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# Decomposing the distributional impact of carbon taxation across six EU countries - Comparing the role of budget shares, carbon intensity, savings rates, and asset ownership

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# Decomposing the distributional impact of carbon taxation across six EU countries - Comparing the role of budget shares, carbon intensity, savings rates, and asset ownership.*

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**Abstract**

This paper decomposes and compares the distributional impact of uniform national carbon taxes across six EU countries. We quantify the contribution of the key determinants of the carbon tax burden to its impact on inequality and regressivity indicators. We identify large cross-country differences in carbon tax burdens, their composition, and the drivers of the within-country distributional impact. A carbon tax is regressive in all countries, but carbon tax burdens and their impact on income inequality are larger in poorer countries of our sample. Cross-country differences in the primary driver of carbon tax regressivity suggest that the most effective policy lever to mitigate carbon tax regressivity differs across countries. Differences in the composition of the consumption basket play an important role in most countries, but not all. Differences in savings rates play the most important role in the wealthier countries of our sample. The carbon intensity of consumption plays a larger role in the poorer countries of our sample. Overall, this article suggests that differences in the structure of carbon tax incidence and the drivers of its distributional impact across countries pose a challenge to cross-country policy learning, and highlights the need for in-depth country-level and comparative analysis.

**Keywords**: Distributional effect, Decomposition, Energy, Income inequality, Carbon intensity, Carbon pricing

**JEL Codes**: C67, D30, H23, P18, Q48, Q52

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# 1 Introduction

Carbon pricing is central to the EU's strategy to reduce CO2 emissions in line with the targets defined in the Paris Agreement. EU-wide carbon pricing increases its effectiveness (Nachtigall, 2019) but affects households differently depending on their country of residence, lifestyle, and income level (Ohlendorf et al., 2021). This challenges the EU's commitment to a just transition. Carbon pricing is regressive in many developed countries, putting a higher burden on the poor (Ohlendorf et al., 2021). Distributional impacts of carbon pricing are driven by multiple factors. Differences in budget shares of carbon-intensive goods are widely recognized as an important driver of the carbon tax distributional impact (Grainger and Kolstad, 2010; Dorband et al., 2019). Differences in carbon intensity of the energy mix consumed by households (Berry, 2019; Steckel et al., 2021; Feindt et al., 2021) or differences in asset ownership (Farrell, 2017; Renner, 2018) also affect its distributional impact of carbon pricing. Carbon tax burdens are often measured relative to income but carbon tax payments are proportional to expenditure. Savings rates relate expenditure to income. Their role in the distributional impact of carbon pricing should therefore be considered. The relative importance of these factors for the distributional impact of a carbon tax is not well understood. Understanding the importance of these factors is however crucial to policy makers in selecting effective policy levers in equalizing the carbon tax burden across households. This paper quantifies the relative importance of budget shares, carbon intensity of consumption, savings rates, and asset ownership for the distributional impact of carbon taxation.

Understanding the drivers of distributional impacts of carbon pricing in the EU is increasingly important as carbon pricing in the EU is set to expand. A key element of the European Commission's Fit for 55 package is the pricing of the residential and the transportation sector under a new Emission Trading Scheme (ETS), the ETS2 (Council of the European Union, 2022). ETS2 will increase consumer prices and broader carbon price coverage will likely disproportionally impact the poor (EC, 2019). Therefore, ETS2 will be accompanied by a Social Climate Fund, of which 70% is allocated to energy efficiency and renewable energy production and 30% to direct income transfers to vulnerable households to counteract regressive distributional impacts. Revenue recycling through income transfers can turn the impact of a carbon tax progressive (Klenert and Mattauch, 2016). However, two challenges persist. Firstly, revenue recycling through income transfers does not directly contribute to emission reductions and likely reduces the effectiveness of the tax (Tovar Reaños and Lynch, 2023; Symons et al., 1994). Secondly, horizontal inequalities resulting from carbon pricing may remain unaddressed or can be exacerbated by revenue recycling (Cronin et al., 2019). Unaddressed distributional impacts can reduce the political acceptability of the tax (Dechezleprêtre et al., 2022). Addressing distributional impacts through income transfers therefore remains a partial solution. Carbon emission mitigation strategies remain important, particularly considering the large share of the Social Climate Fund allocated to such mitigation strategies. Designing mitigation strategies that address carbon tax-induced inequalities requires a deep understanding of their origins. This paper identifies the most important factor for carbon tax regressivity in multiple countries and shows that the role of individual factors can differ drastically across countries.

The narrative on the distributional impacts of carbon taxation highlights the importance of fuel consumption and tax coverage (see Ohlendorf et al. (2021) and Koeppl and Schratzenstaller (2022) for recent reviews). Poor households and households in poorer EU countries spend a larger budget share on carbon-intensive necessities, such as food or home fuels for heating and cooking, and are consequently heavily affected by carbon taxation (Budolfson et al., 2021). Distributional impacts of carbon taxes also differ by energy carrier. Taxing electricity and home fuels is more regressive than taxing transport fuels in most countries (Flues and Thomas, 2015). Progressive impacts of transport fuel taxation are explained by higher concentrations of car ownership among richer households (Sterner, 2012; Missbach et al., 2022). Taxing direct emissions is more regressive than taxing both direct and indirect emissions, i.e. emissions associated with the production of goods and services (Feindt et al., 2021). Overall, it appears that the existence of a subsistence level of carbon-emitting consumption is a strong driver of carbon tax regressivity (Klenert and Mattauch, 2016). A few studies highlight the role of the energy mix consumed by households and its carbon intensity. Verde and Tol (2009) show that the carbon intensity of fuels decreases with income. Steckel et al. (2021) show that coal and solid fuel consumption vary along the income distribution. Feindt et al. (2021) suggest that carbon tax regressivity across EU countries can be explained by a higher average carbon intensity of the transport energy in Eastern European countries, and a higher expenditure share and carbon intensity of the domestic sector in poorer countries. They however do not discuss the role of carbon intensity for distributional impacts within countries.

The comparative literature primarily focuses on comparing distributional impacts (Feindt et al., 2021; Dorband et al., 2019; Vogt-Schilb et al., 2019; Steckel et al., 2021; Symons et al., 2002; Pearson and Smith, 1991) or studies differences in distributional impacts under various carbon tax designs (Flues and Thomas, 2015; Steckel et al., 2021). Few studies decompose the distributional impact of carbon pricing (Dorband et al., 2019; Feindt et al., 2021; Rausch et al., 2011). These approaches focus on the role of budget shares only (Dorband et al., 2019; Rausch et al., 2011), or decompose the distributional impacts across, but not within, countries (Feindt et al., 2021). Section 2 reviews the approach taken in these papers. While these insights are important, they do not assist national policymakers in addressing the primary reason for within-country distributional impacts.

This paper adapts a methodology from the income inequality decomposition literature to consider the drivers of the within-country distributional impact of carbon pricing. Using household budget survey (HBS) data, we compare outcomes across six countries, Hungary, Lithuania, Portugal, Ireland, Finland, and Luxembourg. We simulate a carbon tax that covers national energy-related emissions[1]. To account for indirect emissions embedded in non-energy products, we utilise a Multi-regional Input-Output model (MRIO).

The overall conclusion is that the carbon tax burden, its composition, and the drivers of its distributional impact differ across countries. The carbon tax is regressive in all countries and impacts disposable income inequality

[1]We do not explicitly account for existing carbon pricing schemes, such as national carbon pricing or the EU-ETS. The simulated carbon tax simply increases the national carbon price by 30 euro/tCO2.

most in the poorer countries analysed. Comparable distributional impacts can result from different distributions of factors along the income distribution, making it difficult to draw general lessons. Asset ownership of internal combustion engine vehicles reduces the impact of a carbon tax on income inequality while the other factors generally increase its impact. In most countries, differences in budget shares play an important role, but rarely the most important role. In Lithuania, differences in carbon intensity of the energy mix play the most important role. In Finland, Portugal, and Luxembourg differences in savings rates play the most important role. Such deviations from the standard narrative have important implications for national policy. In Lithuania, adverse distributional impacts may best be addressed by equalizing the energy mix across the population and providing decarbonized energy access to low-income households. In Finland, Portugal, and Luxembourg, adverse distributional impacts may best be mitigated through income redistribution, in-kind provision of transportation services, or energy efficiency improvements targeted at low-income households. In Hungary and Ireland, improved access to cheap low-carbon energy sources for low-income households or improved energy efficiency of assets and dwellings may be the most appropriate strategy.

The contribution of this paper is two-fold. Firstly, we provide an in-depth comparative analysis of a carbon tax in the EU and quantify the contribution of factors shaping the carbon tax burden to its impact on inequality and tax regressivity indicators. In doing so, we identify the most effective policy lever in reducing the regressive impact of the carbon tax and demonstrate that it differs across countries, even where initial distributional patterns look similar. Additionally, we provide insights into the distributional impacts of the expansion of the ETS to the residential and domestic sectors. Secondly, we adapt a methodology from the literature on income inequality to the literature on the distributional impacts of carbon pricing.

Section 3 briefly introduces the literature on income inequality decomposition and the factors of the carbon tax burden, and introduces our decomposition approach. Section 4 describes the data. Section 5 shows the distribution of the factors and describes the results. Section 6 offers concluding remarks and discusses implications for policy.

## 2 Decomposition Approaches in the Literature

The question of the importance of factors for income inequality, such as specific population groups or income sources, has a long history (Bourguignon, 1979; Shorrocks, 1982; Oaxaca, 1973; Cowell, 1980; Juhn et al., 1993; Fields, 2003; Biewen and Juhasz, 2012; Sologon et al., 2021). The ensuing literature can be divided into two groups; microsimulation-based "a priori" approaches and regression-based decomposition approaches (Cowell and Fiorio, 2011) [1]. The approach in this paper falls within the group of "a priori" approaches. Sologon et al. (2023) review the literature on inequality decomposition techniques that use microsimulation to assess the drivers via counterfactual analysis. The advantage of these approaches is that they allow the generation of detailed counterfactual income

[1] Micro-simulation-based approaches may also use regression, re-weighting or calibration to simulate counterfactual distributions (Li and O'Donoghue, 2013).

distributions. Counterfactual income distributions can then be compared to factual income distributions to assess the impact of that tax or benefit.

Our approach resembles the approach proposed by DiNardo et al. (1996), who reweight the sample to generate counterfactual distributions, where population groups are the same with respect to characteristics of interest. By equalizing a characteristic across the population holding all else constant, the contribution of that characteristic to income inequality can be identified [2]. Biewen (2014) takes a similar approach to estimate the direct role of factors for inequality by comparing the change in inequality indicators under factual and counterfactual scenarios. This approach can be described as a ceteris paribus approach to isolate the direct contributions of factors to income inequality. The sum of direct contributions does however typically not sum to the total change in inequality being decomposed, and residual is assigned to interaction effects between components. These interaction effects can be large and difficult to interpret [3].

An alternative approach is to sequentially replace factors with the population average until all factors are equalized. In this case, contributions of factors represent marginal contributions. This approach however suffers from path-dependence, so the marginal contribution of factors depends on the sequence in which individual factors were equalized across the population. To address path dependence, Shorrocks (2013) proposed a Shapley approach, whereby all possible sequences are simulated and the marginal contributions of each factor are then averaged across all sequences. This can however lead to situations where negative and positive effects obtained in different sequences may cancelled out, making it difficult to assign a meaningful economic interpretation to the estimated contributions.

While these approaches have been applied widely in the income inequality literature, they have scarcely been used to study the distributional impacts of carbon pricing. Rausch et al. (2011) use an approach similar to that proposed by Biewen (2014). They generate counterfactual distributions to assess the importance of source-side (income sources) and use-side of income (consumption) effects for the overall impact of a carbon tax on households' incomes. In the first counterfactual, Rausch et al. (2011) equalizes the composition of the consumption basket across households. In the second counterfactual, they equalize the source of income factors across households. Similar approaches are taken in Wu et al. (2022) and Goulder et al. (2019).

Other decomposition approaches were used by Dorband et al. (2019) and Feindt et al. (2021). Studying 87 low and middle-income countries, Dorband et al. (2019) exploits deviations in household budget shares from the national average and in the carbon intensity of sectors from the average carbon intensity of consumption to show that distributional outcomes are primarily driven by energy budget shares. They however do not assess the importance of budget shares and carbon intensity individually. Feindt et al. (2021) decompose the distributional impact of carbon taxation along multiple lines. They first show carbon tax burdens related to direct, indirect, and electricity-related emissions across the income distribution for multiple countries. Next, they show that EU-wide distributional impact

[2]This approach has been applied to study changes in income inequality over time in the US (DiNardo et al., 1996), in Germany (Biewen and Juhasz, 2012) and Australia (Li et al., 2022)

[3]Interaction effects can be decomposed further by simultaneously equalizing two factors, and assigning the excess change in inequality beyond the change in inequality due to individual factors to the interaction between the two factors (Biewen, 2014).

is primarily driven by differences in carbon tax burdens between countries, rather than differences within-country variation or horizontal inequalities. Lastly, they show that the largest contribution to between-country differences in carbon tax burdens is due to differences in the average carbon intensity of the transport and domestic sector in poorer countries, as well as higher average budget shares of the domestic sector in poorer countries. They however focus primarily on decomposing the carbon tax's distributional impact across EU countries, and not across households within countries as done in this paper.

This paper adapts the approach proposed by Biewen (2014) to decompose the distributional impact of a carbon tax within countries into contributions due to budget shares, carbon intensity, asset ownership, and savings rates, and compares the role of these factors across countries. The next section discusses the role of these factors in the carbon tax burden and describes our decomposition approach.

# 3 Methodology

This section focuses on the composition of the carbon tax burden and presents the decomposition approach taken in this paper. A more extensive treatment of the modelling approach of carbon tax payments is provided in O'Donoghue et al. (2023) and Immervoll et al. (2023).

## 3.1 Components of the Inequality in the Carbon Tax Incidence

This paper decomposes the impact of a carbon tax on income inequality and regressivity indicators. Equation 1 summarizes the components of carbon tax payments and their impact on disposable income. Disposable income after a carbon tax can be expressed as:

$$Y_{hc} = Y_h - \sum_i (Y_h * (1 - s_h) * w_{ih} * \frac{e_{ih}}{p_{ih}} * I_{ih}) * P_{tCO_2} \tag{1}$$

where subscript $h$ denotes the household, $Y$ is the household disposable income, $s$ is the savings rate, $w_{ih}$ is the budget shares of expenditure group $i$, $e_{ih}$ is the carbon intensity of expenditure category $i$ of household $h$, expressed as tons of $CO_2$ per unit (kwh for energy goods and euro for non-energy goods), $p_{ih}$ is the price per unit paid by household $h$, and $I_{ih}$ is an indicator variable that is 1 if a household owns a carbon-emitting asset and 0 otherwise. Households are considered to own a carbon-emitting asset if they have positive expenditure on fuels used as input to the asset. Households with positive expenditure on home fuels are considered to own a combustion-based heating system. Households with positive expenditure on motor fuels are considered to own an Internal combustion engine (ICE) vehicle. Finally, $P_{tCO_2}$ denotes the carbon price per ton of $CO_2$. The set of expenditure groups consists of four items ($i = 4$), home fuel, motor fuel, electricity, and other goods and services.

All components of Equation 1, except the carbon price, vary across households. The unequal distribution of these factors across households produces different carbon tax payments across households. The extent to which each factor contributes towards the unequal impact of the carbon tax across households is however unclear. A useful starting point is to study how each factor varies along the income distribution. Savings rates ($s$) are commonly higher at the top and negative at the bottom of the disposable income distribution Dynan et al. (2004). The relationship between budget shares ($w$) and income ($Y$) depends on the good. Food is a necessity and its budget share falls with income (Engel, 1895). Purchased energy can be a luxury or a necessity depending on the context Dorband et al. (2019). The relationship between carbon intensity ($e$) and income is less well understood, and may also vary across countries Farrell (2017); Renner (2018). Similarly, average prices depend on the composition of the expenditure category, with wealthier households likely purchasing more expensive goods. Lastly, wealthier households are more likely to ICE vehicles (Dorband et al., 2019; Farrell, 2017), but it is unclear whether wealthy households are more likely to own electric heating and cooking appliances. With each of the components differing across households and along the income distribution, it becomes difficult to disentangle the contribution of each factor to distributional impact of a carbon tax.

### 3.2 Decomposing the distributional impact of carbon taxation

To decompose the distributional impact of the carbon tax, we construct counterfactual disposable income distributions, replacing one factor of Equation 1 with the country population average at the time, holding all other factors constant, if possible [4]. Equalizing factors across the population eliminates the variation in the impact of the carbon tax on disposable income due to that factor. We then compare the factual and counterfactual distributions, with the difference indicating the contribution of that factor to the distributional impact of the carbon tax. By changing only one factor at a time, we estimate direct ceteris paribus effects.

