ESRI ECONOMIC & SOCIAL RESEARCH INSTITUTE

ESRI Working Paper No. 739

November 2022

Economic and Distributional Impacts of turning the Value-Added Tax into a Carbon Tax

Miguel A. Tovar Reaños[a,b*], Kelly de Bruin[a,b], David Meier[a] and Aykut Mert Yakut[a,b]

a) Economic and Social Research Institute, Dublin, Ireland
b) Trinity College Dublin, Dublin, Ireland

*Corresponding Author:
Dr Miguel A. Tovar Reaños,
Economic and Social Research Institute,
Whitaker Square, Sir John Rogerson's Quay,
Dublin, Ireland
Email: Miguel.AngelTovar@esri.ie

We acknowledge funding from the Economic and Social Research Institute's Environment Research Programme, which is funded by the Environmental Protection Agency's Research Programme 2018–2020. The funder had no role in study design; in the collection, analysis and interpretation of data; in the writing of the report; or in the decision to submit the article for publication.

Abstract

We construct carbon footprints from households' expenditure and employ the EASI demand sys-tem to simulate the distributional and environmental effects of a introducing a 'green VAT' in Ireland. For our analysis, we combine expenditure data from the Irish Household Budget Survey with data on consumption-based emissions. We consider three scenarios: one with no recycling mechanism for addi-tional tax revenue, one with a five percent higher state transfers and one with an income tax cut. In all scenarios, the existing VAT system is replaced by a combination of a uniform base rate of four percent and a strong carbon tax component. The policy leads to a reduction in emissions from households of roughly 6 percent. We find that households' footprints are strongly driven by expenditure on energy and transport. Average emissions footprints are higher for high-expenditure quartiles. We also find that while the tax leads to welfare drops for all households, especially those at the lower end of the distribution of household expenditure, the combined carbon tax and transfer increase are protecting at least the lowest two deciles of the expenditure distribution from the adverse welfare effects. The income tax cut limits the reduction in working hours present in the other two scenarios. Both revenue recycle mechanisms weaken the reduction in emissions.

JEL codes: D12, H23, Q58

1 Introduction

Many economists favour carbon taxation as an instrument to reduce carbon emissions (examples include Fremstad and Paul (2019), Drupp et al. (2022) or Stiglitz (2013)). They argue that greenhouse gas emissions are a prime example of an externality because they impose some costs that are not paid by the polluter. A consumers consumption level of the good in question is higher than the amount that they would have chosen if they had to bear all associated costs themselves. According to Pigou (1920), this inefficiency can be removed if emissions are taxed at such a level that the market price reflects the 'true' costs of the product. The current reforms of the Value-Added Tax (VAT) system in the European Union (EU) will provide Member States with more flexibility to include Pigou (1920)'s principles into the VAT system. One of the explicitly stated goals of the policy is opening the door to differentiated rates intended to promote sustainable consumption (European Commission, 2021). This 'greening' of the VAT is not a new idea, it has come up repeatedly in policy debates (Committee on Economic and Monetary Affairs (2011); Umweltbundesamt (2022)), and is even advocated for by an ongoing Citizens Initiative[1]. However, the environmental and economic effects of a 'green VAT' have not been investigated in the academic literature. This article fills this gap by providing measuring the carbon emissions associated with the current levels of consumption and the implications of implementing a green VAT in Ireland. In addition, we include income taxes and labour supply in our model. Thus, we are able to estimate work time responses of households to changes in consumption and income taxes.

Emissions embedded in the imports made for consumption of Irish households exceed those embedded in Irish exports (see data provided by Wood et al., 2019). Measures that only target greenhouse gasses (GHG) emitted in Ireland itself (e.g. production taxes), therefore miss an important part of the Irish carbon footprint. To address this issue, consumption taxes, like the VAT, should be the preferred measure to reduce the countries carbon footprint. Reduced VAT rates are mentioned as one among many potential instruments to encourage sustainable consumption in policy documents (see European Commission (2012)). Oosterhuis et al. (2008) discuss the potential EU-wide effects of applying existing reduced rates to certain environmentally friendly products, while moving to the standard rate for those environmentally harmful products that currently tend to be taxed at reduced rates. They propose a tax reduction for energy and energy efficient heating appliances as well as an increase in the tax rate on meat as examples. Most current VAT systems do not apply an environmental reasoning in choosing which goods get taxed at the standard rate and which are subject to reduced rates (Bahn-Walkowiak et al., 2017).[2] Both Timmermans and Achten (2018) and De Camillis and Goralczyk (2013) propose an environmental reform of the Value-Added Tax system resulting in a tax rate that is based on the environmental impact of a product, while also containing

[1] See the entry in the EU database of initiatives (https://europa.eu/citizens-initiative/initiatives/details/2021/000011_en) or the initiatives own website (https://greenvat.org/en//).

[2] An exception to this might be China. Eisenbarth (2017) offers some evidence that export VAT rebates employed to discourage exports of pollutant and natural resource intensive goods. While it is an example of an environmentally motivated VAT policy, the indirectness and limited scope of the measure make it quite different from the proposals discussed here.

a uniform base rate that functions like a low, normal value-added tax. Both studies suggest using Life-Cycle-Assessment (LCA) to assess the environmental impacts of a commodity throughout all stages of its existence, from the extraction of the necessary resources to its eventual disposal (De Camillis and Goralczyk, 2013). The aim of a proper LCA is to assess all environmental impacts, including loss of biodiversity, resource extraction and water pollution (Timmermans and Achten, 2018). In this article, we focus on simulating the effects of differentiating VAT rates between eight consumption purposes based on their carbon intensity.

