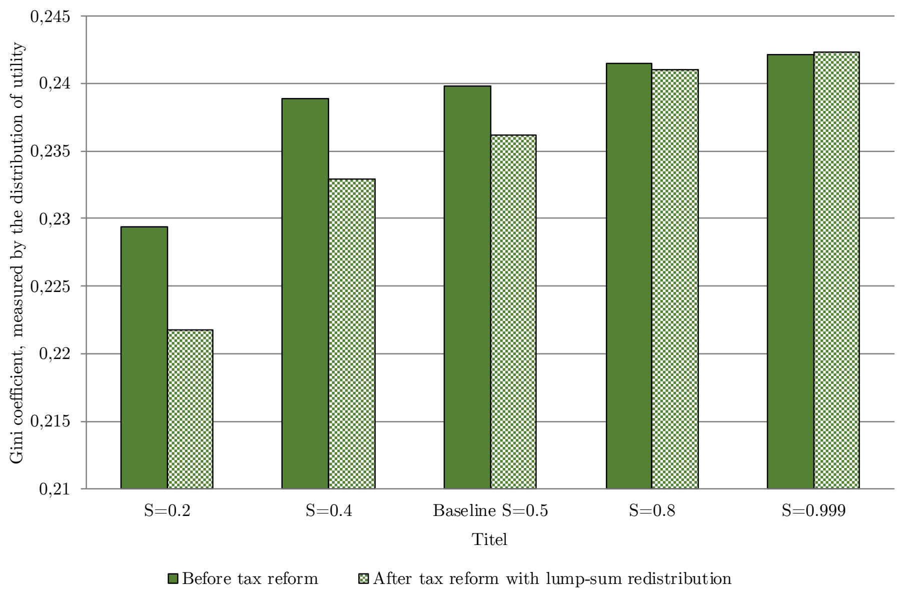
5 Robustness

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 9. 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 9: Robustness check of the elasticity of substitution



Notes: S indicates the level of σ.

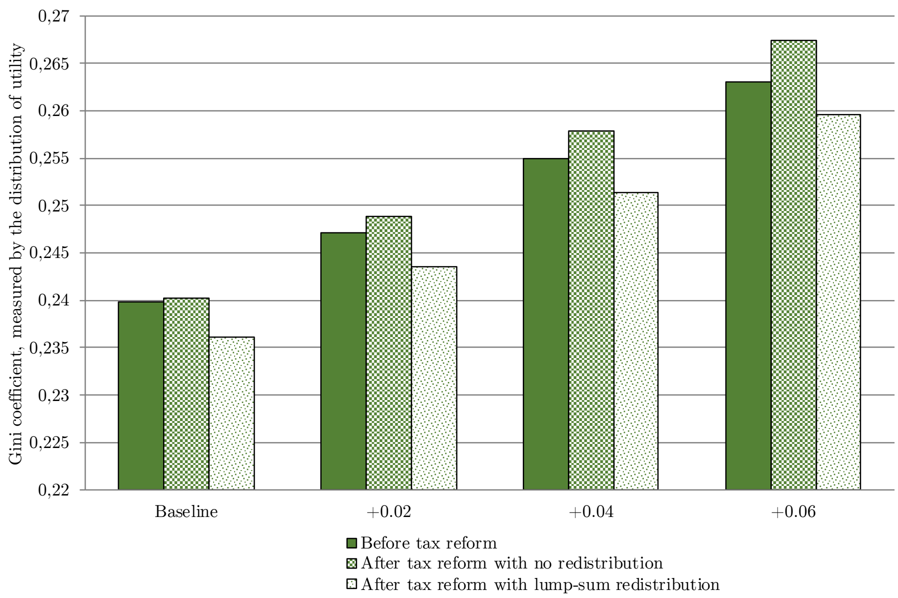
5.2 The role of non-homothetic preferences

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 10 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 10: 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 an open economy, without any border carbon adjustment, would most likely be less regressive, since both firms and consumers would have the possibility to avoid the tax. 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 consumption categories in the Danish Budget Survey. We then proceed to assume only one share parameter, $(1 - \epsilon_g)$, of the carbon emission input in the production of each good representing a consumption category. This is of course a simplifying assumption, since each consumption category consists of a large number of different goods and services. This 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 (2019) 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 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 an upward bias: A carbon tax reform in Denmark will most likely not be 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 1,000 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.