A carbon tax is levied proportionally to the amount of carbon emissions emitted in the production or consumption of goods and services. Carbon emissions from household consumption can be expressed as:

$$tCO_{2h} = \sum_i (Y_h * (1 - s_h) * w_{ih} * \frac{e_{ih}}{p_{ih}} * I_{ih}) \tag{2}$$

We utilize the same notation described above for Equation 1.

The counterfactual distribution with equalized savings for all households is given by:

$$tCO^s_{2h} = \sum_i (Y_h * (1 - \bar{s}) * \frac{w_{ih}}{p_{ih}} * e_{ih} * I_{ih}) \tag{3}$$

[4]Country population averages are calculated using the sub-sample of households with positive expenditure on a good and therefore represent conditional population averages.

where superscript $s$ indicates the savings rate counterfactual, and $\bar{s}$ stands for average savings rate. By equalizing savings rates across households, we increase (decrease) the expenditure for households with above-average (below-average) savings rates, and thus their carbon emissions.

The counterfactual distribution with equalized carbon intensity for all households is given by:

$$tCO_{2h}^{e} = \sum_{i}(Y_h * (1 - s_h) * \frac{w_{ih}}{p_{ih}} * \bar{e_i} * I_{ih}) \tag{4}$$

where $\bar{e_i}$ stands for average carbon intensity. In this scenario, households retain their original volume of energy consumption but receive the average carbon intensity per kwh. Carbon emissions thus increase (decrease) for households consuming relatively less (more) carbon-intensive products and fuels[5]. Importantly, in constructing the carbon intensity counterfactual, we use the carbon intensity per kwh of energy goods rather than the carbon intensity per euro to maintain differences in the volume of consumption across households[6]. The carbon intensity of electricity for households is not affected as households within the same country are assumed to consume the same electricity.

The counterfactual distribution with equalized budget shares is given by:

$$tCO_{2h}^{w} = \sum_{i}(Y_h * (1 - s_h) * \frac{\bar{w_i}}{p_{ih}} * e_{ih} * I_{ih}) \tag{5}$$

where $w_i$ stands for average budget share of expenditure group $i$. Budget shares are the expenditure on group $i$ divided by total household expenditure for household $h$. In order to distinguish the impact of the budget shares from that of asset ownership, we compute different budget shares for households that own all energy-consuming assets (ICE vehicles and combustion-based heating systems), those that do not own any energy-consuming assets, and those that only own one type of asset but not the other. For example, households that do not own assets receive a budget share of zero for motor fuels and home fuels respectively. Therefore, the budget shares counterfactual is constructed using four different sets of average budget shares. Whether wealthier (poorer) households emit more (less) carbon emissions under this depends on whether energy goods are necessities or luxury goods.

To assess the impact of asset ownership, we construct a counterfactual distribution where all households own ICE vehicles and/or combustion-based heating systems. Effectively, this means that positive expenditure on energy

[5]For the expenditure group "Other goods and services", we effectively assume that all households consume the same proportions non-energy products, i.e. for all households, food represents the same share of the "Other goods and services" expenditure category. Arguably, the carbon intensity counterfactual, therefore, picks up some of the effects of the budget share counterfactual, through the composition of the "Other goods and services category". As household carbon tax emissions are primarily driven by energy-related emissions and the variation in carbon intensity of across components of the "Other goods and services" category is relatively small, the impact of this assumption on the results is small. Future work could further disaggregate the expenditure categories used in this application.

[6]If we equalize the carbon intensity per euro (equalizing both carbon intensity per kwh and price per kwh), we reduce the volume of energy consumed by households that consume relatively cheap fuels and increase the volume of energy consumed by households that consume relatively expensive fuels. We would hence overestimate the contribution of carbon intensity to the total carbon tax burden, as its effect would be confounded with that of differences in the volume of energy consumed.

goods is assigned to all households, replacing budget shares, carbon intensity, and price of households that do not own these assets by population average values of the subset of households that own these assets. For households that do not own an asset in the factual distribution, this requires that we adjust their budget shares to ensure that they sum to 1.

To allow for substitution between expenditure groups, we adjust the budget shares allocated to direct substitutes of home and motor fuels. The pairs of direct substitutes are home fuels and electricity, and motor fuels and public transport. For example, for a household that is assigned ICE vehicle ownership in this counterfactual, we reduce their budget share of the substitution public transport[7].

Let the set of households owning carbon emitting assets be $N$. Using $N$, we can omit $I$ from Equation 2, and write the counterfactual distribution as:

$$tCO_{2h}^{I} = \begin{cases} \sum_i ((Y_h * (1 - s_h) * w_{ih}/p_{ih}) * e_{ih}) & \forall \;\; h \in N \\ \sum_i ((Y_h * (1 - s_h) * \bar{w_i}/\bar{p_i}) * \bar{e_i}) & \forall \;\; h \notin N \end{cases} \tag{6}$$

Note that the construction of this counterfactual scenario requires that for all $h \notin N$, $p_i = \bar{p_i}$. Note also that $p_i = \bar{p_i}$ only for commodities affected by the asset (e.g. motor fuels by ICE vehicle ownership), but remain $p_i$ for all other commodities. We distinguish between two types of assets, ICE vehicles $V$ and combustion-based heating systems $H$.

The changes to each of the components for all counterfactual scenarios is summarized in Figure 1. In each counterfactual scenario, except both asset ownership scenarios, only the component of interest is equalized. In both asset ownership counterfactuals, budget shares and carbon intensities are replaced by average values for households that previously did not consume fuels used as input to the assets and therefore had budget shares and carbon intensity of zero.

After computing counterfactual carbon emissions from household consumption for each household, we compute carbon tax payments for factual and counterfactual carbon emissions. Households' carbon tax payments are found by multiplying $tCO_{2h}$ by the carbon price per ton of $CO_2$.

$$CT_h = tCO_{2h} * P_{tCO_2} \tag{7}$$

where $CT_h$ stands for carbon tax paid by household $h$ and $P_{tCO_2}$ denotes the carbon price per ton of $CO_2$.

[7] The extent to which the budget share of the substitute is reduced is determined using linear regression. We first estimate the relationship between the budget share of the substitute and the binary variable for asset ownership, controlling for a number of socioeconomic and demographic characteristics. We then use the estimated coefficient on the asset ownership variable to reduce the budget share of the substitute for households that previously did not own the asset. Finally, all budget shares are adjusted proportionally so that the sum of budget shares is 1. Public transport is part of the "Other goods and services" expenditure group

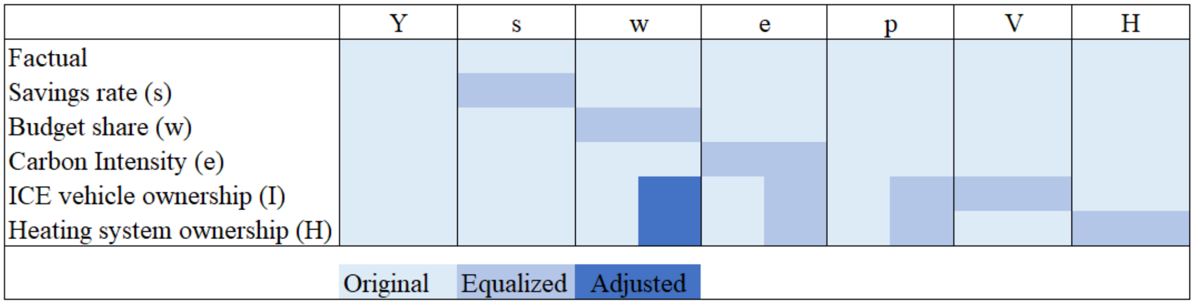



Figure 1: Diagram of changes under counterfactual distributions. Cells in row ICE vehicle ownership and Heating system ownership and columns w, e, and p are split because we assign original values for w, e, and p to households that own ICE vehicles and/or combustion-based heating systems, but we assign average values of w, e, and p to households that do not own the asset under factual distribution. Formula for calculation of consumption carbon emissions: $tCO_{2h} = \sum_i (Y_h * (1 - s_h) * w_{ih} * \frac{e_{ih}}{p_{ih}} * I_{ih})$

Finally, households' post-carbon tax disposable income is found by subtracting carbon tax payments from pre-tax household disposable income:

$$Y_{hc} = Y_h - CT_h \tag{8}$$

Next, we compute a suite of inequality indicators for each country using the factual and counterfactual income distributions. We illustrate the approach using the Gini index. Other inequality or regressivity indicators can be decomposed using the same approach (Shorrocks et al., 1999; Shorrocks, 2013). We first compute the Gini index of the pre-carbon tax disposable income distribution $G_h$, factual post-carbon tax disposable income distribution $G_{hc}$, and counterfactual post-carbon tax disposable income distribution $G^s_{hc}$, $G^e_{hc}$, $G^w_{hc}$, and $G^I_{hc}$.

We first calculate the change in the Gini index due to the carbon tax, $D^o$:

$$D^o = G_{hc} - G_h \tag{9}$$

Next, we compute the change in Gini index under each counterfactual scenario, using the post-carbon tax income distribution as a baseline. For example, the direct ceteris paribus effect of carbon intensity on the Gini index is given by:

$$D^e = G_{hc} - G^e_{hc} \tag{10}$$

Finally, the change in Gini in Equation 9 can be written as

$$D^o = (D^s + D^e + D^w + D^I) + (D^o - (D^s + D^e + D^w + D^I)) \tag{11}$$

where the first term on the right-hand side of the equation gives the direct effects due to the individual factors and the second term gives the residual effect, due to interaction effects between the factors. The relative contribution of each factor is computed as the direct effect divided by the total change in the Gini coefficient due to the carbon tax $D^o$.

Other inequality or progressivity indicators can be decomposed following the same approach. This paper also decomposes the Suits index of tax progressivity (Suits, 1977). The Suits index is a concentration index of the tax incidence along the income distribution and can be written as:

$$S = 1 - \frac{1}{K}\int_0^{100} T_x(y) d_y \tag{12}$$

where $K$ is the area below the line of perfect equality, $y$ are disposable income centiles and $T_x$ is the relative accumulated tax burden of a household. This can also be written as

$$S = 1 - \frac{L}{K} \tag{13}$$

where $L$ is the area below the Lorenz curve of the carbon tax minus $K$. For a proportional tax $K = L$ and $S = 0$. It ranges from -1 (perfectly regressive) to 1 (perfectly progressive). Relative to the Gini index and the related Kakwani index of progressivity, it puts a higher weight on the tails of the distribution.

### 3.3 Computing carbon emissions associated with households consumption

Modelling $CO_2$ emissions from household consumption requires information on households' fuel consumption and the carbon intensity of the fuels consumed and information on the carbon emissions associated with the production process of other goods and services.

The consumption of fuels by households produces direct emissions. To estimate direct emissions, we source prices and carbon intensity factors for fuels, such as gas, solid fuels, diesel, and petrol, for each country. Combining this information with expenditure data from HBS, we compute the quantity of fuel consumed and the carbon intensity of the energy mix consumed by each household for motor fuels and home fuels. For each expenditure group, direct carbon emissions per euro are calculated as:

$$dir_{ih} = \sum_j (\frac{e_j}{p_j}) \tag{14}$$

where $dir_{ih}$ refers to the direct carbon emissions per euro of expenditure group $i$ and household $h$, subscript $j$ refers to goods that fall within expenditure category $i$, such as petrol and diesel for motor fuels. Both $e_j$ and $p_j$ are expressed as tons of $CO_2$ per kwh and price per kwh respectively. Note that for all non-fuel expenditure categories, $dir_{ih}$ is zero.

Household consumption produces indirect emissions, associated with the production process of goods and services. To compute indirect emissions, we use economy-wide information showing linkages between industries and carbon emissions by industry. We utilize a multi-regional input-output table (MRIO) provided by the World Input-Output Database (WIOD) (Timmer et al., 2015), mapping monetary flows across 56 industries in 44 countries, keeping with the latest advances in the field (Feindt et al., 2021; Dorband et al., 2019; Lévay et al., 2021). To transform the WIOD into an Environmentally extended MRIO (EE-MRIO), we assign carbon intensity factors to the three energy industries present in the WIOD based on the EU-average input structure used by these industries[8]. The carbon intensity of the consumption of non-energy goods and services therefore reflects the energy inputs used in the production of these goods and services[9]. This paper simulates a carbon tax on domestic energy-related emissions, i.e. only emissions produced within a country are subject to the tax. This more closely resembles current practice. Miller and Blair (2009) provides an extensive discussion of Input-Output analysis. Kitzes (2013) provides an introduction to environmentally extended Input-Output analysis. A more extensive treatment of our approach can be found in O'Donoghue et al. (2023) and Immervoll et al. (2023).

To map industries' carbon emissions onto households' total carbon footprint, MRIO, and household expenditure information need to be matched. HBS data commonly reports households' consumption expenditure across different consumption purposes (COICOP). WIOD tables report household final consumption expenditure in industry output terms (NACE rév 2). Matching information from WIOD tables to HBS data necessitates translating goods by consumption purpose into industry outputs using a bridging matrix (Mongelli et al., 2010). A bridging matrix maps the use of a product to satisfy a consumption purpose. The integration of HBS data into multisectoral models is described in Mongelli et al. (2010) and Cazcarro et al. (2022). The present paper utilizes bridging matrices supplied by Cai and Vandyck (2020).

Finally, the total carbon intensity per euro of household expenditure is calculated by adding direct and indirect

[8] The three energy industries are Mining and quarrying, Manufacturing of coke and refined petroleum products, and Electricity, gas, steam, and air conditioning supply.

[9] An alternative approach is to use data on CO2 Emissions by industry published by the European Commission Joint Research Centre (Arto et al., 2020), which includes energy-related, process-related, and fugitive emissions.

emissions:

$$c_h = \sum_i (dir_i + ind_i) \tag{15}$$

# 4 Data

This analysis utilizes two main data sources; Household Budget Surveys (HBS) and the World Input Output Database (WIOD). We used the most recent available HBS data for each country. For all countries except Luxembourg, we use the 2015 wave of the European Union HBS (EU-HBS), provided by Eurostat. For Luxembourg, we use the 2020 wave of the HBS (LU-HBS), provided by Statec. The data sets are representative of the population and are comparable[4]. They contain detailed information on household expenditures by item, household composition, socioeconomic and demographic characteristics of household members, and household disposable incomes. We group expenditure items into 19 expenditure groups. We assign a value of indirect carbon emissions per Euro to each expenditure group. For home fuels and motor fuels, we further differentiate direct carbon emissions for their sub-components. Home fuel is composed of liquid fuels, gas, solid fuels, and district heating. Motor fuel is composed of Diesel and Petrol.

The 2016 release of WIOD includes 56 industries and 44 large economies, including the "Rest of the World". The WIOD allows us to trace energy inputs embedded in the production of goods and services down the supply chain. The carbon intensity of energy inputs used by industries results from the fuel mix used by domestic energy industries. The composition of energy industries' fuel mix is sourced from UNIDO MINSTAT.

Fuel price data was collected from different sources. Natural gas and electricity prices are provided by Eurostat, except for Finland where data is provided by Statistics Finland. Prices of oil products (Diesel, Petrol, Heating oil) are taken from the European Commission Weekly Oil Bulletin. Solid fuel prices were provided by National Statistical Offices upon request. District heating prices are sourced from Werner (2016). Carbon Intensity factors are sourced from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. For district heating, carbon intensity per kwh is sourced from Werner (2017) and Jonynas et al. (2020).

# 5 Results

Households' carbon tax burden depends on their consumption patterns, energy use, the type of energy consumed, the assets owned by the household, and how much they consume relative to their income. Distributional impacts of carbon taxation in turn result from the distribution of these factors across the population. This section first shows how these factors are distributed along the income distribution in each country. It then shows the carbon tax burden along the income distribution. Finally, it decomposes the carbon tax burden and its impact on inequality and regressivity indicators.

[4]Some differences across data sets remain due to differences in sampling design and differences in the calculation of imputed rents.

## 5.1 Distribution of Energy Consumption and Carbon Emissions

A carbon tax is levied in relation to the carbon emissions associated with the consumption of goods and services. The carbon tax burden describes how carbon tax incidence relates to disposable. Table 1 shows savings rates, disposable income, energy consumption, and carbon emissions per equivalized disposable income quantile. Low-income households spend more than they earn in income in all countries. As a carbon tax is levied in relation to consumption, carbon tax payments as a share of income are higher for low-income households than high-income households, holding all else equal. Additionally, the difference in income between low and high-income households is larger than the difference in energy consumption, indicating that energy is a necessity. Across countries, the ratio of energy consumption between low and high-income households is much larger in poorer countries than in rich countries, suggesting that in poorer countries fuel poverty may be more prevalent.