Bahn-Walkowiak and Wilts (2015) offer a detailed discussion of potential reforms of the VAT for environmental purposes. In particular, they address legal constraints neglected by other authors. Under current law, member states of the European Union are allowed to set no more than two reduced rates. They are, however, free to choose how high their standard rate and each of their reduced rates are, as long as they are at least 5%. At the same time, there is an ongoing (although slow moving) effort to harmonize rates between member states, which potentially reduces tax competition and increases overall revenue (Bahn-Walkowiak and Wilts, 2015). This might imply that actually implementing a tax that varies considerably depending on the carbon content of different goods could be associated with substantial legal and political challenges. However, as mentioned above, the European Commission has recently moved in the opposite direction by increasing the range of goods to which member states can apply reduced rates (European Commission, 2021). The new regulation explicitly includes sustainability concerns in the list of potential justifications for applying reduced VAT rates (see Council of the European Union, p.2f).

To assess the environmental impact of different consumption patterns, we combine micro data on household expenditure with estimates for the carbon content of different commodity groups. We then use the Exact Affine Stone Index implicit Marshallian demand system (hereafter referred to as the 'EASI demand system'), developed by Lewbel and Pendakur (2009) to estimate the households reaction to an environmental reform of the value-added tax.[3] Previous studies have used a similar approach to study the relationship between environmental impacts and household expenditure in Germany: Pothen and Tovar Reaños (2018) use German expenditure and material consumption data to study the distribution material footprints of German households. These studies do not consider changes in labour supply and their impacts in consumption. We follow van der Ploeg et al. (2022)' approach and include labour supply responses. They use the EASI demand system and simulate the effect of a tax on emissions in combination with different revenue recycling schemes. They find that while a carbon tax on its own is clearly regressive, these effects can be offset by redistributing the revenue to households in the form of a lump-sum transfer. However, they stress that because of large household heterogeneity, no revenue recycling scheme makes all households better off. At the same time, some recycling methods, like a reduction in income taxes, might even amplify the regressive effect of the tax.

In this study, we simulate three different policy scenarios: One in which the current VAT system is replaced by a low base rate and a strong carbon tax, but additional revenue is not recycled, one in which the additional revenue is used to increase existing state transfers, and one in which the additional revenue is used to reduce all income tax rates. We compare these to the baseline scenario of no policy change. Our data reveal that consuming products related to 'energy' and 'transport' is associated with the highest amounts of CO_2 per Euro spend by far. We find that carbon footprints are unevenly distributed across households: while most households cluster around the average annual footprint of 11 tons CO_2-equivalents, a few households have footprints of 40 tons and more. The overall footprints rise with a household's expenditure for each consumption purpose we consider. The simulations using the EASI demand system show that replacing the existing value-added tax system by the green VAT leads to reductions in emissions of around six percent. These come at the cost of reduced household welfare and lower levels of consumption and working hours. We find the carbon tax itself to be regressive, confirming previous findings from other countries (see e.g. van der Ploeg et al., 2022). Combining the green VAT reform with an increase in state transfers manages to offset some of the welfare impacts for the lowest expenditure households, but overall inequality still increases, and emissions reductions are about one percentage point smaller under this scenario. Reducing the income tax rate for all households instead can counter the impact on consumption levels and mitigate the reduction in working hours.

Our study differs from previous entries in the literature in two major ways: Firstly, to the best of our knowledge, we are the first academic study of the effects of a 'green VAT' reform using microsimulation methods that includes both direct and indirect taxation. Secondly, we provide estimates of carbon footprints of Irish households based on the most recent available wave of the Irish Household Budget Survey and show how they change across household types and income levels.

The paper is structured as follows: Section 2 describes how we construct the new prices under the 'green' VAT rates. It also provides an overview of the EASI demand system. Section 3 gives an overview of the different simulation scenarios and the associated revenue recycling mechanisms. Section 4 describes our data and provides summary statistics on household characteristics, expenditure patterns, carbon footprints, and the current value-added tax system. Section 5 presents our results and compares the outcomes of our three scenarios along various metrics such as the magnitude of emissions reductions or welfare effects. Section 6 describes potential limitations of our analysis and gives an overview of relevant arguments for a green VAT that are not captured by our model. Finally, section 7 concludes.

2 Methodology

2.1 Constructing the 'Green VAT'

Figure 1 graphically summarizes the new VAT concept we simulate: a fixed base rate with an additional component that varies depending on the embedded carbon of a good added on top. To differentiate it from

[3] See Pendakur (2009) for a less technical summary of the EASI demand system.

the 'DaVAT' proposed by Timmermans and Achten (2018), we refer to the version of the value-added tax we simulate in this study as the 'green VAT' or 'GVAT'.

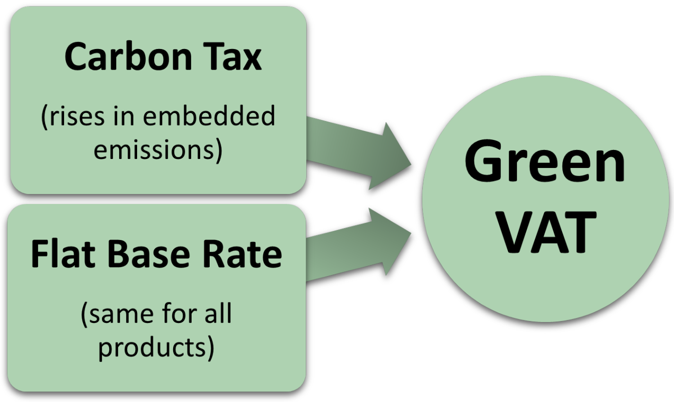


Figure 1: General structure of the Green VAT

To calculate the price changes that are induced by the green VAT, we follow the approach taken by Tiezzi and Verde (2016) and first remove the initial tax rate from each price index. Subsequently, we add the new base rate of 4% to each index. Thirdly, we take our carbon tax per ton of CO_2 and multiply it with the intensities we obtain by combining our emissions data with the expenditure data from the HBS (for a detailed description of how the intensities are calculated, see section 4.3). Since the intensities are given in tons of CO_2-equivalents per Euro, the result of the calculation is dimensionless and can be combined with the dimensionless price index. We can express the carbon tax as a product specific tax rate by dividing the dimensionless carbon tax by the price index that includes the new base rate. Finally, we calculate the price index after the green VAT reform by adding the carbon tax rate to the price that includes the new 4% base rate.[4]