A Appendix

A.1 Explanation of the production function

Equation (3.1) proposed by Klenert et al. (2018b) is motivated here, following appendix A of Copeland and Taylor (1994). We suppress the subscript g such that $F(T, Z) = y$, as this applied to all goods. We let T_y be the amount of labor needed to produce good y. To simplify calculations, we let $\sigma = 1$ such that our CES production function collapses to a Cobb-Douglas production. Then we assume

$$y = x^{1-\epsilon} T_y \tag{A.1}$$

$$Z_0(y) = x^{\epsilon} y = x T_y, \tag{A.2}$$

where $Z_0(y)$ is the amount of carbon emissions when no abatement is undertaken. The firm is assumed to have an abatement technology given by

$$A(T_a, Z_0(y)) = Z_0(y) - \left[\frac{x^{-\epsilon} Z_0(y)}{(Z_0(y)/x + T_a)^{\epsilon}}\right]^{\epsilon}, \tag{A.3}$$

where T_a is the amount of labor assigned to abatement. Note that $A(0, Z_0(y)) = 0$ and that $\partial A / \partial T_a > 0$. The abatement function is concave in T_a and is asymptotic to $Z_0(y)$, reflecting diminishing returns to abatement activity. Emissions from the firm is equal to the unconstrained level of pollution, less abatement:

$$Z(y, T_a) = Z_0(y) - A(T_a, Z_0(y)) = \left[\frac{x^{-\epsilon} Z_0(y)}{(Z_0(y)/x + T_a)^{\epsilon}}\right]^{\epsilon}. \tag{A.4}$$

This can be rewritten, using (A.1) and (A.2) as

$$Z(y, T_a) = \left[\frac{y}{[T_y + T_a]^{\epsilon}}\right]^{\epsilon}. \tag{A.5}$$

The total labor employed by the firm is $T = T_y + T_a$, and we can rearrange to obtain the Cobb-Douglas production function

$$y = T^{\epsilon} Z^{1-\epsilon}. \tag{A.6}$$

Since $y = x^{1-\epsilon} T_y$, this equation is only valid for $y \leq x^{1-\epsilon} T$, or equivalently for $Z \leq xT$.

A.2 First-order conditions

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

$$\frac{\alpha_g}{\alpha_{g+1}} \frac{(X_{g+1,i} - X0_{g+1})}{(X_{g,i} + X0_g)} = \frac{p_g}{p_{g+1}} \tag{A.7}$$

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

$$\frac{\alpha_{41}}{\gamma} \frac{l_i}{(X_{41,i} + X0_{41})} = \frac{p_{41}}{w \phi_i (1 - \tau_{w,i})} \tag{A.8}$$

$$\sum_{g=1}^{41}(p_g X_{g,i}) = (1-\tau_{w,i})\phi_i w(T-l_i) + L \tag{A.9}$$

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.

FOC's with differentiated tax cuts:

$$\frac{\alpha_{41}}{\gamma}\frac{l_i}{(X_{41,i}+X0_{41})} = \frac{p_{41}}{w\phi_i(1-\tau_{w,i}-\tau^0_{w,i}-\tau_w)} \tag{A.10}$$

$$\sum_{g=1}^{41}(p_g X_{g,i}) = (1-\tau^0_{w,i}-\tau_{w,i})\phi_i w(T-l_i) \tag{A.11}$$

FOC's with linear tax cuts:

$$\frac{\alpha_{41}}{\gamma}\frac{l_i}{(X_{41,i}+X0_{41})} = \frac{p_{41}}{w\phi_i(1-\tau^0_{w,i}-\tau_w)} \tag{A.12}$$

$$\sum_{g=1}^{41}(p_g X_{g,i}) = (1-\tau^0_{w,i}-\tau_w)\phi_i w(T-l_i) \tag{A.13}$$

FOC's with lump-sum transfers:

$$\frac{\alpha_{41}}{\gamma}\frac{l_i}{(X_{41,i}+X0_{41})} = \frac{p_{41}}{w\phi_i(1-\tau^0_{w,i})} \tag{A.14}$$

$$\sum_{g=1}^{41}(p_g X_{g,i}) = (1-\tau^0_{w,i}-\tau_w)\phi_i w(T-l_i) + L \tag{A.15}$$

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

$$w = \frac{\partial F_g(T_g, Z_g)}{\partial T_g}p_g = \epsilon_g T_g^{(r-1)} F_g^{(1-r)} p_g \tag{A.16}$$

$$\tau_P = \frac{\partial F_g(T_g, Z_g)}{\partial Z_g}p_g = (1-\epsilon_g) Z_g^{(r-1)} F_g^{(1-r)} p_g \tag{A.17}$$

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 (2019). Basisfremskrivning 2019. `https://ens.dk/service/fremskrivninger-analyser-modeller/basisfremskrivninger`. Accessed: May 24, 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 24, 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 24, 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 24, 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.

Von Stackelberg, H. (2010). *Market structure and equilibrium*. Springer Science & Business Media.

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.