The direct CO2 emissions (resulting from the combustion of motor fuels and home fuels) per unit of energy consumed however differs across countries, indicating differences in the energy mix consumed by households across countries. Similarly, it appears that in Hungary, Lithuania, and to a lesser extent Ireland and Luxembourg, low-income households consume more carbon-intensive fuels. In Portugal and Finland, the reverse is true. Lastly, comparing the ratios of energy consumption between low and high-income households across countries reveals that this ratio is much larger in Portugal and Finland than elsewhere.

## 5.2 Asset Ownership

An important factor shaping households' carbon tax incidence is their asset ownership. We focus on two types of assets, internal combustion engine (ICE) vehicles, and combustion-based heating systems, i.e. heating systems that use fossil fuels or biomass as inputs.

Figure 2 shows asset ownership across disposable income ventiles. Ownership of combustion-based heating systems is high in all countries except Finland, where electric heating systems are more common. In Lithuania, Ireland, and Finland, combustion-based heating is more common among high-income than low-income households.

ICE vehicle ownership is more common among high-income households in all countries. ICE vehicle ownership is highest in Portugal and Ireland[10] Additionally, ICE vehicle ownership increases close to linearly with income in poorer countries, but approximates an inverted U curve in wealthier countries.

To better understand asset ownership, we regress ownership on household expenditure and demographic characteristics. Regression results are provided in Table 11 and 12 in the appendix. The regression analysis reveals that this simple model predicts heating system ownership poorly in Portugal, Ireland, and Luxembourg, and performs better in Lithuania and Finland. Household structure and socioeconomic indicators are not consistently significantly related to heating system ownership across countries. Overall, heating system ownership is only consistently related

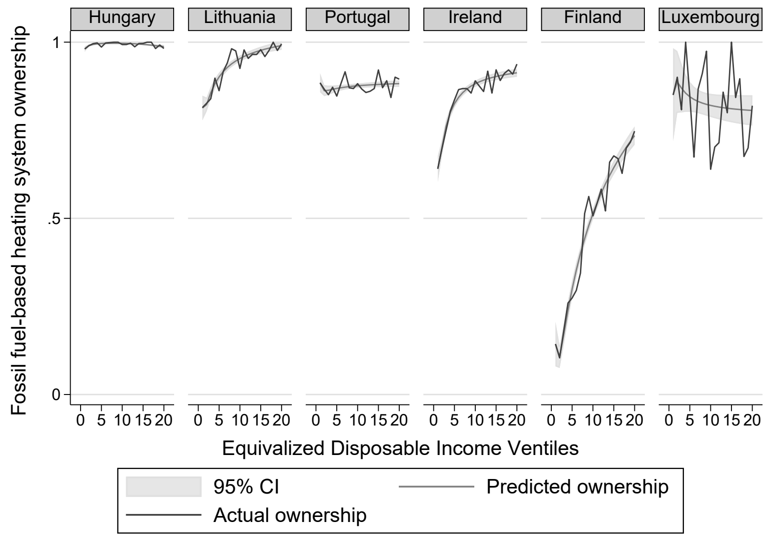
[10] Households are considered to own ICE vehicles if they have positive expenditure on diesel or petrol used for private transportation. HBS data underestimates ICE vehicle ownership, particularly in Luxembourg, where many households benefit from company cars. Ownership of company cars and fuel expenditure covered by employers are not included here.

Table 1: Savings rate, disposable income, Volume (in kwh) and Tons of CO2 per equivalized disposable income quintile

| | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| Savings rate | | | | | | |
| Bottom quintile | -0,14 | -0,19 | -0,34 | -0,61 | -0,16 | -0,29 |
| 2 | 0,05 | -0,00 | -0,01 | 0,11 | 0,09 | -0,02 |
| 3 | 0,08 | 0,01 | 0,07 | 0,21 | 0,14 | -0,13 |
| 4 | 0,12 | 0,05 | 0,12 | 0,25 | 0,19 | 0,10 |
| Top quintile | 0,22 | 0,17 | 0,25 | 0,37 | 0,28 | 0,31 |
| Average | 0,06 | 0,01 | 0,02 | 0,07 | 0,11 | -0,00 |
| Disposable income (eqv.) | | | | | | |
| Bottom quintile | 3.368 | 3.431 | 5.986 | 13.693 | 13.913 | 24.198 |
| 2 | 5.130 | 4.962 | 9.553 | 22.362 | 21.792 | 35.104 |
| 3 | 6.460 | 6.472 | 12.596 | 30.832 | 28.382 | 44.279 |
| 4 | 8.137 | 8.436 | 16.911 | 40.727 | 35.973 | 58.013 |
| Top quintile | 12.776 | 13.014 | 30.901 | 63.893 | 57.409 | 100.444 |
| Average | 7.173 | 7.259 | 15.188 | 34.297 | 31.486 | 52.279 |
| Volume - kwh (eqv.) | | | | | | |
| Bottom quintile | 13.766 | 10.141 | 7.942 | 15.181 | 5.957 | 19.365 |
| 2 | 17.140 | 12.935 | 11.304 | 19.524 | 9.916 | 20.906 |
| 3 | 18.564 | 14.118 | 12.675 | 21.655 | 14.044 | 22.334 |
| 4 | 20.777 | 14.585 | 14.523 | 23.691 | 16.542 | 25.658 |
| Top quintile | 23.071 | 17.928 | 18.980 | 27.453 | 20.410 | 23.808 |
| Average | 18.667 | 13.937 | 13.084 | 21.487 | 13.371 | 22.397 |
| Tons of direct CO2 (eqv.) | | | | | | |
| Bottom | 3,84 | 2,8 | 1,63 | 3,66 | 0,97 | 3,99 |
| 2 | 4,45 | 3,32 | 2,64 | 4,73 | 1,89 | 4,2 |
| 3 | 4,6 | 3,03 | 2,89 | 5,08 | 2,71 | 4,52 |
| 4 | 4,93 | 2,73 | 3,28 | 5,51 | 3,29 | 5,36 |
| Top | 5,24 | 3,25 | 4,36 | 6,32 | 3,86 | 4,71 |
| Average | 4,61 | 3,03 | 2,96 | 5,06 | 2,54 | 4,55 |

Volume is calculated as the sum of home fuel, motor fuel and electricity expenditure dividing their price. We assume no standing charge and we assume that all households within a country face the same volumetric price.

(a) combustion-based heating system ownership.




(b) Internal combustion engine (ICE) vehicle ownership

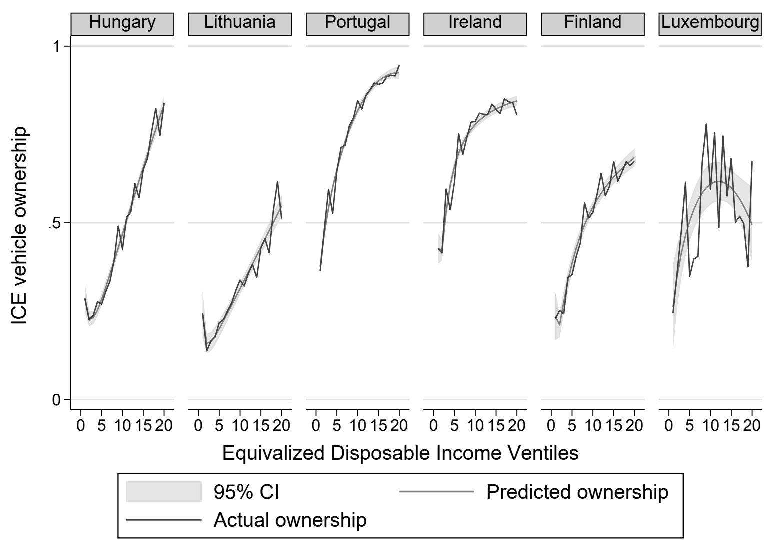



Figure 2: Average asset ownership by equivalized disposable income ventiles, actual and predicted from estimating a fractional polynomial of disposable income on asset ownership.

to expenditure.

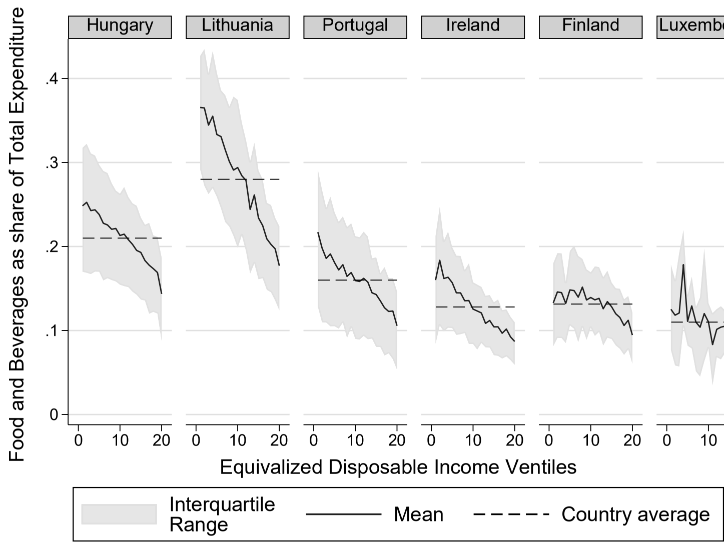
The model performs better for ICE vehicle ownership and performs best in poorer countries. ICE vehicle ownership is significantly associated with expenditure in all countries. Living in rural areas and being married is positively and significantly associated with ICE vehicle ownership, except in Luxembourg.

### 5.3 Consumption Patterns

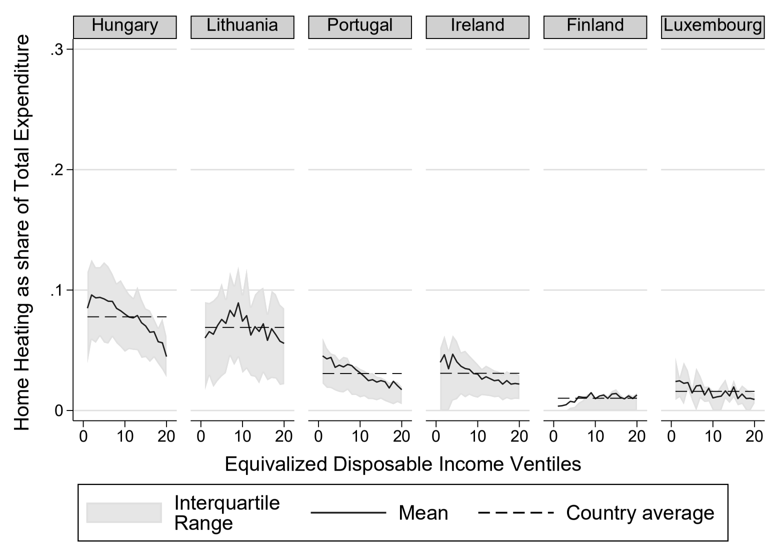
Figure 3 shows budget shares for the four most carbon-intensive expenditure categories; Food and non-alcoholic Beverages, Home Fuel, Electricity, and Motor Fuel. Home fuels are used for heating and cooking, motor fuels are used for transportation, and electricity is used for heating, cooling, and to power electronic appliances.

Figure 3 shows mean budget shares at each ventile along the disposable income distribution and compares it to country average values. In line with Engel's law (Engel, 1895), falling food budget shares with income reflect wealth differentials across households and countries. Heating fuel and electricity follow similar distributional patterns, indicating that they are necessities. These patterns are consistent across countries, except in Finland. In Finland, wealthier households spend more on home fuels. As shown in Figure 2, home fuel consumption is uncommon among low-income households in Finland. Mean motor fuel budget shares increase with income, indicating that they are a luxury good. In wealthier countries, the distribution of motor fuel expenditure is flatter in the middle of the distribution and follows an inverted U-shape. Focusing on mean budget shares only is however misleading, as lower mean budget shares among low-income households result from lower rates of ICE vehicle ownership as shown in Figure 2. Motorized low-income households dedicate a similar or higher budget share to motor fuels relative to high-income households (see Appendix 8), so that motor fuels may be considered a necessity among motorized households.

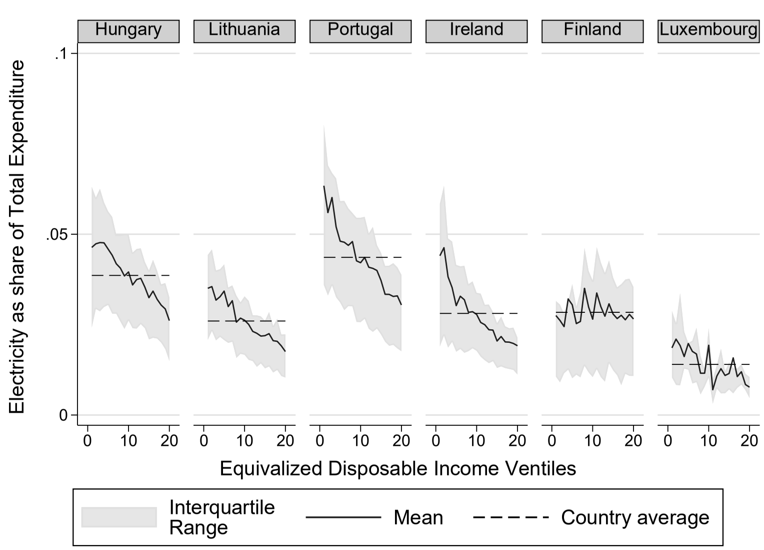
(a) Food and non-Alcoholic Beverages Budget Share.




(b) Home Fuel Budget Share




(c) Electricity Budget Share




(d) Motor Fuel Budget Share

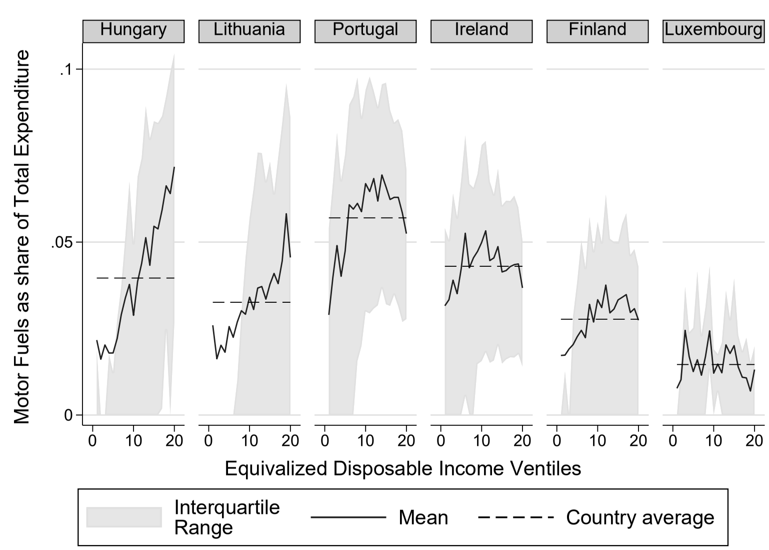



Figure 3: Budget shares of carbon-intensive goods by equivalized disposable income deciles. The interquartile range shows the range between the $25^{th}$ and the $75^{th}$ percentile.

## 5.4 Energy Mix and Carbon Intensity

The extent to which living costs are affected by a carbon tax depends on the level of energy consumption, the energy mix consumed, and the carbon intensity of that energy. Table 2 shows differences in the carbon intensity of energy commodities. Solid fuels, such as coal and wood, are the most carbon-intensive, followed by liquid fuels. Natural gas is less carbon-intensive than liquid and solid fuels but is twice as carbon-intensive as EU average heat energy.

Table 2: Carbon intensity per kwh by energy commodity

| | Liquid fuel | Natural gas | Coal | District heat | Firewood |
|---|---|---|---|---|---|
| kgCO2 per kwh | 0,259 | 0,202 | 0,403 | 0,108 | 0,403 |

Direct emissions only. Does not include indirect emissions released during the production process and transportation. The value for district heat represents an EU average.

Figure 4 shows that the composition of the home fuel energy mix can vary substantially along the income distribution and across countries. In Hungary, Lithuania, and Ireland, low-income households rely more heavily on carbon-intensive solid fuels. Simultaneously, high-income households more commonly have access to low-carbon district heating in Hungary and Lithuania, while the reverse is true in Finland. In Portugal, Luxembourg, and Finland, differences in the energy mix consumed are less pronounced than in Hungary, Lithuania, and Ireland. Differences in energy mix can be explained by price and access to energy infrastructure. Solid fuels are the cheapest fuel (see Appendix 10) and district heating is only accessible to urban households.