2.2 The Affine Stone Index (EASI) implicit Marshallian demand system

2.2.1 Household expenditure

We follow the methodology of Tovar Reaños and Lynch (2022) and Tovar Reaños and Wölfing (2018), who use the EASI demand system to calculate the changes in welfare at the household and aggregated level that result form environmental tax reforms. The EASI (Lewbel and Pendakur, 2009) allows to derive a demand system by giving a first-order approximation of an arbitrary expenditure function, which has to have all the properties that hold for a theoretical expenditure function (Varian, 1992).

The EASI only requires information on expenditure for different goods and their prices. This allows it to represent flexible Engel Curves (which show the relationship between expenditure and income). The EASI demand system can be estimated either by an iterated linear approximation or the generalized method of moments (GMM) estimator. The logarithmic form of the expenditure function given in Lewbel and Pendakur (2009) is the following:

$$\begin{aligned}\log\left[C(\boldsymbol{p},y)\right] = y &+ \sum_{i=1}^{I} m_i(y,\boldsymbol{z})\log(p_i) \\ &+ \frac{1}{2}\sum_{i=1}^{I}\sum_{j=1}^{I} a_{ij}\log(p_i)\log(p_j) \\ &+ \frac{1}{2}\sum_{i=1}^{I}\sum_{j=1}^{I} b_{ij}\log(p_i)\log(p_j)y \\ &+ \sum_{i=1}^{I}\varepsilon_i\log(p_i)\end{aligned} \tag{1}$$

with

$$m_i = \sum_{r=0}^{R} b_r \log(y)^r + \sum_l d_{il} z_l \log(y) + \sum_l g_{il} z_l \tag{2}$$

Here, y is the implicit household utility, z_l reflects demographic characteristics, and i and j are indices for different commodities. p_i is the price of commodity i. R determines the degree of the polynomial m_i.

[4]The formula for calculating the price under the 'green VAT' tax regime form the initial price thus is the following:

$$\begin{aligned}\log(p_j^1) = &\log(p_j^0) \\ &- \log(1+VAT_j^0) + \log(1+VAT^1) \\ &+ \log\left\{1+\left[\frac{\pi * intensity_j}{\exp\left[\log(p_j^0) - \log(1+VAT_j^0) + \log(1+VAT^1)\right]}\right]\right\}\end{aligned}$$

Where j is an index for the consumption purpose, p^1 is the price index under the green VAT regime, p^0 is the initial price index, VAT^0 and VAT^1 are the initial and new value-added tax rates, respectively. π is the carbon tax in Euro per ton of CO_2, while $intensity_j$ is the carbon intensity in ton of CO_2 per Euro.

It is chosen by the modeller. The parameters $a_{i,j,l}$, $b_{i,j}$, $b_{i,r}$, $d_{i,l}$ and g_{il} are to be estimated. ϵ_i represents unobserved preference heterogeneity. As Lewbel and Pendakur (2009) show, the implicit utility y can be expressed in the following way:

$$y = \frac{\log(x) - \sum_i w_i \log(p_i) + \frac{1}{2}\sum_i \sum_j a_{i,j} \log(p_i)\log(p_j)}{1 - \frac{1}{2}\sum_i \sum_j b_{i,j} \log(p_i)\log(p_j)} \tag{3}$$

The term w_i is the budget share of commodity i. It can be calculated by applying Shepard's lemma to the cost function embedded in expression (1), which results in:[5]

$$\begin{aligned} w_i = &\sum_j a_{i,j}\log(p_j) + \sum_j b_{i,j}\log(p_j) y \\ &+ \sum_{r=0}^{R} b_{i,r}[\log(y)]^r + \sum_l g_{i,l} z_l + \sum_l d_{i,l} z_l \log(y) + \epsilon_i. \end{aligned} \tag{4}$$

Lewbel and Pendakur (2009) show that estimating (4) with an approximation of y[6] or using (3) produces very similar estimates. To reduce the computational burden of the parameter estimation, we chose the first approach.[7] We follow Lewbel (1989) and use information on intra-group variation of the aggregated consumption categories to obtain household-specific prices. After estimating the parameters in equation (4), we can calculate own-price elasticities (OPE) and expenditure elasticities (EE):

$$OPE = \left\{\frac{\partial w_i}{\partial \log(p_i)}\right\}\frac{1}{w_i} - 1 \tag{5}$$

$$EE = \left\{\frac{\partial w_i}{\partial \log(X)}\right\}\frac{1}{w_i} + 1 \tag{6}$$

2.2.2 Tax incidence

Like Tovar Reaños and Wölfing (2018) and Creedy and Sleeman (2006), we use Hicks' Equivalent Variation (HEV) to estimate changes in household welfare that occur after changes in commodity prices or income. The HEV is a monetary value reflecting the difference between the level of expenditure (at old prices) needed to achieve the new level of utility and the level of expenditure needed to achieve the old level of utility. Mathematically, this can be expressed as $C(p^0, y^1) - C(p^0, y^0)$ where the indices 1 and 0 stand in for the states before and after the shock, respectively. We calculate a metric for Hicks' equivalent variation for this specification as follows:

$$\begin{aligned} HEV = exp &\left\{ \sum_i {p_i}^0 w_i(y, {p_i}^0) - \kappa \left[\sum_i {p_i}^1 w_i(y, {p_i}^1)\right] \right. \\ &- \left. \left[\frac{1}{2}\sum_{l=0}^{L}\sum_{i,j} a_{i,j,l} {p_i}^0 {p_j}^0 z_l - \kappa \frac{1}{2}\sum_{l=0}^{L}\sum_{i,j} a_{i,j,l} p_i^1 p_j^1 z_l\right] + \kappa X^1 \right\} \\ &- X^0 \end{aligned} \tag{7}$$

where

$$\kappa = \frac{[1 - \frac{1}{2}\sum_{i,j} b_{i,j} {p_i}^0 {p_j}^0]}{[1 - \frac{1}{2}\sum_{i,j} b_{i,j} p_i^1 p_j^1]} \tag{8}$$