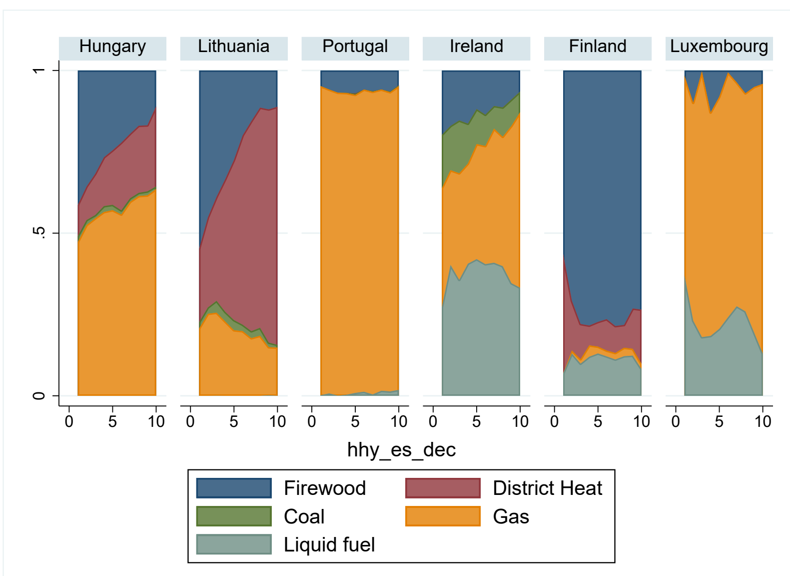



Figure 4: Composition of home fuel by fuel.

Table 3 summarizes average carbon intensity and price for energy commodities across countries. On average, the most carbon-intensive home fuel energy mix is found in Ireland and Finland, and the least carbon-intensive home fuel energy mix in Lithuania, where 52% of home fuel expenditure is allocated to low-carbon district heating (see Appendix 2). The carbon intensity of motor fuels is similar across countries.

Price differences across countries are large, particularly for home fuels. Cross-country differences in prices result from differences in fuel mix and taxation. Home fuel is cheapest in the poorest and richest countries of our sample, and most expensive in Portugal. In all countries, prices for home fuels are substantially lower than prices for motor fuels. The price change of motor fuels due to the carbon tax results from a combination of the carbon intensity and initial price levels. Prices in Hungary, Lithuania, and Finland change most. In Finland, the price change is large because of the high indirect emissions associated with the production of home fuels on the national territory. Similarly, price changes of motor fuels for Ireland and Luxembourg are lower than elsewhere because indirect emissions associated with motor fuels are not produced on the national territory.

Table 3: Average price, carbon intensity, and price change due to a €30 carbon tax (in 2015)

| | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| Home fuel | | | | | | |
| kg of CO2 per kwh | 0,238 | 0,211 | 0,215 | 0,271 | 0,350 | 0,226 |
| Euro per kwh | 0,036 | 0,046 | 0,094 | 0,067 | 0,064 | 0,045 |
| kg of CO2 per Euro | 8,057 | 7,311 | 2,426 | 4,007 | 5,772 | 5,017 |
| Price change with €30/tCO2 tax* | 36,3% | 31,3% | 15,4% | 14,6% | 25,8% | 18,3% |
| Price change due to VAT tax* | 7,7% | 4,7% | 7,7% | 1,2% | 5,0% | 7,7% |
| Motor fuel | | | | | | |
| kg of CO2 per kwh | 0,251 | 0,256 | 0,259 | 0,257 | 0,254 | 0,257 |
| Euro per kwh | 0,113 | 0,111 | 0,122 | 0,129 | 0,141 | 0,117 |
| kg of CO2 per Euro | 2,229 | 2,339 | 2,157 | 2,008 | 1,818 | 2,242 |
| Price change with €30/tCO2 tax* | 11,5% | 11,9% | 13,0% | 6,3% | 10,7% | 6,8% |
| Price change due to VAT tax* | 3,1% | 2,5% | 1,7% | 1,4% | 2,6% | 1,2% |

Authors' own calculation. Source: UNFCCC, Eurostat, EC Weekly Oil Bulletin, Statistics Finland, Statec, CSO, Statistics Portugal, Hungarian Central Statistical Office, EU-HBS, WIOD, EEA. Values represent average values for the population of households with positive expenditure on the expenditure group. Kg of CO2 per kwh includes direct emissions only. *Price change with €30/tCO2 tax includes direct and indirect emissions.

Table 4 shows differences in average carbon intensity and price of home fuels along the income distribution. In Hungary, Lithuania, and Ireland, low-income households consume a more carbon-intensive fuel mix than high-income households. Simultaneously, the price of home fuel is notably lower for low-income households in Hungary and Lithuania. The combination of carbon-intensive fuel and low prices means that CO2 per euro spent is much higher among low-income households in Hungary and Lithuania. Consequently, low-income households experience larger increases in home fuel costs due to a carbon tax. In Finland, low-income households consume less carbon-intensive fuel and their home fuel cost is impacted less by a carbon tax.

### 5.5 Distributional Impact of a Carbon Tax

Figure 5 compares the initial distributional impact of a carbon tax across equivalized disposable income and expenditure deciles. Panel (a) shows the carbon tax as a share of total expenditure across expenditure deciles,

Table 4: Home fuel price, carbon intensity and price change across disposable income deciles

| Income deciles | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| kg of CO2 per kwh | | | | | | |
| Bottom quintile | 0,273 | 0,283 | 0,213 | 0,288 | 0,319 | 0,231 |
| Median quintile | 0,234 | 0,204 | 0,216 | 0,272 | 0,356 | 0,224 |
| Top quintile | 0,211 | 0,160 | 0,214 | 0,251 | 0,342 | 0,221 |
| Euro per kwh | | | | | | |
| Bottom quintile | 0,032 | 0,035 | 0,095 | 0,068 | 0,067 | 0,046 |
| Median quintile | 0,037 | 0,047 | 0,094 | 0,067 | 0,064 | 0,045 |
| Top quintile | 0,039 | 0,054 | 0,095 | 0,067 | 0,065 | 0,044 |
| kg of CO2 per Euro | | | | | | |
| Bottom quintile | 10,107 | 11,719 | 2,379 | 4,226 | 5,184 | 4,992 |
| Median quintile | 7,830 | 6,854 | 2,446 | 4,026 | 5,871 | 4,990 |
| Top quintile | 6,503 | 4,369 | 2,412 | 3,740 | 5,607 | 5,006 |
| Price change with €30/tCO2 tax* | | | | | | |
| Bottom quintile | 35,5% | 40,6% | 12,4% | 14,0% | 19,0% | 16,8% |
| Median quintile | 27,9% | 25,4% | 12,6% | 13,4% | 21,1% | 16,8% |
| Top quintile | 23,3% | 17,0% | 12,4% | 12,6% | 20,3% | 16,9% |
| Price change due to VAT tax* | | | | | | |
| Bottom quintile | 9,6% | 7,8% | 2,8% | 1,3% | 4,6% | 1,3% |
| Median quintile | 7,5% | 4,4% | 2,9% | 1,2% | 5,1% | 1,3% |
| Top quintile | 6,3% | 2,5% | 2,8% | 1,1% | 4,9% | 1,4% |

Authors' own calculation. Source: UNFCCC, Eurostat, EC Weekly Oil Bulletin, Statistics Finland, Statec, CSO, Statistics Portugal, Hungarian Central Statistical Office, EU-HBS, WIOD, EEA. Values represent average values for the population of households with positive expenditure on the expenditure group. Kg of CO2 per kwh includes direct emissions only. *Price change with €30/tCO2 tax includes direct and indirect emissions.

effectively showing the carbon intensity of a euro of expenditure. The carbon tax as a share of expenditure is slightly regressive or proportional in all countries, except Finland where it is progressive. In most countries, high-income households have less carbon-intensive consumption baskets.

Most low-income households spend more than their income, so their ability to cope with increased prices may be overestimated using expenditure as a reference metric. Panel (b) shows the carbon tax as a share of household disposable income. In all countries, the carbon tax as a share of household disposable income is larger for the poorest and thus regressive, but close to proportional in Finland. The impact on households in poorer countries is larger. The impact on the richest in poorer countries is comparable to the impact on the poor in the richest countries. Additionally, the within-decile variance is substantially larger among low-income households and in low-income countries, than among wealthier households and countries.

(a) Carbon Tax payments as share of household expenditure.

(b) Carbon Tax payments as share of household disposable income.

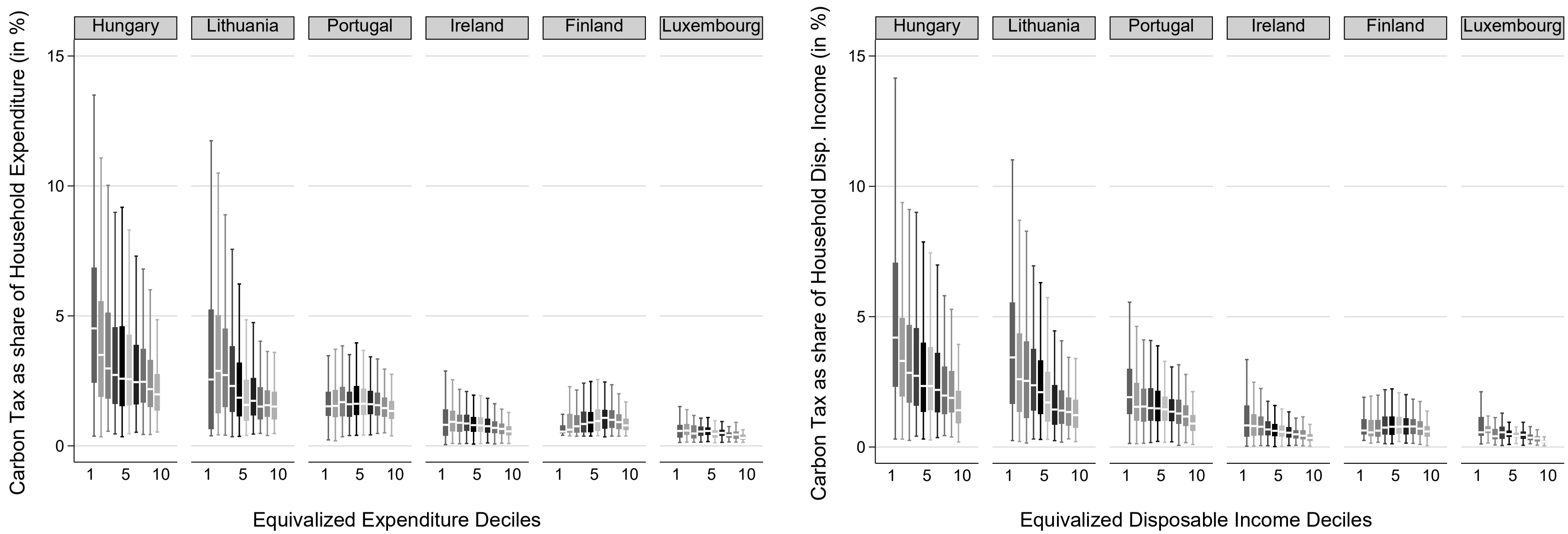



Figure 5: National Carbon Tax burden by expenditure and equivalized household disposable income deciles. Each column represents one decile, ordered from lowest to highest decile. The white line marks the median, and the box represents the interquartile range from the $25^{th}$ to the $75^{th}$ percentile. The whiskers indicate the range from the $5^{th}$ to the $95^{th}$ percentile.

## 5.6 Decomposing the distributional impact of a carbon tax

To understand the drivers of the distributional impact of the carbon tax, we apply two decompositions. First, we decompose carbon tax payments into parts due to home fuel consumption, motor fuel consumption, electricity consumption, and indirect emissions. Second, we decompose the impact of the carbon tax on disposable income inequality and carbon tax regressivity into contributions of budget shares, carbon intensity, asset ownership, and savings rates.

### 5.6.1 Decomposing the Carbon Tax Incidence

Figure 6 highlights substantial cross-country heterogeneity in the composition of carbon tax payments. In Hungary and Lithuania, home fuel-related direct emissions contribute the largest share to total carbon tax payments. In Finland and Portugal, where electricity is more commonly used for heating and cooling, home fuel-related tax payments contribute less to the total carbon tax incidence and the contribution of electricity is larger. Across countries, the contribution of motor fuel-related emissions appears to follow an inverted U-shape. The contribution of indirect emissions rises as countries become wealthier. In Luxembourg, indirect emissions are lower than in Finland, because many of the products consumed are imported and their indirect emissions are therefore not covered under the national carbon tax[11]. Figure 6 suggests that the inclusion of indirect emissions increases the carbon tax incidence most in wealthy countries, and equalizes carbon tax burdens across countries.

Within all countries except Finland, the contribution of home fuel and electricity to total carbon tax payments is larger for low-income households. The contribution of motor fuel-related carbon tax payments is larger at the top of the distribution, particularly in Hungary and Lithuania, following an invested U-shape in Portugal, Ireland, Finland, and Luxembourg. This again reflects car ownership across the income distribution, rather than budget shares. In Hungary, Lithuania, and Luxembourg, indirect emissions make up a larger share of the carbon tax payments for high-income than for low-income households. In these countries, a carbon tax on indirect emissions equalizes carbon tax payments across households. In Ireland and Portugal, the contribution of indirect emissions follows a U-shape. In Finland, indirect emissions are larger for low-income households. This highlights difficulties in making generalizations on the distributional impact of pricing emissions of different sources.

We quantify the relative contribution of each emission source to inequality in the carbon tax incidence using Shorrocks decomposition (Shorrocks, 1982). Table 15 in the appendix presents the results of this decomposition. Under a national carbon tax without carbon border adjustment, the largest contribution is due to home fuel-related emissions in all countries except Finland (shown in the column to the right). In Finland, the largest contribution is due to motor fuel-related emissions. In all countries, the smallest contribution is due to electricity-related emissions. The contribution from indirect emissions is larger in wealthier countries.

The inequality in the carbon tax incidence could be reduced most by exempting emission sources with large

[11] Figure 7 in the appendix shows the contribution of imported indirect emissions to a comprehensive carbon tax.

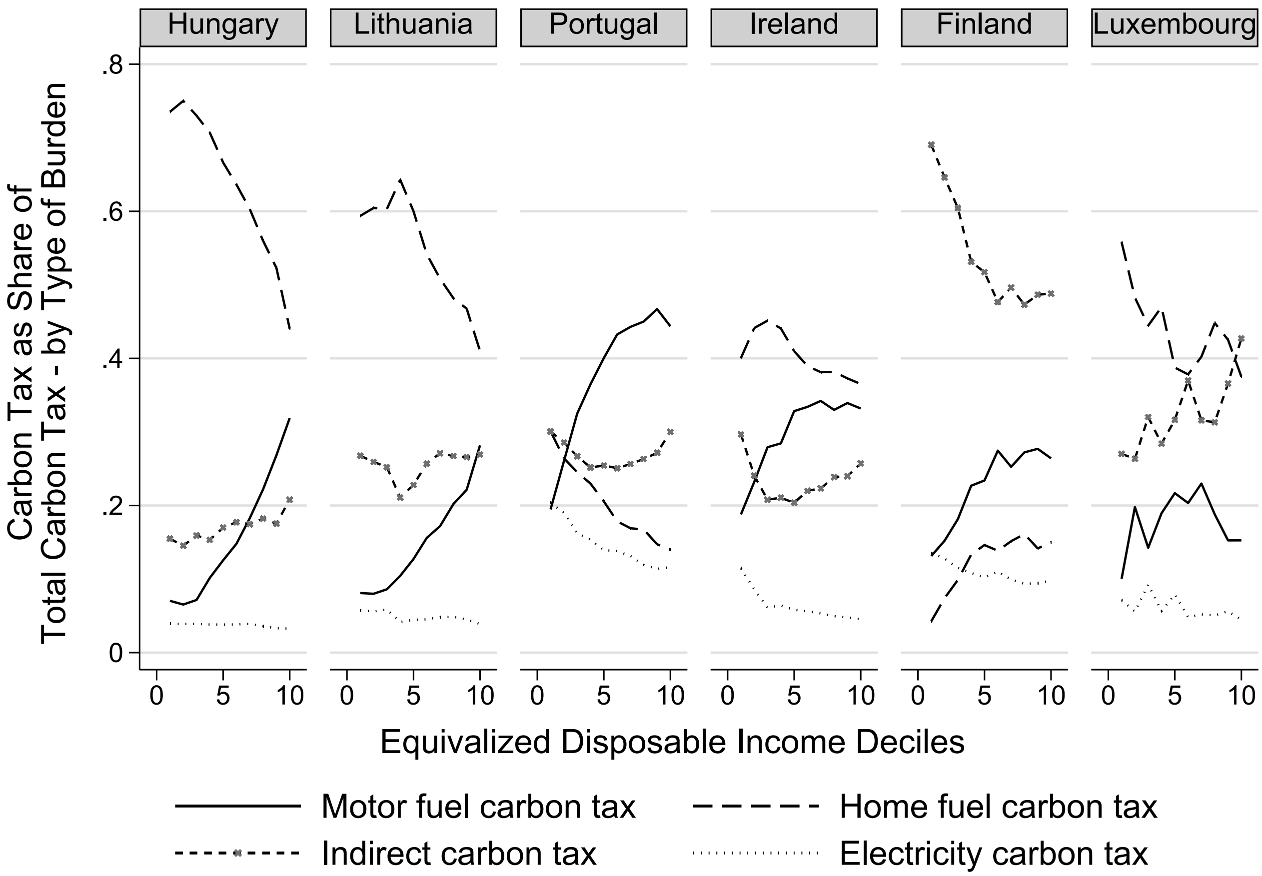



Figure 6: Decomposition of carbon tax payments by emission source.

contributions from the carbon tax. This is an important insight for carbon tax design. Table 15 and Figure 6 do however not tell us about the most effective policy lever to reduce adverse distributional impacts of carbon taxation.

Table 5 shows that the impact of carbon taxation on disposable income inequality differs across countries[12]. A carbon tax increases disposable income inequality in all countries. The increase is larger in poorer countries, as shown by the Reynolds-Smolenksy (RS) measure of redistribution. Finland experiences the smallest increase in inequality, followed by Luxembourg and Ireland. The Suits and Kakwani indices indicate that the carbon tax is regressive in all countries [13]. The carbon tax is least regressive in Finland and reaches comparable levels in other countries.

Table 5: Progressivity and redistribution of the carbon tax

| | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| Gini Pre-tax (G*100) | 26,07 | 26,46 | 32,48 | 29,49 | 27,59 | 28,96 |
| Gini Post - Carbon tax (Gt*100) | 26,53 | 26,85 | 32,70 | 29,60 | 27,65 | 29,05 |
| Average Tax rate (ATR) | 0,027 | 0,020 | 0,015 | 0,006 | 0,008 | 0,004 |
| Tax Concentration Coefficient (C) | 0,100 | 0,081 | 0,186 | 0,113 | 0,211 | 0,079 |
| Carbon Tax Regressivity (K) | -0,160 | -0,183 | -0,139 | -0,182 | -0,065 | -0,210 |
| Carbon Tax Suits Index (S) | -0,166 | -0,184 | -0,150 | -0,189 | -0,076 | -0,220 |
| Carbon Tax Redistribution (RS*100) | -0,462 | -0,390 | -0,223 | -0,112 | -0,053 | -0,088 |

Notes: G = Gini index of equivalized household disposable income ; Gt = Gini index of equivalized household disposable income minus equivalized household carbon tax ; K = Kakwani = C - Gt ; S = Suits index; RS = Reynolds-Smolensky = G - Gt; Calculations are based on equivalized household disposable income. We drop households with negative or zero disposable income (4 observations for Hungary).

#### 5.6.2 Decomposing the Impact of a Carbon Tax on Disposable Income Inequality and Carbon Tax Regressivity

Table 6 decomposes the change in the Gini index into contributions due to each factor. It shows the change in the Gini index changes under each counterfactual and quantifies the contribution of each factor to this change. The largest contributor to the dis-equalizing impact of a carbon tax differs across countries. Differences in budget shares and savings rates are important in all countries, except Lithuania. In Lithuania, the contribution of budget shares is surprisingly low and may be outweighed by other factors. In Lithuania and Hungary, the carbon intensity of consumption plays an important role. This results from large differences in the carbon intensity of the energy mix consumed. In Hungary and Ireland, budget shares contribute the most. It appears that the contribution of the savings rate is larger in wealthier countries. Lastly, the distribution of asset ownership is equalizing in all countries, except Hungary where its contribution is small and dis-equalizing. The implication is that both assets are more concentrated among high-income households. Its impact may however become more dis-equalizing if access to assets improves for low-income households, particularly ICE vehicles.

[12]Formulas and a description of these indices can be found in Sologon et al. (2022).

[13]Both the Suits and the Kakwani index are measures of tax progressivity. The Suits index ranges from -1 to 1 and the Kakwani index ranges from -2 to 2. The Kakwani index has a larger sensitivity to changes in the middle of the distribution while the Suits index is more sensitive to changes in its tails.

Table 6: Relative contribution to the change in the Gini index due to a carbon tax of savings rates, budget shares, asset ownership and carbon intensity

| | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| Gini Pre-tax (G*100) | 26,07 | 26,46 | 32,48 | 29,49 | 27,59 | 28,96 |
| Gini Post - Carbon tax (Gt*100) | 26,53 | 26,85 | 32,70 | 29,60 | 27,65 | 29,05 |
| Change due to Carbon tax | 0,46 | 0,39 | 0,22 | 0,11 | 0,05 | 0,09 |
| Change in Gini | | | | | | |
| Savings rate (s) | 0,15 | 0,11 | 0,15 | 0,06 | 0,07 | 0,04 |
| Budget share (w) | 0,17 | 0,02 | 0,11 | 0,06 | 0,04 | 0,03 |
| Carbon Intensity (e) | 0,11 | 0,11 | 0,01 | 0,01 | 0,00 | 0,00 |
| ICE vehicle ownership (V) | -0,06 | -0,10 | -0,06 | -0,03 | -0,08 | -0,02 |
| Heating system ownership (H) | -0,06 | -0,07 | -0,05 | -0,02 | -0,04 | -0,01 |
| Contribution of factors (in %) | | | | | | |
| Savings rate (s) | 31,8 | 27,4 | 69,3 | 49,4 | 140,9 | 50,6 |
| Budget share (w) | 37,3 | 5,1 | 50,8 | 50,2 | 73,5 | 30,0 |
| Carbon Intensity (e) | 24,6 | 28,5 | 6,6 | 7,1 | 9,3 | -0,2 |
| ICE vehicle ownership (V) | -12,7 | -17,6 | -23,9 | -14,0 | -72,5 | -12,1 |
| Heating system ownership (H) | 1,1 | -8,5 | -1,7 | -12,7 | -80,6 | -5,9 |
| Interactions | 17,9 | 65,1 | -1,1 | 20,0 | 29,3 | 37,7 |
| Total | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 |

Notes: All changes are calculated as: Change in Gini=(Gc*100)- (G*100), where G is the pre-tax Gini index of equivalized household disposable income and Gc is the counterfactual Gini index of equivalized household disposable income; Calculations are based on equivalized household disposable income. We drop households with negative or zero disposable income (4 observations for Hungary).

Table 6 decomposes the impact of the carbon tax on income inequality. Policymakers are often interested in the regressivity of a tax, due to its prominence in the public discourse. Considering carbon tax regressivity is also important as small impacts on income inequality may co-exist with high regressivity, as evidenced by Luxembourg. Table 8 shows the results of our decomposition for the Suits index of progressivity. The overall conclusions from Table 6 hold for carbon tax regressivity. Differences in savings rates along the income distribution contribute most to carbon tax regressivity in all countries, followed by budget shares. Again, the exception is Lithuania, where differences in difference in carbon intensity are more important. The role of asset ownership is less clear in carbon tax regressivity than in its impact on disposable income inequality. Difference between the contributions in Table 6 and Table 8 can be attributed to the difference in weights placed by the Gini and Suits index for different parts of the distribution, with the Suits index being more sensitive to changes in the tails of the distribution.

# 6 Conclusion and Policy Implications

This paper decomposes and compares the distributional impact of a carbon tax of €30/tCO2 levied on domestic energy use across six EU countries. It quantifies the contribution of consumption patterns, carbon intensity of consumption, savings rates, and asset ownership to inequality and regressivity indicators, and compares the contributions of these factors across countries. By identifying the most important factors for the distributional impact of carbon taxation,

Table 7: Relative contribution to the carbon tax regressivity of savings rates, budget shares, asset ownership and carbon intensity

| | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| Suits index | -0,17 | -0,18 | -0,15 | -0,19 | -0,08 | -0,22 |
| Counterfactual Gini | | | | | | |
| Savings rate (s) | -0.07 | -0.06 | -0.11 | -0.11 | -0.10 | -0.13 |
| Budget share (w) | -0.06 | -0.04 | -0.07 | -0.10 | -0.05 | -0.07 |
| Carbon Intensity (e) | -0.04 | -0.10 | 0.00 | -0.01 | -0.01 | 0.00 |
| ICE vehicle ownership (V) | 0.01 | -0.01 | 0.02 | 0.01 | 0.03 | -0.01 |
| Heating system ownership (H) | 0.00 | 0.01 | 0.00 | 0.01 | 0.03 | -0.01 |
| Contribution of factors (in %) | | | | | | |
| Savings rate (s) | 40,0 | 34,8 | 72,0 | 58,9 | 127,2 | 57,3 |
| Budget share (w) | 35,6 | 21,0 | 48,3 | 50,9 | 68,4 | 34,1 |
| Carbon Intensity (e) | 21,9 | 53,0 | 3,0 | 5,7 | 11,5 | -0,6 |
| ICE vehicle ownership (V) | -5,0 | 3,5 | -13,8 | -3,9 | -34,4 | 3,7 |
| Heating system ownership (H) | 1,4 | -5,0 | 0,9 | -4,9 | -43,6 | 4,5 |
| Interactions | 6,2 | -7,4 | -10,4 | -6,6 | -29,2 | 0,9 |
| Total | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 |

Notes: Calculations are based on equivalized household disposable income. We drop households with negative or zero disposable income (4 observations for Hungary).

this paper supports policymakers in identifying the most effective policy lever in managing the distributional impacts of carbon taxation without relying on income transfers. This is important for two reasons. Firstly, regressive distributional impacts of carbon pricing reduce the political acceptability of the tax (Dechezleprêtre et al., 2022; Douenne and Fabre, 2020) and income transfers may increase horizontal inequalities (Cronin et al., 2019). Second, carbon pricing in the EU is set to expand to the residential and transportation section. To mitigate distributional impacts, a Social Climate Fund is put in place, of which 70% is allocated to energy efficiency investments and renewable energy production. To design policies equitable and effective policy, policymakers need to understand the sources of the distributional impacts of carbon pricing.

The results show that national carbon taxes are regressive in all six EU countries, and impact households in poorer countries more than in richer countries. A carbon tax increases disposable income inequality more in poorer countries. This does however not translate into higher regressivity in poorer countries. The most regressive impact of a carbon tax is found in Luxembourg, the richest country of the sample. The most important driver of the carbon tax distributional impact, and thus the most effective policy lever to address these impacts, differs substantially across countries. In Lithuania, the most effective approach is to reduce differences in the carbon intensity of the energy mix consumed. This could be achieved through the provision of decarbonized energy options to low-income households, particularly those reliant on solid fuels. This approach is also effective in Hungary. Differences in the composition of the consumption basket, notably energy budget shares, play an important role in all countries except Lithuania. An effective strategy could be to improve access to affordable low-carbon energy sources such as district heating or affordable and decarbonized electric heating. Additionally, governments should aim to improve the energy efficiency of assets and dwellings owned by low-income households. Savings rate differentials along the income distribution are important, particularly in wealthier countries. This implies that in wealthy countries distributional impacts of carbon taxes may be addressed best through policies aiming to increase the savings rates of low-income households. This could be achieved through access to subsidized food, cheap transportation services, or improved energy efficiency of their dwellings. Asset ownership plays an equalizing role, primarily because of the higher concentration of asset ownership among high-income households. This indicates potential challenges, whereby carbon tax regressivity increases as low-income households become increasingly motorized. The main message is that the carbon tax burden, its composition the drivers of its distributional impact differ substantially across countries. Comparable distributional outcomes can arise due to different factors, making it difficult to draw general lessons.

Our study confirms many insights from the literature but shows that some insights can not be generalized. Carbon taxes on home fuels and electricity are regressive, and taxes on motor fuels and indirect emissions are generally progressive (Sterner, 2012; Flues and Thomas, 2015). Motor fuel taxation however has important impacts on horizontal inequality as motor fuels resemble a necessity among motorized households. Impacts of carbon pricing are larger in poorer and Eastern European countries (Feindt et al., 2021). The regressivity of a carbon tax does however not appear to increase with income. This challenges the conjecture that carbon taxation is more progressive in low and middle-income countries than in high-income countries (Flues and Thomas, 2015) once a certain development stage is reached. Budget shares are important for the distributional impact of carbon taxation (Grainger and Kolstad, 2010; Dorband et al., 2019), but are not necessarily the most important factor. The case of Finland illustrates that deviations from the standard narrative can be large. In Finland, budget shares of home fuels are progressively distributed. The overall message of this paper is that the drivers of distributional impacts vary substantially across countries, echoing Steckel et al. (2021)'s finding that distributional impacts and their drivers are highly country-specific effects.

Important limitations of this study relate to the exclusion of general equilibrium effects and household behavioural responses, and limitations inherent to the data. The extent to which these limitations jointly affect carbon tax regressivity is not clear. The inclusion of general equilibrium effects and behavioural responses is often, but not always, found to reduce carbon tax regressivity **?**. The implication for our decomposition result is ambiguous, but their inclusion would likely decrease the importance of budget shares and carbon intensity if households can easily substitute between energy commodities. The primary limitation of the data relates to its timeliness. At the time of writing, HBS and IO data are at least 8 and 7 years old. Over that period, companies and governments made substantial efforts to decarbonize, and external shocks, such as the war in Ukraine, induced large changes in energy supplies. Additionally, under-reporting of fuels in the HBS is common (Lévay et al., 2021). The availability of company cars may be an important factor in some countries, like Luxembourg, leading to underestimation of car ownership and motor fuel use. Additionally, the EE-IO methodology suffers from limitations relating to the assumed homogeneity of goods and prices (Lévay et al., 2021). As wealthier households tend to buy more expensive products, we likely overestimate the price increase of these products due to the carbon tax and hence the carbon tax burden for the rich.

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# A Appendix

## A.1 Detailed budget shares

Table 8: Average budget shares for Motor Fuel for households non-zero expenditure by equivalized household disposable income

| Income deciles | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| Motor Fuel | | | | | | |
| Bottom | 7,4% | 11,0% | 8,1% | 7,7% | 7,2% | 3,0% |
| 2 | 7,4% | 11,2% | 7,9% | 6,5% | 6,7% | 4,9% |
| 3 | 7,0% | 10,8% | 8,0% | 6,9% | 6,2% | 3,8% |
| 4 | 8,6% | 10,9% | 8,1% | 6,1% | 5,4% | 2,6% |
| 5 | 7,3% | 9,8% | 7,7% | 6,2% | 5,8% | 2,6% |
| 6 | 7,9% | 9,9% | 7,9% | 6,1% | 5,6% | 2,2% |
| 7 | 8,0% | 9,7% | 7,4% | 5,7% | 5,1% | 2,9% |
| 8 | 8,1% | 8,9% | 7,2% | 5,1% | 5,2% | 2,9% |
| 9 | 7,9% | 8,7% | 6,9% | 5,1% | 4,9% | 2,1% |
| Top | 8,6% | 9,2% | 6,0% | 4,9% | 4,4% | 1,9% |
| Average | 7,9% | 9,7% | 7,4% | 5,9% | 5,4% | 2,8% |

Notes: Averages are calculated for households with positive non-zero expenditure only.