2.2.3 Income taxes and labour supply

The budget constraint of a household in our model is:

$$x_h + \sigma_h + T(W_h l_h + \bar{x}_h) = W_h l_h + \bar{x}_h \tag{9}$$

Here, h is an index for the household. x is the households spending, while s denotes state transfers. The income tax schedule is given by T(.), in which W_h denotes the gross wage and l_h denotes the amount of hours worked. $\bar{x}_h$ is additional income that is unrelated to work hours, and σ_h are the exogenous savings of the household. We obtain the total utility of household h by subtracting both the disutility of work and the disutility of aggregate pollution from the indirect utility from the bundle of consumption goods. Its separable form therefore is:

$$u_h = y_h(\vec{q}_h, x_h) - \phi_h \frac{l_h^{1+1/\varepsilon^F}}{1 + 1/\varepsilon^F} - \psi_h E, \;\; \phi_h > 0, \; \varepsilon^F > 0, \psi_h \geq 0 \tag{10}$$

[5]Note that $\log(x) = \log[C(\boldsymbol{p}, y)]$.

[6]Lewbel and Pendakur approximate y by using $\log(x) - \sum_i \bar{w}_i \log(p_i)$ where $\bar{w}_i$ is the mean of the budget share.

[7]The following restrictions apply and ensure that the estimated expenditure function is theoretically consistent:

$$a_{i,j,l} = a_{j,i,l} \quad \text{and} \quad \sum_i a_{i,j,l} = 0 \;\forall\; l; b_{i,j} = b_{j,i} \quad \text{and} \quad \sum_i b_{i,j} = 0,$$

$$\sum_i d_{i,l} = \sum_i g_{i,l} = 0 \;\forall\; l; \sum_i b_{i,r} = 0 \text{ for } r \neq 0; \sum_i b_{i,r} = 1 \text{ for } r = 0$$

.

Here, ϕ_h is a disutility of work cost parameter (in Euro per disutility of work), ε^F is the Frischian wage elasticity of labour supply, ψ_h is the utility cost of pollution for household h (in Euro per aggregate pollution), and E denotes aggregate emissions. The disutility from aggregate emissions might be different across households. For example, high income households might be less affected by pollution than lower income ones.

Because households take taxes and transfers and aggregate emissions as exogenous, maximising (10) subject to (9) gives the following labour supply for household h:

$$l_h = \left(\frac{1}{\phi_h} \frac{(1-t_h)W_h}{P_h^M} \right)^{\varepsilon^F} \tag{11}$$

Here, $P_h^M \equiv dx_h/dy_h$ represents the marginal cost of utility of household h, and t_h its average tax rate. The supply of labour decreases in the marginal cost of utility and rises in the after-tax wage. Since the utility function (10) is quasi-linear, there are no income effects on the labour supply. Consumer prices increase when carbon is taxed at rate $\pi > 0$. The increased prices cause the marginal cost of utility to rise and thus reduce the labour supply. Using the additional revenue to lower marginal income tax rates mitigates this effect, while recycling it via transfers has no additional effect on labour supply.[8]

2.2.4 The government budget constraint

The revenues raised by the income tax and the GVAT have to cover the exogenous transfers:

$$(1-\lambda)\sum_{h=1}^{H} N_h T_h(W_h l_h + \bar{x}_h) + \pi E = transfers_h \tag{12}$$

Here λ is the reduction in income taxation. This is a number between 0 and 1.

3 Scenarios

Table 1 shows an overview of the three scenarios we simulate. Simulated changes are measured with respect to a baseline scenario in which there is no policy change. In each of the other scenarios, the existing value-added tax of each consumption purpose is replaced by a base rate of 4%. We follow Timmermans and Achten (2018) and chose this rate because it is the lowest average VAT rate for a consumption purpose we observe in the data (see figure 5). In addition, a carbon tax of 120€ per embedded ton of CO_2 is charged. This is the concept of the 'green VAT' graphically represented in Figure 1. We use this level of carbon tax because at this levels we can achieve similar levels of tax revenue to the VAT revenues in the base scenario. Our scenarios differ in how additional revenue from the new tax scheme is recycled. The amount of revenue that would have been obtained without a change in the VAT system is assumed to be already budgeted for public expenditure elsewhere. In our first scenario (GVAT), the green VAT is introduced, but no revenue recycling mechanism is simulated. The other two scenarios include different options of how to recycle additional revenue. Comparing the results of the GVAT scenario to those of the two scenarios with additional revenue recycling allows us to differentiate the effect of the new tax system from that of the revenue recycling mechanism.

	Base scenario	Green VAT (GVAT)	GVAT+transfers	GVAT+income tax
VAT Rate	Observed in data	4%	4%	4%
Carbon Price	0 €/ton	120 €/ton	120€/ton	120€/ton
Revenue Recycling	None	None	5% increase of transfers	4% reduction of income tax

Table 1: Overview of the scenarios to be simulated.