Table 9: Share of households consuming home fuel

| Income deciles | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| 1 | 98,6% | 82,0% | 87,6% | 66,8% | 12,4% | 87,5% |
| 2 | 99,7% | 86,9% | 86,2% | 77,7% | 22,1% | 89,3% |
| 3 | 99,2% | 89,0% | 86,5% | 85,1% | 28,5% | 76,1% |
| 4 | 99,9% | 96,1% | 89,3% | 86,8% | 42,9% | 89,0% |
| 5 | 99,7% | 95,0% | 87,5% | 87,3% | 53,5% | 80,2% |
| 6 | 99,5% | 96,6% | 86,2% | 86,8% | 56,3% | 70,9% |
| 7 | 99,2% | 96,5% | 86,4% | 88,7% | 59,0% | 82,9% |
| 8 | 99,8% | 96,9% | 89,6% | 90,6% | 67,3% | 92,0% |
| 9 | 99,1% | 98,8% | 86,7% | 91,6% | 66,3% | 83,2% |
| 10 | 98,7% | 98,6% | 89,8% | 92,3% | 73,2% | 75,9% |
| Total | 99,3% | 93,6% | 87,6% | 85,4% | 48,1% | 82,8% |

## A.2 Energy prices and carbon intensity by commodity

Table 10: Disaggregated energy commodity prices

| | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| Price per kwh | | | | | | |
| Liquid fuel | 0,107 | 0,052 | 0,100 | 0,065 | 0,081 | 0,049 |
| Natural Gas | 0,035 | 0,042 | 0,098 | 0,067 | 0,084 | 0,050 |
| Solid fuel | 0,020 | 0,019 | 0,044 | 0,071 | 0,058 | 0,050 |
| Heat energy | 0,063 | 0,062 | 0,095 | 0,095 | 0,084 | 0,095 |
| Diesel | 0,105 | 0,099 | 0,107 | 0,115 | 0,121 | 0,092 |
| Petrol | 0,113 | 0,119 | 0,141 | 0,139 | 0,147 | 0,116 |
| kg of CO2 per kwh | | | | | | |
| Liquid fuels | 0,264 | 0,264 | 0,264 | 0,264 | 0,264 | 0,264 |
| Natural Gas | 0,202 | 0,202 | 0,202 | 0,202 | 0,202 | 0,202 |
| Solid fuels | 0,403 | 0,403 | 0,403 | 0,403 | 0,403 | 0,403 |
| District Heating | 0,108 | 0,108 | 0,108 | 0,108 | 0,108 | 0,108 |
| Diesel | 0,267 | 0,267 | 0,267 | 0,267 | 0,267 | 0,267 |
| Petrol | 0,249 | 0,249 | 0,249 | 0,249 | 0,249 | 0,249 |
| kg of CO2 per Euro | | | | | | |
| Liquid fuel | 2,424 | 4,974 | 2,577 | 3,992 | 3,206 | 5,294 |
| Natural Gas | 5,721 | 4,774 | 2,069 | 3,001 | 2,404 | 4,072 |
| Solid fuel | 19,965 | 21,224 | 9,223 | 5,647 | 6,952 | 8,064 |
| Heat energy | 1,714 | 1,733 | 1,137 | 1,137 | 1,282 | 1,137 |
| Diesel | 2,547 | 2,687 | 2,482 | 2,328 | 2,199 | 2,884 |
| Petrol | 2,202 | 2,105 | 1,771 | 1,789 | 1,698 | 2,153 |

Source. Authors' own calculation. Source: UNFCCC, Eurostat, EC Weekly Oil Bulletin, Statistics Finland, Statec, CSO, Statistics Portugal, Hungarian Central Statistical Office, WIOD. Solid fuels are assumed to be Fire wood. Where district heating is not used, the table shows the average of price across Finland, Lithuania and Hungary.

### A.3 Components of a carbon tax including foreign indirect emissions

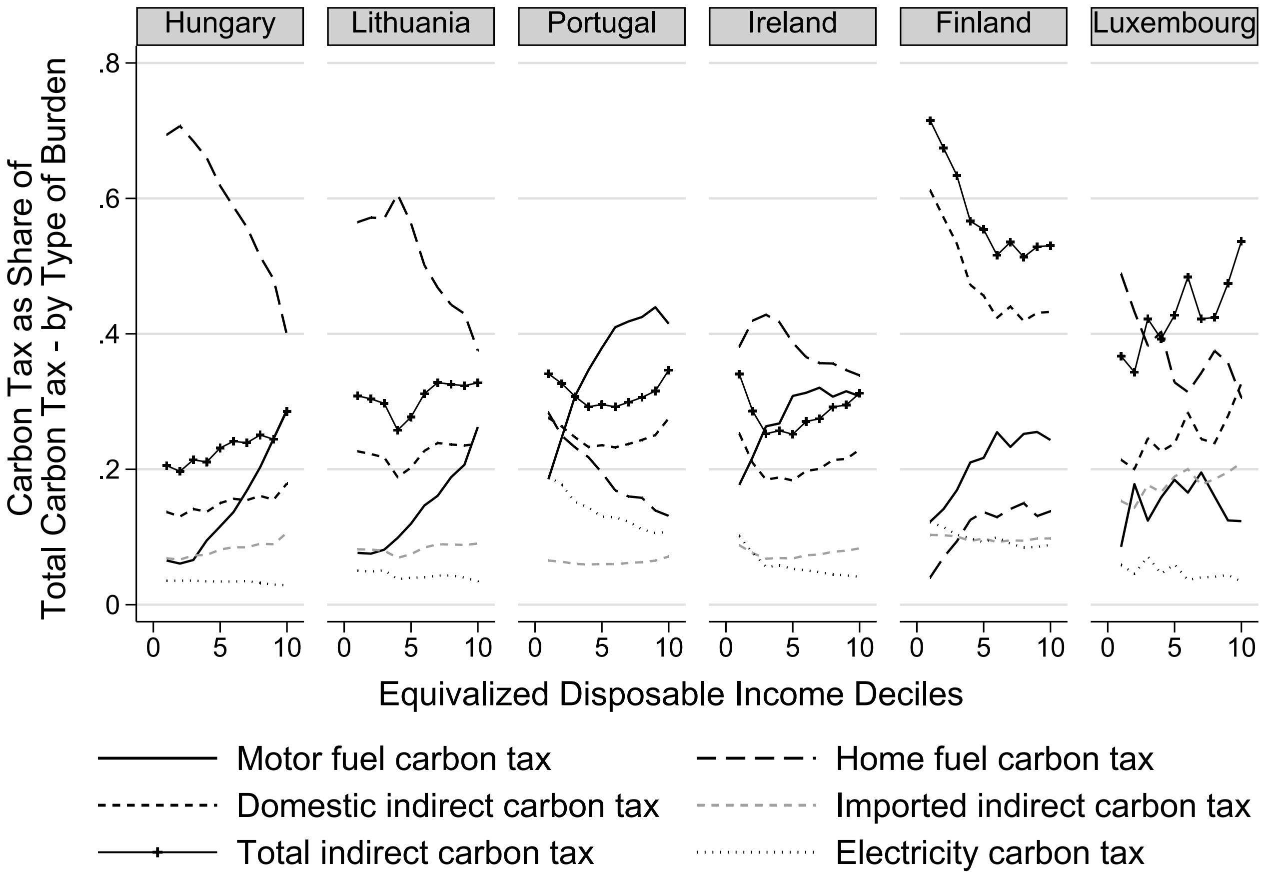


Figure 7: Decomposition of carbon tax incidence by type of burden - including foreign indirect emissions. Total carbon tax is calculated as the sum of all emission sources, except total indirect emissions.

## A.4 Determinants of asset ownership

Table 11: Logit regression - ownership of combustion-based heating system on expenditure and socioeconomic characteristics.

| | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| $Pseudo R^2$ | 0,1288 | 0,1933 | 0,0243 | 0,0965 | 0,2484 | 0,0959 |
| $N$ | 5,811 | 3,425 | 11,398 | 6,837 | 3,672 | 586 |
| Log expenditure | 10.35*** | 10.35*** | 2.680*** | 2.571** | 4.868*** | 4.917 |
| | (2.107) | (1.664) | (0.651) | (1.004) | (1.388) | (3.944) |
| Sqr. of log expenditure | -0.573*** | -0.543*** | -0.130*** | -0.0975** | -0.209*** | -0.223 |
| | (0.117) | (0.0901) | (0.0338) | (0.0495) | (0.0664) | (0.179) |
| Below median exp. - Single with children | -0.260 | 0.00736 | -0.0207 | -0.0544 | 0.338*** | -0.207 |
| | (0.189) | (0.229) | (0.0895) | (0.104) | (0.106) | (0.361) |
| Below median exp.- Couple | -1.047* | 0.174 | 0.168 | 0.118 | -0.185 | -0.392 |
| | (0.615) | (0.347) | (0.208) | (0.146) | (0.248) | (0.496) |
| Below median exp.- Couple with children | - | - | -0.0163 | -0.150 | -0.442 | 0.0530 |
| | | | (0.231) | (0.319) | (0.462) | (0.761) |
| Below median exp.- Other | 0.179 | 0.386* | 0.300*** | -0.162 | 0.0569 | 1.061** |
| | (0.414) | (0.211) | (0.0967) | (0.104) | (0.124) | (0.439) |
| Above median exp.- Single | -0.429 | 0.232 | 0.173 | -0.0336 | 0.399*** | 0.332 |
| | (0.436) | (0.261) | (0.109) | (0.123) | (0.125) | (0.472) |
| Above median exp. - Single with children | - | 0.311 | 0.449*** | -0.0449 | -0.0230 | 0.869* |
| | | (0.326) | (0.149) | (0.134) | (0.209) | (0.477) |
| Above median exp. - Couple | -1.181* | 0.816** | 0.210 | 0.149 | 0.448** | 0.873 |
| | (0.667) | (0.394) | (0.151) | (0.154) | (0.187) | (0.537) |
| Above median exp. - Couple with children | -0.466 | 0.446 | 0.523*** | -0.218* | 0.0139 | 1.328** |
| | (0.371) | (0.292) | (0.134) | (0.123) | (0.185) | (0.552) |
| Above median exp. - Other | - | 0.203 | 0.340** | -0.163 | 0.358** | 2.110*** |
| | | (0.321) | (0.153) | (0.152) | (0.178) | (0.747) |
| Married | -0.131 | -0.141 | -0.0778 | 0.0196 | 0.111 | 0.229 |
| | (0.260) | (0.158) | (0.0598) | (0.0626) | (0.0701) | (0.264) |
| Retired in HH | -0.372* | 0.291 | 0.0189 | 0.0405 | 0.0137 | 0.141 |
| | (0.200) | (0.248) | (0.0732) | (0.0908) | (0.110) | (0.494) |
| Student in HH | 0.288 | 0.742 | -0.238 | -0.637*** | 0.190 | 0.255 |
| | (0.674) | (0.497) | (0.348) | (0.134) | (0.213) | (0.280) |
| Age of HH head: 45-59 | 0.130 | 0.199 | 0.137** | 0.367*** | 0.635*** | 0.262 |
| | (0.242) | (0.157) | (0.0656) | (0.0637) | (0.0773) | (0.218) |
| Age of HH head: 60+ | 0.416 | 0.326 | 0.175** | 0.309*** | 0.829*** | 0.454 |
| | (0.261) | (0.249) | (0.0881) | (0.0944) | (0.109) | (0.534) |
| Number of children | 0.573 | -0.112 | 0.0318 | 0.0639* | 0.155** | -0.171 |
| | (0.355) | (0.0870) | (0.0526) | (0.0379) | (0.0642) | (0.125) |
| Number of persons 65+ | 0.445 | -0.237** | -0.0192 | 0.260*** | 0.398*** | -0.538** |
| | (0.307) | (0.119) | (0.0643) | (0.0720) | (0.100) | (0.257) |
| Number of adults | 0.537* | -0.192* | -0.00898 | 0.0446 | 0.250*** | -0.530*** |
| | (0.279) | (0.101) | (0.0584) | (0.0478) | (0.0836) | (0.191) |
| Number of earners | -0.0416 | 0.207** | -0.0202 | -0.0394 | 0.0667 | 0.102 |
| | (0.189) | (0.0984) | (0.0412) | (0.0389) | (0.0634) | (0.181) |
| Rural area | 0.650*** | -0.410*** | -0.0580 | 0.0698 | 0.711*** | -0.523* |
| | (0.210) | (0.125) | (0.0482) | (0.0487) | (0.0580) | (0.268) |
| Intercept | -44.77*** | -47.27*** | -12.79*** | -15.36*** | -29.52*** | -25.84 |
| | (9.503) | (7.594) | (3.128) | (5.080) | (7.241) | (21.65) |
| *** p<0.01, ** p<0.05, * p<0.1 | | | | | | |

Table 12: Logit regression - ownership of ICE vehicle on expenditure and socioeconomic characteristics.

| | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| $Pseudo R^2$ | 0,2865 | 0,3118 | 0,4201 | 0,2038 | 0,1632 | 0,1229 |
| $N$ | 7,165 | 3,443 | 11,398 | 6,837 | 3,672 | 586 |
| Log expenditure | 5.721*** | 9.205*** | 5.695*** | 5.940*** | 9.506*** | 13.09*** |
| | (1.894) | (2.484) | (1.176) | (1.090) | (1.455) | (3.910) |
| Sqr. of log expenditure | -0.245** | -0.419*** | -0.235*** | -0.250*** | -0.413*** | -0.564*** |
| | (0.105) | (0.135) | (0.0614) | (0.0528) | (0.0691) | (0.176) |
| Below median exp. - Single with children | 0.184** | -0.378** | 0.234*** | -0.0264 | -0.139 | 0.0424 |
| | (0.0826) | (0.153) | (0.0798) | (0.0872) | (0.104) | (0.321) |
| Below median exp. - Couple | 0.0335 | -0.294 | 0.587*** | 0.0432 | 0.0210 | -0.115 |
| | (0.201) | (0.338) | (0.161) | (0.130) | (0.230) | (0.416) |
| Below median exp. - Couple with children | 0.304 | -0.676* | 0.669*** | -0.110 | -0.260 | 0.0685 |
| | (0.361) | (0.386) | (0.256) | (0.321) | (0.463) | (0.633) |
| Below median exp. - Other | 0.0315 | -0.294* | 0.411*** | -0.0583 | -0.0970 | 0.353 |
| | (0.0940) | (0.160) | (0.0899) | (0.0909) | (0.113) | (0.415) |
| Above median exp. - Single | 0.285*** | -0.454** | 0.602*** | -0.0181 | -0.0428 | -0.128 |
| | (0.106) | (0.177) | (0.103) | (0.105) | (0.119) | (0.395) |
| Above median exp. - Single with children | 0.293** | -0.313 | 0.736*** | 0.124 | 0.168 | 0.0934 |
| | (0.135) | (0.224) | (0.150) | (0.124) | (0.193) | (0.404) |
| Above median exp. - Couple | 0.428*** | -0.157 | 0.643*** | -0.154 | 0.0846 | -0.103 |
| | (0.159) | (0.241) | (0.191) | (0.136) | (0.173) | (0.445) |
| Above median exp. - Couple with children | -0.0932 | -0.588*** | 0.188 | -0.172 | -0.130 | -0.229 |
| | (0.126) | (0.200) | (0.125) | (0.110) | (0.155) | (0.511) |
| Above median exp. - Other | 0.160 | -0.298 | 0.387** | 0.127 | -0.152 | -0.479 |
| | (0.143) | (0.229) | (0.158) | (0.145) | (0.167) | (0.538) |
| Married | 0.409*** | 0.381*** | 0.510*** | 0.245*** | 0.107 | 0.0219 |
| | (0.0532) | (0.0912) | (0.0575) | (0.0571) | (0.0671) | (0.218) |
| Retired in HH | -0.247*** | -0.185 | -0.124 | -0.0793 | -0.116 | -0.0554 |
| | (0.0909) | (0.126) | (0.0831) | (0.0815) | (0.112) | (0.351) |
| Unemployed HH head | -0.0627 | -0.0565 | -0.219** | -0.0759 | 0.0162 | 0.138 |
| | (0.132) | (0.195) | (0.109) | (0.0766) | (0.150) | (0.340) |
| Student in HH | -1.191** | -0.582 | -0.00821 | -0.543*** | 0.130 | -0.0276 |
| | (0.500) | (0.681) | (0.343) | (0.141) | (0.187) | (0.192) |
| Age of HH head: 45-59 | 0.0645 | -0.203** | -0.168** | 0.153*** | 0.00278 | 0.174 |
| | (0.0620) | (0.0879) | (0.0707) | (0.0567) | (0.0752) | (0.183) |
| Age of HH head: 60+ | 0.123 | -0.277** | -0.330*** | -0.0661 | -0.0265 | -0.288 |
| | (0.0949) | (0.124) | (0.0934) | (0.0853) | (0.100) | (0.373) |
| Number of children | -0.0907** | -0.194*** | -0.195*** | 0.00369 | -0.0977* | -0.122 |
| | (0.0363) | (0.0655) | (0.0565) | (0.0350) | (0.0507) | (0.0974) |
| Number of persons 65+ | 0.0268 | -0.0503 | 0.0264 | -0.00317 | 0.0169 | 0.190 |
| | (0.0613) | (0.0880) | (0.0696) | (0.0645) | (0.0892) | (0.246) |
| Number of adults | 0.169*** | 0.0711 | 0.234*** | 0.0908* | 0.0913 | 0.0628 |
| | (0.0536) | (0.0796) | (0.0614) | (0.0504) | (0.0720) | (0.195) |
| Number of earners | 0.0363 | 0.0836 | 0.110** | 0.0291 | -0.0467 | 0.156 |
| | (0.0428) | (0.0614) | (0.0493) | (0.0464) | (0.0709) | (0.132) |
| Rural area | 0.236*** | 0.746*** | 0.337*** | 0.647*** | 0.444*** | 0.169 |
| | (0.0434) | (0.0741) | (0.0456) | (0.0468) | (0.0555) | (0.257) |
| Intercept | -32.25*** | -49.59*** | -32.87*** | -34.48*** | -54.08*** | -75.78*** |
| | (8.509) | (11.37) | (5.606) | (5.608) | (7.629) | (21.62) |