One revenue recycling option is to increase all existing social transfers in our model by 5%. Figure 2 plots the share that transfers make up in a household's pre-tax income against the household's size-adjusted income (before all taxes and transfers). The graph shows a clear downward trend, indicating that households with lower income tend to receive relatively higher transfer payments. At low levels of overall income, there is a cluster of households that report an income which is solely made up of transfers. We therefore expect lower income households to benefit more from the increased transfers than high income households. Our

[8] The full expression of the marginal cost of utility is :

$$P_h^M \equiv \frac{dx_h}{dy_h} = \frac{x_h}{y_h}\left\{1+\sum_{j=1}^{I}\log(p_{hj})\left[\sum_{r=1}^{R} b_{ir} r \log(y_h)^{r-1} + \sum_{j=1}^{J} b_{ij}\log(p_j) + \sum_{l=1}^{L} g_{il} z_l\right]\right\}$$

It is the derivative of household expenditure with respect to indirect utility, with constant consumer prices but changing budget shares. It is equal to the average cost of utility (fraction outside of the curly brackets) times a correction factor (in curly brackets). We follow van der Ploeg et al. (2022) in our approach, but modify their equation (5) to accommodate our expanded version of the demand system which includes an extra term (b_{ij}) in the budget share calculation (see equation (4)). Cobb-Douglas preferences imply constant budget shares, which results in a correction factor of one and all coefficients except the b_{i0} in (4) being zero. In the more general case of all coefficients except the b_{i0}, g_{il} and a_{ij} being equal to zero, demand is homothetic. The correction term in curly brackets is still one in this case and the expression in the equation above simplifies to $\frac{dx_h}{dy_h} = \frac{x_h}{y_h}$ or $P_h^M = P_h^A$. This means aggregate demand is unaffected by the distribution of income. However, in the more general case of non-homothetic demand, the marginal cost of utility is different form the average cost of living for each household, since the term in curly brackets is different from one.

hypothesis is also supported by previous literature, like Muszyńska et al. (2021), who find that the existing Irish transfer system is effective in reducing inequality. Recycling the additional revenue in a progressive manner is particularly attractive because the academic literature has shown carbon taxes to be regressive on their own (see e.g. Tovar Reaños and Lynch, 2022; Fremstad and Paul, 2019; Karydas and Zhang, 2019). The same is true for the value-added tax itself: In their study of VAT evasion in Armenia, Asatryan and Gomtsyan (2020) find that lower income households are hit the hardest by increased enforcement. Bahn-Walkowiak and Wilts (2015) present similar results in their overview of the German VAT system. Importantly for our study, Leahy et al. (2011) have found that the VAT is regressive in Ireland.[9]

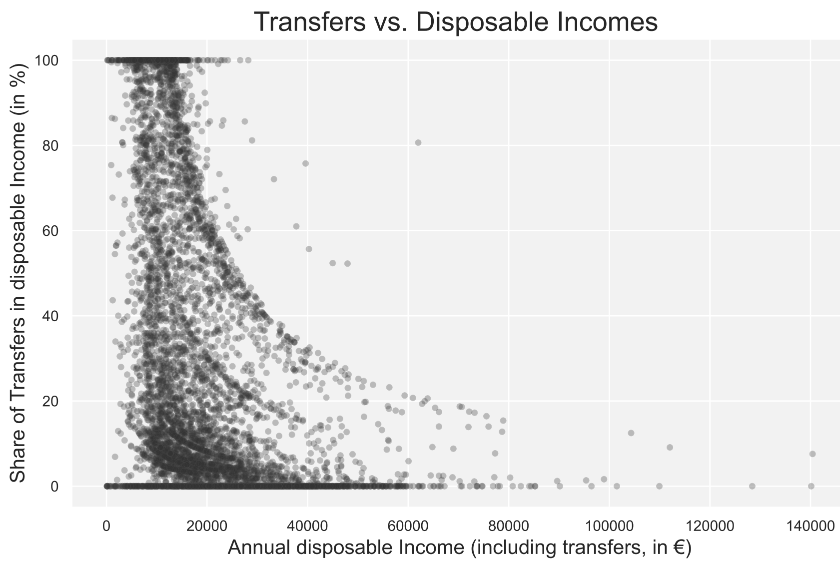


Figure 2: Share of Transfers in equivalised pre-Tax Income

The second recycling option we simulate is a 4% reduction of the income tax. The advantage of such a tax cut is that it not only compensates households for the loss of purchasing power due to the higher consumption taxes (Fremstad and Paul, 2019). In replacing the income tax with a carbon tax, it also substitutes a distortionary tax with a non-distortionary one, since the carbon tax, if calibrated correctly, simply internalises the externality costs associated with carbon emissions (Stiglitz, 2013; Goulder, 1995). However, such a so-called "double dividend" is not guaranteed. Its emergence depends on the carbon price being non-optimal before the environmental tax is introduced (Klenert et al., 2018). Otherwise, shifting tax rates will actually reduce welfare (Fullerton et al., 2010). In their simulation of carbon taxes based on a German household survey, van der Ploeg et al. (2022) find that uniform income tax cuts are regressive, meaning richer households benefit more than poorer ones. This is an especially grave drawback, because as discussed above, carbon taxes and the VAT on their own already are regressive.

In analysing the three scenarios outlined above, this paper aims to shed light on whether the regressive effects of the carbon tax found in the literature emerge in the same way when a value-added tax is used as a carbon tax, and whether they are amplified or mitigated by different revenue recycling mechanisms.

4 Data

4.1 Household consumption and labour supply data

We use the Household Budget Survey (HBS) as our main data set. The Central Statistical Office (CSO) conducts the survey every five years with the goal of "determin[ing] in detail the pattern of household expenditure in order to update the weighting basis of the Consumer Price Index".[10] In this study, we use multiple cross sections provided by the survey (namely 1994, 1999, 2004, 2009 and 2015-2016) in combination with indices for commodity prices for the same years provided by the CSO.

We aggregate consumption goods into eight 'consumption purposes': transportation, services, housing, health, food, energy, education, and durables. This grouping resembles those used in Tovar Reaños and Wölfing (2018), Tovar Reaños and Lynch (2022) and Böhringer et al. (2017) and follows the Classification of Individual Consumption According to Purpose (COICOP). Under the consumption purpose "Durables", we summarize all non-perishable consumption goods, such as clothing, furniture, textiles, kitchen, and garden equipment, as well as repair services related to these products. The consumption purpose "Education" covers not only expenditure for training, education and reading materials, but also internet subscriptions and expenditure on sports and leisure. The consumption purpose "Energy" summarizes expenditure on electricity and different fuels used for heating. All expenditure on foodstuff, including alcoholic drinks, at home as well as in restaurants is summarized in the consumption purpose "Food". It also includes tobacco. In addition to all expenditure for medical services, medical equipment and pharmaceuticals the consumption purpose "Health" includes equipment for babies, household services and cosmetics. The consumption purpose "Housing" comprises expenditure directly related to the households dwelling, like mortgage payments, rent,

[9]The current second reduced VAT rate of 9% was not part of the analysis of Leahy et al. (2011), but, according to the findings of Crawford et al. (2010), additional differentiated tax rates are unlikely to substantially counter its regressivity. The standard and first reduced rate they analyse are the same as today. Thus, it is very likely that the Irish VAT system is regressive to this day.
[10]See https://www.cso.ie/en/methods/housingandhouseholds/householdbudgetsurvey/

water charges, property tax and cost for home maintenance or improvement. Beyond these, the category also includes some furniture, like rugs and TV sets. Under "Services", we summarize all expenditure on services that are not already covered by other purposes, like is the case for medical services (which are part of "Health") or specific repairs ("Transport" and "Durables"). "Services" thus includes expenditure on for example banking and insurance fees, phone payments or estate agents. "Transport" covers tickets for public transports as well as maintenance and fuel costs for personal vehicles like cars or motor bikes. It also includes related services like repairs and driving lessons. It does however not include the purchase of vehicles, which is part of "Durables". Table A.11 in Appendix A provides a comprehensive overview of the content of each category and how it corresponds to the classifications used in the Household Budget Survey and the input-output emissions data.

Table A.1 in Appendix A provides summary statistics of the variables used to estimate the demand system. It includes information on each consumption purposes' expenditure share and price index. We also include socioeconomic variables in our model, such as the age group of a dwelling, whether a dwelling is in a rural area (according to the CSO classification), whether the dwelling has a dishwasher, a washing machine, and whether the household owns a car. Our econometric specification also includes dummies for the quarter of the year in which the data were collected. Like for prices and budget shares, summary statistics for these variables are shown in Table A.1 in Appendix A.

Table A.9 in Appendix A provides some summary statistics on households' labour supply. The table also shows that about 68% of households are urban, 60% include a member with low education, 39% include children and 11% are single households.

4.2 Emissions data

We use emissions data that reflect the amount of emissions embedded in the consumption of different products. This is known as "consumption-based carbon accounting". It's opposite is "production-based carbon accounting", which captures only those greenhouse gasses emitted in a certain territory, e.g. a country (Wood et al., 2019). The main advantage of consumption-based carbon accounting is that global trade patterns are considered. In consumption-based carbon accounting, emissions embedded in imported products are added to those embedded in domestically produced products, since both are ultimately made in service of domestic consumption. Emissions associated with the production of exports are excluded, because while they happen to be emitted here, they are ultimately emitted to enable consumption elsewhere (Davis and Caldeira, 2010). Depending on the trade patterns of a country, using consumption- instead of production-based emissions can make a substantial difference. Multiple studies have established a general pattern in which emissions are exported from emerging economies, like China and imported into rich, industrialised regions like Europe, Japan and the US (Chen et al., 2018; Davis and Caldeira, 2010; Hubacek et al., 2021). Data from Wood et al. (2019) suggest that for Ireland, consumption-based emissions are larger than production-based emissions, albeit by less than 10%, which is a small difference compared to other European countries.

In essence, consumption-based emissions methodology corrects for emissions embedded in imports and exports. Consumption-based emissions are, therefore: production-based emissions plus embedded CO_2 in imported goods minus embedded CO_2 in exported goods. To estimate this, we first calculate the production-based emissions for different goods. This is done by estimating carbon usage (and associated emissions) in different production sectors in the economy. We apply the Ireland Environment, Energy and Economy (I3E), which is an intertemporal computable general equilibrium (CGE) model, which reproduces the structure of the economy in its entirety. It includes productive sectors, households, and the government, among others. In the model, the nature of all existing economic transactions among diverse economic agents is quantified. The I3E model models in detail the carbon usage across production sectors (42 in total) and households. The model traces the use of specific energy inputs.[11] The resulting production based emissions for different commodities (39 in total) can be estimated by the carbon usage in the production process of a commodity. The I3E model is calibrated using the Irish Supply and Use table, the Irish Energy Balance (EB) and other data sources (de Bruin and Yakut, 2021a).

To estimate emissions embedded in imports, we combine the I3E model with the input-output database EXIOBASE. EXIOBASE is a global, detailed Multi-Regional Environmentally Extended Supply-Use Table (MR-SUT) and Input-Output Table (MR-IOT). It was developed by harmonizing and detailing Supply-Use tables for a large number of countries, estimating emissions and resource extractions by industry. Subsequently, the country Supply-Use tables were linked via trade, creating an MR-SUT and producing a MR-IOTs from this. EXIOBASE maps imports to each production sector, households, and the government in Ireland to an exporting production sector from a specific country. We calculate the emission intensity (based on EXIOBASE data) per production sector for each country and multiply this by the goods imported by each Irish production sector, households, and the government. We take into account CO_2, N_2O and CH_4 emissions. We add the embedded emissions from imports to final goods or to inputs to the production sectors in the I3E model. The model then computes the embedded emissions used as inputs to produce a specific commodity. Subsequently, CSO data is applied to scale imports up to the 2018 level per product category. The I3E model is used to determine which agents consume the imported commodity, i.e., production sectors, household types, and government. The shares of Irish production consumed nationally and exported are determined within I3E. This allows for the calculation of consumption-based emissions, where production-based emissions and embedded emissions in imports are summed up for the goods consumed within Ireland.