*** p<0.01, ** p<0.05, * p<0.1

Table 13: Logit regression - ownership of combustion-based heating system on disposable income and socioeconomic characteristics.

| | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| *Adj.*$R^2$ | 0,0077 | 0,0854 | 0,013 | 0,0693 | 0,2887 | 0,0495 |
| *N* | 7,165 | 3,443 | 11,398 | 6,837 | 3,672 | 586 |
| Log disposable income | 0.129*** | 1.205*** | -0,089 | 0,097 | -0,023 | -0,978 |
| | *(-0,037)* | *(-0,237)* | *(-0,092)* | *(-0,103)* | *(-0,266)* | *(-0,785)* |
| Sqr. of log disposable inc. | -0.007*** | -0.062*** | 0,005 | 0,000 | 0,009 | 0,041 |
| | *(-0,002)* | *(-0,013)* | *(-0,005)* | *(-0,005)* | *(-0,013)* | *(-0,035)* |
| Below median exp. - Single with children | -0.007* | 0,007 | 0.0450*** | -0,001 | 0.118*** | 0,034 |
| | *(-0,004)* | *(-0,018)* | *(-0,017)* | *(-0,022)* | *(-0,030)* | *(-0,070)* |
| Below median exp. - Couple | -0,012 | 0.062* | 0.080*** | 0.067** | -0,033 | -0,118 |
| | *(-0,008)* | *(-0,033)* | *(-0,026)* | *(-0,031)* | *(-0,058)* | *(-0,102)* |
| Below median exp. - Couple with children | 0,004 | 0,051 | 0,051 | -0,024 | -0,134 | 0,095 |
| | *(-0,018)* | *(-0,045)* | *(-0,039)* | *(-0,084)* | *(-0,127)* | *(-0,163)* |
| Below median exp. - Other | 0,003 | 0.069*** | 0.101*** | 0,001 | 0.056* | 0.229*** |
| | *(-0,004)* | *(-0,020)* | *(-0,015)* | *(-0,020)* | *(-0,033)* | *(-0,084)* |
| Above median exp. - Single | -0,005 | 0,032 | 0.090*** | -0,002 | 0.146*** | 0,143 |
| | *(-0,005)* | *(-0,023)* | *(-0,018)* | *(-0,024)* | *(-0,037)* | *(-0,094)* |
| Above median exp. - Single with children | 0,000 | 0.065** | 0.138*** | 0,039 | 0,039 | 0.239** |
| | *(-0,006)* | *(-0,028)* | *(-0,021)* | *(-0,026)* | *(-0,050)* | *(-0,104)* |
| Above median exp. - Couple | -0,007 | 0.073** | 0.094*** | 0,039 | 0.168*** | 0.259** |
| | *(-0,007)* | *(-0,031)* | *(-0,023)* | *(-0,030)* | *(-0,050)* | *(-0,112)* |
| Above median exp. - Couple with children | -0,004 | 0.081*** | 0.148*** | 0,006 | 0.077** | 0.275** |
| | *(-0,006)* | *(-0,023)* | *(-0,019)* | *(-0,024)* | *(-0,038)* | *(-0,111)* |
| Above median exp. - Other | 0,001 | 0.045* | 0.118*** | -0,015 | 0.126** | 0.352** |
| | *(-0,007)* | *(-0,027)* | *(-0,022)* | *(-0,029)* | *(-0,051)* | *(-0,157)* |
| Married | -0,001 | -0,011 | -0,014 | 0,002 | 0.047** | 0,033 |
| | *(-0,003)* | *(-0,014)* | *(-0,008)* | *(-0,012)* | *(-0,020 )* | *(-0,048)* |
| Retired in HH | -0,005 | 0,020 | 0,013 | -0,002 | 0,002 | 0,057 |
| | *(-0,004)* | *(-0,021)* | *(-0,013)* | *(-0,018)* | *(-0,033)* | *(-0,072)* |
| Unemployed HH head | -0,004 | -0.130*** | 0,012 | -0.050*** | 0,015 | -0,039 |
| | *(-0,006)* | *(-0,022)* | *(-0,018)* | *(-0,016)* | *(-0,039)* | *(-0,107)* |
| Student in HH | -0.039*** | 0,033 | -0,040 | -0.208*** | 0.092* | 0,050 |
| | *(-0,013)* | *(-0,048)* | *(-0,067)* | *(-0,032)* | *(-0,047)* | *(-0,056)* |
| Age of HH head: 45-59 | 0,002 | 0.020* | 0.022** | 0.081*** | 0.188*** | 0.069* |
| | *(-0,003)* | *(-0,012)* | *(-0,009)* | *(-0,011)* | *(-0,021)* | *(-0,041)* |
| Age of HH head: 60+ | 0,006 | 0,022 | 0.028** | 0.080*** | 0.234*** | 0,091 |
| | *(-0,004)* | *(-0,020)* | *(-0,013)* | *(-0,017)* | *(-0,029)* | *(-0,071)* |
| Number of children | 0,002 | -0,012 | 0,006 | 0,010 | 0.039*** | -0,035 |
| | *(-0,002)* | *(-0,009)* | *(-0,007)* | *(-0,007)* | *(-0,013)* | *(-0,029)* |
| Number of persons 65+ | 0,002 | -0.035*** | -0,006 | 0.043*** | 0.113*** | -0,070 |
| | *(-0,003)* | *(-0,013)* | *(-0,009)* | *(-0,013)* | *(-0,027)* | *(-0,056* |
| Number of adults | 0,003 | -0.016* | -0,003 | 0,011 | 0.061*** | -0,069 |
| | *(-0,002)* | *(-0,010)* | *(-0,007)* | *(-0,009)* | *(-0,021)* | *(-0,051)* |
| Number of earners | -0,001 | -0,002 | 0,001 | -0.014* | 0,019 | 0,033 |
| | *(-0,002)* | *(-0,009)* | *(-0,007)* | *(-0,009)* | *(-0,016)* | *(-0,040)* |
| Rural area | 0.007*** | -0.048*** | -0.014* | 0.018** | 0.220*** | -0.129*** |
| | *(-0,167)* | *(-0,010)* | *(-0,456)* | *(-0,532)* | *(-1,407)* | *(-4,429)* |
| Intercept | 0.384** | -4.820*** | 1.185*** | -0,254 | -0,687 | 6,537 |
| | *(-0,167)* | *(-1,076)* | *(-0,456)* | *(-0,532)* | *(-1,407)* | *(-4,429)* |

*0.10 **0.05 ***0.01

Table 14: Logit regression - ownership of ICE vehicle on disposable income and socioeconomic characteristics.

| | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| *Adj.$R^2$* | 0,2936 | 0,2545 | 0,3927 | 0,1794 | 0,1431 | 0,0654 |
| *N* | 7,165 | 3,443 | 11,398 | 6,837 | 3,672 | 586 |
| Log disposable income | -0,295 | 0,260 | 1.002*** | 0,105 | 0.862*** | 1,633 |
| | *(-0.191)* | *(-0,413)* | *(-0,093)* | *(-0,121)* | *(-0,293)* | *(-1,030)* |
| Sqr. of log disposable inc. | 0.026** | -0,006 | -0.042*** | -0,001 | -0.037*** | -0,072 |
| | *(-0.01)* | *(-0,023)* | *(-0,005)* | *(-0,006)* | *(-0,014)* | *(-0,045)* |
| Below median exp. - Single with children | 0.140*** | -0,018 | 0.156*** | 0.147*** | 0.066** | 0,134 |
| | *(-0.022)* | *(-0,032)* | *(-0,017)* | *(-0,026)* | *(-0,033)* | *(-0,092)* |
| Below median exp. - Couple | 0,033 | -0,005 | 0.312*** | 0.107*** | 0.116* | 0,004 |
| | *(-0.041)* | *(-0,058)* | *(-0,026)* | *(-0,037)* | *(-0,064)* | *(-0,134)* |
| Below median exp. - Couple with children | 0.248*** | -0,060 | 0.323*** | 0,155 | 0,042 | 0,122 |
| | *(-0.093)* | *(-0,079)* | *(-0,039)* | *(-0,100)* | *(-0,139)* | *(-0,213)* |
| Below median exp. - Other | 0.045** | -0,041 | 0.270*** | 0.124*** | 0.066* | 0.198* |
| | *(-0.024)* | *(-0,034)* | *(-0,015)* | *(-0,024)* | *(-0,036)* | *(-0,111)* |
| Above median exp. - Single | 0.229*** | 0,009 | 0.324*** | 0.174*** | 0.153*** | 0,098 |
| | *(-0.027)* | *(-0,040)* | *(-0,018)* | *(-0,029)* | *(-0,041)* | *(-0,124)* |
| Above median exp. - Single with children | 0.178*** | 0,028 | 0.342*** | 0.204*** | 0.204*** | 0,080 |
| | *(-0.033)* | *(-0,050)* | *(-0,021)* | *(-0,030)* | *(-0,055)* | *(-0,137)* |
| Above median exp. - Couple | 0.249*** | 0.166*** | 0.280*** | 0.147*** | 0.203*** | 0,115 |
| | *(-0,037)* | *(-0,054)* | *(-0,023)* | *(-0,035)* | *(-0,055)* | *(-0,147)* |
| Above median exp. - Couple with children | 0.069** | -0,031 | 0.270*** | 0.146*** | 0,033 | -0,092 |
| | *(-0,029)* | *(-0,040)* | *(-0,019)* | *(-0,028)* | *(-0,042)* | *(-0,146)* |
| Above median exp. - Other | 0.201*** | 0.113** | 0.265*** | 0.194*** | 0.135** | -0,117 |
| | *(-0,034)* | *(-0,047)* | *(-0,022)* | *(-0,034)* | *(-0,056)* | *(-0,206)* |
| Married | 0.165*** | 0.145*** | 0.092*** | 0.074*** | 0.052** | -0,003 |
| | *(-0,013)* | *(-0,025)* | *(-0,008)* | *(-0,014)* | *(-0,022)* | *(-0,063)* |
| Retired in HH | -0.078*** | -0,018 | -0.068*** | -0.038* | -0.069* | 0,022 |
| | *(-0,023)* | *(-0,036)* | *(-0,013)* | *(-0,021)* | *(-0,036)* | *(-0,094)* |
| Unemployed HH head | -0.062** | -0,048 | -0.072*** | -0.078*** | -0,052 | -0,006 |
| | *(-0,030)* | *(-0,038)* | *(-0,018)* | *(-0,019)* | *(-0,042)* | *(-0,141)* |
| Student in HH | -0.178*** | -0,088 | 0,013 | -0.185*** | 0,006 | 0,048 |
| | *(-0,067)* | *(-0,084)* | *(-0,067)* | *(-0,038)* | *(-0,052)* | *(-0,074)* |
| Age of HH head: 45-59 | 0,008 | -0.066*** | -0.042*** | 0.034** | 0,003 | 0,074 |
| | *(-0,014)* | *(-0,020)* | *(-0,009)* | *(-0,013)* | *(-0,023)* | *(-0,053)* |
| Age of HH head: 60+ | 0,027 | -0.093*** | -0.080*** | -0,015 | -0,004 | -0,149 |
| | *(-0,023)* | *(-0,034)* | *(-0,013)* | *(-0,021)* | *(-0,032)* | *(-0,093)* |
| Number of children | -0.029*** | -0.041** | -0.032*** | 0,002 | -0,018 | -0,023 |
| | *(-0,010)* | *(-0,016)* | *(-0,007)* | *(-0,008)* | *(-0,014)* | *(-0,038)* |
| Number of persons 65+ | -0,005 | -0.038* | -0.022** | 0,010 | 0,020 | 0.140* |
| | *(-0,015)* | *(-0,023)* | *(-0,009)* | *(-0,015)* | *(-0,030)* | *(-0,074)* |
| Number of adults | 0.046*** | 0,022 | 0.033*** | 0.028** | 0.055** | 0,084 |
| | *(-0,012)* | *(-0,017)* | *(-0,007)* | *(-0,011)* | *(-0,023)* | *(-0,067)* |
| Number of earners | 0,014 | 0.0518191*** | 0,000 | 0,009 | 0,000 | 0,050 |
| | *(-0,011)* | *(-0,016)* | *(-0,007)* | *(-0,011)* | *(-0,017)* | *(-0,053)* |
| Rural area | 0.029*** | 0.113*** | 0.046*** | 0.154*** | 0.131*** | 0,038 |
| | *(-0,868)* | *(-0,017)* | *(-0,456)* | *(-0,629)* | *(-1,545)* | *(-5,809)* |
| Intercept | 0.730** | -1,641 | -5.224*** | -0,506 | -4.667*** | -8,974 |
| | *(-0,868)* | *(-1,880)* | *(-0,456)* | *(-0,629)* | *(-1,545)* | *(-5,809)* |

*0.10 **0.05 ***0.01

#### A.4.1 Shorrocks inequality decomposition

Inequality decomposition techniques were pioneered by Shorrocks (1982), who proposed a method to decompose income inequality indices by population group or income source (factors). Shorrocks (1982) devised this method to decompose income inequality into its additive components (e.g. market income, capital income, pension income). This method can be seen as purely descriptive and is commonly used to compare the structure of inequality across time or countries (Brewer and Wren-Lewis, 2016)

Factors' contributions are calculated as the covariance between the factor and total income, or in this case, carbon tax payments:

$$s_k = \frac{S_k}{I(Y)} = \frac{cov[Y^k, Y]}{\sigma^2(Y)} \tag{16}$$

where $s_k$ sums to 1 over all $k$. For each individual, the carbon tax incidence is split into its components $Y_i^k$, where $k = 4$.

If the Coefficient of variation is used as inequality measure, Shorrocks showed that $s_k$ can also be written as

$$s_k = cov[Y^k, Y] * (\bar{Y^k}/\bar{Y}) * (CV(Y^k)/CV(Y)) \tag{17}$$

where $\bar{Y}$ is total income and $CV(.)$ stands for the coefficient of variation.

The last column of Table 15 shows the proportional contribution of motor fuel and home fuel-related emissions, electricity-related emissions, and other indirect emissions to inequality in the carbon tax incidence.