[11]The energy commodities included in the model are peat, coal, crude oil, gasoline, kerosene, fuel oil, liquid petroleum gas, diesel, electricity, natural gas, and other petroleum products (de Bruin and Yakut, 2021b).

4.3 Computing the carbon footprints

We use the 2015/2016 wave of the Irish Household Budget Survey (HBS) to estimate the demand system. The HBS includes weekly expenditure data on over 500 commodity groups for 6839 households. In the survey, each household is assigned a sample weight to make the survey representative. In addition to the weekly expenditure data, the survey also contains several other household characteristics, which we use to determine each household's size, tax credits, etc.

Our data on emissions embedded in the annual total household consumption cover 42 commodity types, 36 of which can be linked to equivalent categories in the HBS.[12] The emissions are divided into emissions embedded in imports and emissions embedded in domestic production.

As described in section 4.1, we aggregate the data into eight consumption purposes in our microsimulation model: durables, education, energy, food, health, housing, services and transport. The sectors from the embedded emissions data cannot be unambiguously sorted into the eight consumption purposes. In order to attribute the emissions data from the 34 sectors to our eight consumption purposes, we therefore need a "bridge classification" that is compatible with both. For a comprehensive list of the correspondence between the commodity classifications used in the HBS, the input-output estimates and the eight consumption purposes, see table A.11 in the appendix.

We match our emissions data with data on household expenditure using the equivalences in table A.11[13]. We divide the amount emissions for each sector by the total expenditure associated with it. We call the resulting measure of emissions per Euro spend the "carbon intensity" of that consumption purpose.[14]

Using these intensities, we calculate the emissions associated which each household's expenditure on our bridge categories.[15] We then aggregate these to household specific footprints for our eight consumption purposes, again using the equivalences between bridge categories and consumption purposes as shown in table A.11. Finally, we divide the emissions associated which each consumption purpose for each household by the it's expenditure on that consumption purpose. The result is a carbon intensity (in tons of CO_2 equivalent emissions per Euro spend) for each household for each of the eight consumption purposes.

We conduct three versions of this calculation of intensities for each sector: once using all emissions, once using only the ones embedded in the consumption of imports and once using only the emissions embedded in the consumption of domestically produced goods. Note that the Household Budget Survey does not differentiate between expenditure on imported or domestically produced products. We are therefore only able to calculate the amount of emissions from domestic production per overall Euro spend. This is different from the amount of emissions from domestic production per Euro spend on domestically produced products, which would be a measure of their "emissions intensity". The key difference between the domestic emissions per overall Euro spend, which we calculate, and the true "domestic emissions intensity" is the following: While the domestic intensity reflects how "dirty" domestic products are, the domestic emissions per overall euro spend are also influenced by the share of domestic products in overall expenditure (which we do not know). A high value of domestic emissions per overall Euro spend might reflect dirty domestic products but might just as well mean that domestically produced product make up a large part of the expenditure of this category. The same reasoning applies to the case of emissions embedded in imported products.

4.4 Distribution of carbon footprints

4.4.1 Total emissions and expenditure

The distribution of emissions footprints is shown in figure 3, with the annual amount of CO_2 equivalent emissions in tons on the horizontal axis and the share of households in each interval on the vertical one. To improve readability, the horizontal axis is truncated at 40 tons of CO_2. To make households of different sizes comparable, we follow the method of Pothen and Tovar Reaños (2018) and divide their expenditure by the square root of the number of household members.[16] We call this the 'equivalised' footprint.

The average footprint (including all emissions) in our sample is 11.51 tons of CO_2-equivalents per year. As panel (a) of figure 3 shows, the distribution is strongly right skewed (skewness = 6.82), which means that most households have footprints below the mean. There are however some substantial outliers: While 98.41% of the households in our sample have footprints of 40 tons or less and are thus presented in the graph, a small number of households (roughly 0.2%) have extremely large footprints that exceed 100 tons per year.

Panel (b) of figure 4 presents the emissions associated which each consumption purpose for the average household of each expenditure quartile. Like for the overall footprints presented in figure 3, the value is divided by the square root of household size to get an equalised value that is comparable across different

[12] The sectors "coal", "crude oil", "fuel-oil", "liquid petroleum gas", "other mining", and "water transportation" do not have equivalences in the HBS.

[13] Prior to this step, we multiply our weekly expenditure data by the factor 52.14 to get an annual value, and are subsequently able combine expenditures with annual emissions data.

[14] The process outlined in the paragraph above is summarized in the following equation:

$$INT_{ij}\left[\frac{\text{t}}{€}\right] = \frac{\sum_{k=1}^{K}(INT_{ik}\left[\frac{\text{t}}{€}\right] * EXP_{ik}\ [€])}{\sum_{k=1}^{K}(EXP_{ik}\ [€])} = \frac{EM_{ij}\ [\text{t}]}{EXP_{ij}\ [€]} \tag{13}$$

with i being an index for the household, j being an index for the consumption purpose and k being an index for the bridge category. Each k is a sub-category of a specific j.

[15] Our assumption that the intensity of each bridge category is equal to the intensity of the larger sector which the bridge category is a subset of is fully valid if there is a uniform distribution of emissions across all bridge categories that are subsets of the same sector from the emissions data. Although this seems improbable, the categories for which we have embedded emissions are detailed enough that the variation in their components carbon intensities is unlikely to be of substantial magnitude.

[16] For some types households (e.g. lone parents or those with 4 or more adults), the HBS does not specify the exact number of children in the household. In these cases, it is assumed that there are two children, which is the most frequent number among households with two adults. If the exact number of adults is unknown, it is assumed to be five. This is the most conservative estimate possible, since all numbers of adults below that would be explicitly captured in a different category.