Table 15: Contribution of emission sources to inequality in the carbon tax incidence - Shorrocks decomposition

| | $100 * \bar{Y^k}/\bar{Y}$ | $cov[Y^k, Y]$ | $(CV(Y^k)/CV(Y))$ | $100 * s_f$ |
|---|---|---|---|---|
| | | Hungary | | |
| Motor fuel | 18,74 | 0,15 | 1,94 | 18,89 |
| Home Fuel | 66,99 | 0,61 | 1,25 | 76,48 |
| Indirect emissions | 11,52 | 0,03 | 0,74 | 3,30 |
| Electricity | 2,75 | 0,01 | 0,94 | 1,33 |
| | | Lithuania | | |
| Motor fuel | 23,24 | 0,28 | 2,36 | 36,74 |
| Home Fuel | 56,55 | 0,41 | 1,27 | 55,20 |
| Indirect emissions | 17,03 | 0,05 | 0,86 | 6,76 |
| Electricity | 3,18 | 0,01 | 0,90 | 1,30 |
| | | Portugal | | |
| Motor fuel | 44,92 | 0,30 | 1,08 | 31,02 |
| Home Fuel | 23,66 | 0,55 | 3,10 | 57,45 |
| Indirect emissions | 21,16 | 0,08 | 0,80 | 8,42 |
| Electricity | 10,26 | 0,03 | 0,97 | 3,12 |
| | | Ireland | | |
| Motor fuel | 35,11 | 0,27 | 1,49 | 35,14 |
| Home Fuel | 43,71 | 0,43 | 1,62 | 56,29 |
| Indirect emissions | 17,25 | 0,06 | 0,92 | 7,71 |
| Electricity | 3,94 | 0,01 | 0,82 | 0,85 |
| | | Finland | | |
| Motor fuel | 33,30 | 0,39 | 1,78 | 48,85 |
| Home Fuel | 17,41 | 0,19 | 2,23 | 23,54 |
| Indirect emissions | 40,46 | 0,18 | 0,83 | 22,03 |
| Electricity | 8,83 | 0,04 | 1,18 | 5,58 |
| | | Luxembourg | | |
| Motor fuel | 20,64 | 0,15 | 2,16 | 26,09 |
| Home Fuel | 48,11 | 0,32 | 1,42 | 54,93 |
| Indirect emissions | 26,86 | 0,10 | 1,13 | 17,42 |
| Electricity | 4,39 | 0,01 | 1,12 | 1,56 |

Notes: Shorrocks decomposition gives the inequality contribution of each factor to total inequality. Row $100 * s_f$ gives the inequality contribution of each factor, and is calculated as $s_k = (\bar{Y^k}/\bar{Y}) * cov[Y^k, Y] * (CV(Y^k)/CV(Y))$

## A.5 Decomposing the impact of a carbon tax on disposable income inequality and carbon tax regressivity - including interaction terms

Table 16: Relative contribution to the change in the Gini index due to a carbon tax of savings rates, budget shares, asset ownership, carbon intensity and two-way interaction effects

| | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| Gini Pre-tax (G*100) | 26,07 | 26,46 | 32,48 | 29,49 | 27,59 | 28,96 |
| Gini Post - Carbon tax (Gt*100) | 26,53 | 26,85 | 32,70 | 29,60 | 27,65 | 29,05 |
| Change due to Carbon tax | 0,46 | 0,39 | 0,22 | 0,11 | 0,05 | 0,09 |
| Change in Gini | | | | | | |
| Savings rate (s) | 0,15 | 0,11 | 0,15 | 0,06 | 0,07 | 0,04 |
| Budget share (w) | 0,17 | 0,02 | 0,11 | 0,06 | 0,04 | 0,03 |
| Carbon Intensity (e) | 0,11 | 0,11 | 0,01 | 0,01 | 0,00 | 0,00 |
| ICE vehicle ownership (V) | -0,06 | -0,10 | -0,06 | -0,03 | -0,08 | -0,02 |
| Heating system ownership (H) | -0,06 | -0,07 | -0,05 | -0,02 | -0,04 | -0,01 |
| Contribution of factors (in %) | | | | | | |
| Savings rate (s) | 31,8 | 27,4 | 69,3 | 49,4 | 140,9 | 50,6 |
| Budget share (w) | 37,3 | 5,1 | 50,8 | 50,2 | 73,5 | 30,0 |
| Carbon Intensity (e) | 24,6 | 28,5 | 6,6 | 7,1 | 9,3 | -0,2 |
| ICE vehicle ownership (V) | -12,7 | -17,6 | -23,9 | -14,0 | -72,5 | -12,1 |
| Heating system ownership (H) | 1,1 | -8,5 | -1,7 | -12,7 | -80,6 | -5,9 |
| Contribution of two-way interactions (in %) | | | | | | |
| H & w | -0,9 | -1,1 | -0,6 | -1,0 | -9,5 | -0,1 |
| H & e | 18,0 | 27,8 | 5,7 | -0,1 | -0,9 | -2,1 |
| V & w | -3,3 | -0,8 | -2,9 | -1,9 | -10,9 | -0,7 |
| V & e | -25,6 | -29,1 | -9,7 | -8,4 | -14,6 | 0,7 |
| w & e | -2,2 | 15,8 | -4,2 | -2,0 | -6,5 | -1,1 |
| 3-way interactions | 31,9 | 52,5 | 10,7 | 33,3 | 71,8 | 41,1 |
| Total | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 |

Notes: All changes are calculated as: Change in Gini=(Gc*100)- (G*100), where G is the pre-tax Gini index of equivalized household disposable income and Gc is the counterfactual Gini index of equivalized household disposable income; Calculations are based on equivalized household disposable income. We drop households with negative or zero disposable income (4 observations for Hungary).

Table 17: Relative contribution to the carbon tax regressivity of savings rates, budget shares, asset ownership, carbon intensity and two-way interaction effects

| | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| Suits index | -0,17 | -0,18 | -0,15 | -0,19 | -0,08 | -0,22 |
| Counterfactual Gini | | | | | | |
| Savings rate (s) | -0.07 | -0.06 | -0.11 | -0.11 | -0.10 | -0.13 |
| Budget share (w) | -0.06 | -0.04 | -0.07 | -0.10 | -0.05 | -0.07 |
| Carbon Intensity (e) | -0.04 | -0.10 | 0.00 | -0.01 | -0.01 | 0.00 |
| ICE vehicle ownership (V) | 0.01 | -0.01 | 0.02 | 0.01 | 0.03 | -0.01 |
| Heating system ownership (H) | 0.00 | 0.01 | 0.00 | 0.01 | 0.03 | -0.01 |
| Contribution of factors (in %) | | | | | | |
| Savings rate (s) | 40,0 | 34,8 | 72,0 | 58,9 | 127,2 | 57,3 |
| Budget share (w) | 35,6 | 21,0 | 48,3 | 50,9 | 68,4 | 34,1 |
| Carbon Intensity (e) | 21,9 | 53,0 | 3,0 | 5,7 | 11,5 | -0,6 |
| ICE vehicle ownership (V) | -5,0 | 3,5 | -13,8 | -3,9 | -34,4 | 3,7 |
| Heating system ownership (H) | 1,4 | -5,0 | 0,9 | -4,9 | -43,6 | 4,5 |
| Interactions and other | 6,2 | -7,4 | -10,4 | -6,6 | -29,2 | 0,9 |
| Contribution of two-way interactions (in %) | | | | | | |
| H & w | -0,7 | -0,5 | -1,8 | -3,1 | -11,6 | -3,6 |
| H & e | 10,2 | 1,8 | 1,5 | 0,1 | -1,8 | 0,3 |
| V & w | -5,1 | -4,5 | -5,0 | -4,5 | -14,1 | -4,9 |
| V & e | -22,4 | -52,7 | -5,5 | -7,2 | -14,9 | 1,2 |
| w & e | -2,9 | -21,2 | -1,2 | -0,6 | -8,8 | -0,2 |
| 3-way interactions | 27,0 | 69,7 | 1,5 | 8,7 | 22,1 | 8,1 |
| Total | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 |

Notes: Calculations are based on equivalized household disposable income. We drop households with negative or zero disposable income (4 observations for Hungary).

## A.6 Robustness checks

Table 18: Observations under the "no high expenditure to income ratio"* scenario.

| | Dropped | Original number of observations | Percentage dropped |
|---|---|---|---|
| Hungary | 38 | 7169 | 0.5% |
| Lithuania | 31 | 3443 | 0.9% |
| Portugal | 153 | 11398 | 1.3% |
| Ireland | 116 | 6839 | 1.7% |
| Finland | 29 | 3673 | 0.8% |
| Luxembourg | 14 | 586 | 2.4% |

Notes: *We drop household with an expenditure to income ratio higher than 2.5.

Table 19: Comparison of carbon tax payments as share of household disposable income under four scenarios.

| Equiv. Disp. Income Deciles | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Hungary | | | | | | | | | | |
| National energy only | 4.6% | 3.8% | 3.4% | 3.3% | 3.0% | 2.8% | 2.7% | 2.5% | 2.3% | 1.7% |
| National energy only (robust) | 4.3% | 3.8% | 3.5% | 3.2% | 3.0% | 2.8% | 2.7% | 2.4% | 2.3% | 1.7% |
| ETS energy only | 4.9% | 4.1% | 3.7% | 3.5% | 3.2% | 3.0% | 2.9% | 2.6% | 2.5% | 1.9% |
| WIOD | 5.4% | 4.5% | 4.0% | 3.8% | 3.5% | 3.2% | 3.1% | 2.8% | 2.6% | 1.9% |
| Lithuania | | | | | | | | | | |
| National energy only | 4.0% | 3.0% | 2.9% | 2.8% | 2.5% | 2.0% | 1.8% | 1.7% | 1.5% | 1.4% |
| National energy only (robust) | 3.7% | 2.9% | 2.9% | 2.8% | 2.5% | 2.0% | 1.8% | 1.7% | 1.5% | 1.4% |
| ETS energy only | 4.1% | 3.1% | 3.0% | 2.9% | 2.6% | 2.1% | 1.9% | 1.8% | 1.6% | 1.4% |
| WIOD | 4.8% | 3.7% | 3.4% | 3.3% | 2.9% | 2.4% | 2.1% | 2.0% | 1.8% | 1.5% |
| Portugal | | | | | | | | | | |
| National energy only | 2.6% | 2.1% | 2.0% | 2.0% | 1.8% | 1.7% | 1.6% | 1.5% | 1.4% | 1.0% |
| National energy only (robust) | 2.2% | 2.0% | 2.0% | 2.0% | 1.8% | 1.7% | 1.5% | 1.5% | 1.4% | 1.0% |
| ETS energy only | 2.8% | 2.3% | 2.1% | 2.1% | 1.9% | 1.7% | 1.7% | 1.6% | 1.5% | 1.1% |
| WIOD | 2.9% | 2.3% | 2.1% | 2.1% | 1.9% | 1.7% | 1.6% | 1.5% | 1.4% | 1.1% |
| Ireland | | | | | | | | | | |
| National energy only | 2.2% | 1.0% | 0.9% | 0.8% | 0.7% | 0.7% | 0.6% | 0.5% | 0.5% | 0.4% |
| National energy only (robust) | 1.1% | 0.9% | 0.9% | 0.8% | 0.7% | 0.6% | 0.6% | 0.5% | 0.5% | 0.4% |
| ETS energy only | 2.2% | 1.0% | 0.9% | 0.8% | 0.7% | 0.7% | 0.6% | 0.5% | 0.5% | 0.4% |
| WIOD | 4.6% | 2.1% | 1.9% | 1.7% | 1.5% | 1.4% | 1.4% | 1.2% | 1.2% | 1.0% |
| Finland | | | | | | | | | | |
| National energy only | 1.1% | 0.8% | 0.8% | 0.9% | 0.9% | 0.9% | 0.8% | 0.8% | 0.8% | 0.6% |
| National energy only (robust) | 0.9% | 0.9% | 0.8% | 0.9% | 0.9% | 0.9% | 0.8% | 0.8% | 0.8% | 0.6% |
| ETS energy only | 1.2% | 0.9% | 0.9% | 1.0% | 1.0% | 1.0% | 0.9% | 0.9% | 0.8% | 0.7% |
| WIOD | 2.7% | 2.0% | 1.9% | 1.8% | 1.8% | 1.7% | 1.7% | 1.6% | 1.5% | 1.2% |
| Luxembourg | | | | | | | | | | |
| National energy only | 0.8% | 0.7% | 0.5% | 0.5% | 0.6% | 0.4% | 0.5% | 0.4% | 0.3% | 0.2% |
| National energy only (robust) | 0.7% | 0.7% | 0.5% | 0.6% | 0.5% | 0.4% | 0.5% | 0.4% | 0.3% | 0.2% |
| ETS energy only | 0.9% | 0.8% | 0.6% | 0.6% | 0.6% | 0.5% | 0.5% | 0.4% | 0.4% | 0.3% |
| WIOD | 2.9% | 2.8% | 2.2% | 2.1% | 2.3% | 2.1% | 1.9% | 1.7% | 1.5% | 1.1% |

Notes: Under *National energy only*, only national energy emissions from energy use are taxed (central scenario). Under *National energy only (robust)*, only national energy emissions from energy use are taxed and household with an expenditure to income ratio higher than 2.5 are excluded. Under *ETS energy only*, energy emissions from energy use produced within EU countries are taxed. Under *WIOD*, all carbon emissions, including process based and fugitive emissions are based (equiv. to a CBAM). Here we use the carbon emission vector provided by the JRC.

Table 20: Relative contribution to the change in the Gini index due to a carbon tax of savings rates, budget shares, asset ownership, carbon intensity and two-way interaction effects- No households with high expenditure to income ratios.

| | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| Gini Pre-tax (G*100) | 25.80 | 26.31 | 32.12 | 28.94 | 27.35 | 28.64 |
| Gini Post - Carbon Tax (Gt*100) | 26.26 | 26.69 | 32.32 | 29.04 | 27.40 | 28.72 |
| Change due to Carbon tax | 0.45 | 0.37 | 0.20 | 0.10 | 0.05 | 0.08 |
| Change in Gini | | | | | | |
| Savings rate (s) | 0.14 | 0.10 | 0.14 | 0.05 | 0.07 | 0.04 |
| Budget share (w) | 0.18 | 0.02 | 0.11 | 0.05 | 0.04 | 0.03 |
| Carbon Intensity (e) | 0.11 | 0.11 | 0.01 | 0.01 | 0.00 | 0.00 |
| ICE vehicle ownership (V) | -0.06 | -0.10 | -0.06 | -0.03 | -0.08 | -0.01 |
| Heating system ownership (H) | -0.06 | -0.07 | -0.05 | -0.01 | -0.04 | -0.01 |
| Contribution of factors (in %) | | | | | | |
| Savings rate (s) | 31.40 | 25.67 | 67.90 | 51.26 | 144.25 | 48.12 |
| Budget share (w) | 39.12 | 6.58 | 54.59 | 53.65 | 82.34 | 36.71 |
| Carbon Intensity (e) | 25.16 | 29.49 | 6.84 | 6.74 | 9.99 | 0.18 |
| ICE vehicle ownership (V) | -12.87 | -17.89 | -25.24 | -13.54 | -77.66 | -9.81 |
| Heating system ownership (H) | 1.13 | -8.89 | -1.50 | -11.37 | -85.96 | -4.17 |
| Interactions and other | 16.06 | 65.04 | -2.59 | 13.25 | 27.04 | 28.98 |
| Contribution of two-way interactions (in %) | | | | | | |
| H & w | -0.88 | -1.14 | -0.66 | -0.92 | -10.28 | -0.09 |
| H & e | 18.30 | 28.71 | 5.93 | -0.07 | -1.16 | -2.69 |
| V & w | -3.37 | -0.86 | -3.24 | -1.93 | -11.71 | -0.73 |
| V & e | -26.19 | -30.13 | -10.34 | -8.12 | -15.89 | 0.69 |
| w & e | -2.44 | 15.77 | -4.28 | -0.83 | -7.16 | -0.94 |
| 3 way interactions | 30.63 | 52.69 | 10.00 | 22.74 | 73.25 | 32.75 |
| Total | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 |

Notes: All changes are calculated as: Change in Gini=(Gc*100)- (G*100), where G is the pre-tax Gini index of equivalized household disposable income and Gc is the counterfactual Gini index of equivalized household disposable income; Calculations are based on equivalized household disposable income.

Table 21: Relative contribution to the carbon tax regressivity of savings rates, budget shares, asset ownership, carbon intensity and two-way interaction effects - No households with high expenditure to income ratios.

| | Hungary | Lithuania | Portugal | Ireland | Finland | Luxembourg |
|---|---|---|---|---|---|---|
| Suits index | -0.16 | -0.18 | -0.14 | -0.18 | -0.07 | -0.21 |
| Counterfactual Gini | | | | | | |
| Savings rate (s) | -0.06 | -0.06 | -0.10 | -0.10 | -0.09 | -0.11 |
| Budget share (w) | -0.06 | -0.04 | -0.07 | -0.10 | -0.05 | -0.08 |
| Carbon Intensity (e) | -0.04 | -0.10 | 0.00 | -0.01 | -0.01 | 0.00 |
| ICE vehicle ownership (V) | 0.01 | -0.01 | 0.02 | 0.01 | 0.03 | -0.01 |
| Heating system ownership (H) | 0.00 | 0.01 | 0.00 | 0.01 | 0.03 | -0.01 |
| Contribution of factors (in %) | | | | | | |
| Savings rate (s) | 38.9 | 33.0 | 70.4 | 56.1 | 128.9 | 54.1 |
| Budget share (w) | 37.0 | 21.9 | 50.9 | 53.5 | 73.5 | 37.9 |
| Carbon Intensity (e) | 22.3 | 53.7 | 3.1 | 5.5 | 12.0 | -0.3 |
| ICE vehicle ownership (V) | -5.1 | 3.2 | -14.8 | -3.6 | -36.6 | 5.4 |
| Heating system ownership (H) | 1.4 | -5.3 | 0.9 | -4.1 | -46.0 | 5.8 |
| Interactions and other | 5.5 | -6.5 | -10.6 | -7.3 | -31.8 | -2.9 |
| Contribution of two-way interactions (in %) | | | | | | |
| H & w | -0.7 | -0.6 | -1.8 | -3.1 | -12.6 | -4.1 |
| V & w | -5.3 | -4.6 | -5.3 | -4.7 | -15.3 | -5.5 |
| H & e | 10.5 | 2.6 | 1.6 | 0.1 | -2.1 | -0.1 |
| V & e | -22.8 | -53.4 | -5.8 | -7.1 | -15.6 | 1.2 |
| w & e | -2.8 | -20.9 | -1.2 | 0.1 | -9.2 | -0.2 |
| 3 way interactions | 26.6 | 70.5 | 2.0 | 7.4 | 22.9 | 5.8 |
| Total | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 |

Notes: Calculations are based on equivalized household disposable income.

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