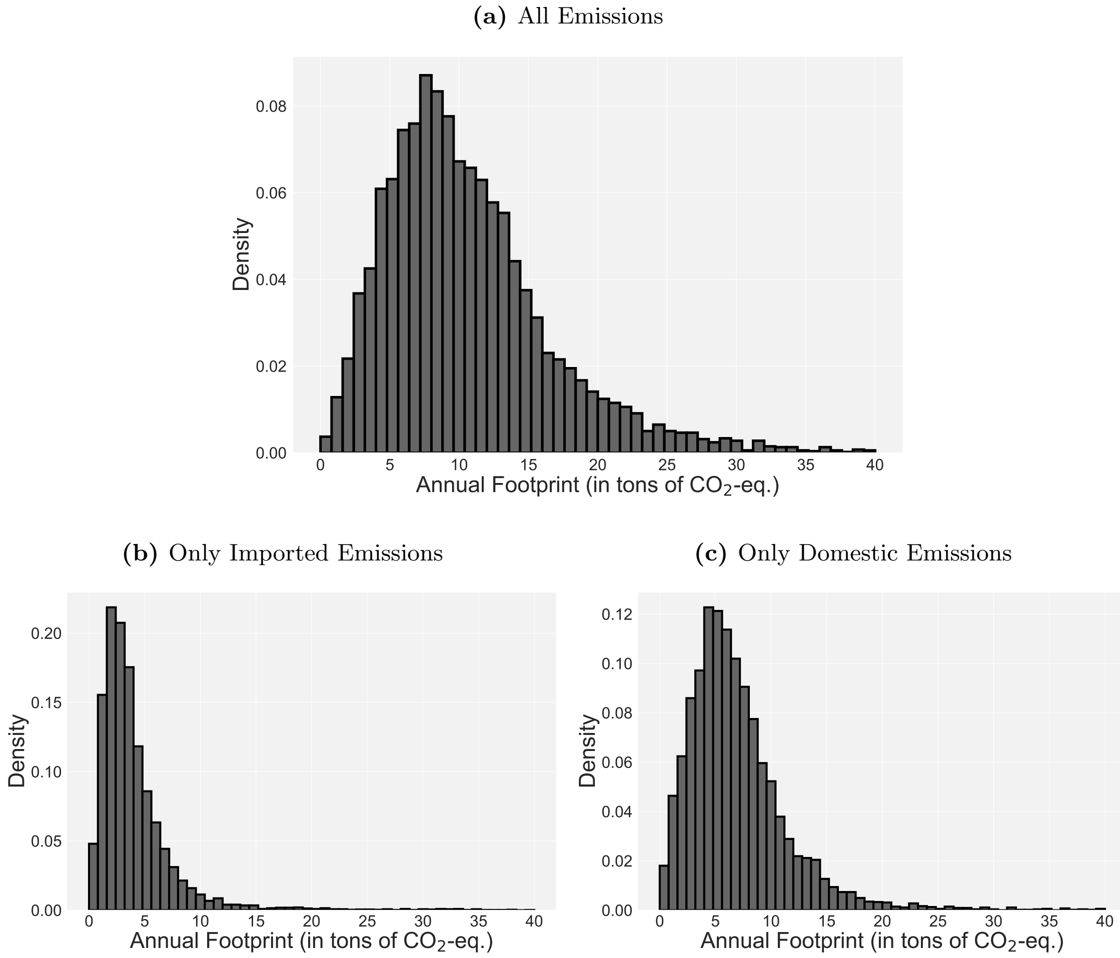


Figure 3: Distributions of households' annual equivalised emissions footprints in Ireland. The distribution is truncated at 40 tons of CO_2-equiv. in this figure.

household sizes (Pothen and Tovar Reaños, 2018). For each consumption purpose, the footprint increases in income. By far the largest absolute emissions are associated with expenditure on transport and energy.

Panel (c) shows the emissions intensities for each category by quartile. We want to highlight two features of the graph in particular: Firstly, each Euro spend on transport and especially energy is associated with a lot more emissions than a Euro spend on any of the other consumption purposes.[17] Secondly, there is no common trend in intensities across all categories: while the intensities for energy, housing and transport are higher for quartiles with high expenditure levels, intensities decrease in equivalised expenditure for the rest of the consumption purposes. Compared to panel (b), the differences between quartiles are often less pronounced in terms of intensities than in terms of absolute emissions.

In panel (a), we present the respective expenditure share for each consumption purpose for the average household in each quartile. Most consumption purposes exhibit a clear trend: While the share of expenditure that is spend on durables, education, health and services increases with the overall amount of expenditure, energy and food tend to be of smaller relative importance the higher the household's expenditure quartile is. Consumption of housing and transport follows ambiguous trends. In the case of transport, the expenditure share of the second quartile is marginally higher than for the first quartile, but lower for the third and fourth one. The share of equivalised expenditure that is spend on housing is relatively stable across all four quartiles. Taken together, panels (a) and (c) of figure 4 reveal that the dominance of energy and transport in terms of overall emissions observed in panel (b) is predominantly driven by their extraordinary intensities, since their expenditure shares are comparatively low across all quartiles. Conversely, the high expenditure shares of food and housing do not result in high absolute emissions associated with these consumption purposes due to their low intensities. In contrast, the unambiguous trend of higher absolute footprints of higher quartiles is driven by the higher absolute expenditure of these households, which more than offsets the decreasing expenditure shares of some purposes (e.g. food).

4.4.2 Imported emissions and expenditure

As mentioned above, we also construct footprints and intensities only using domestic and imported emissions, respectively. Note that, as explained in section 4.3, we do not have data on how expenditure is distributed across domestically produced and imported products. The graphs for domestic and imported emissions therefore do not capture variation in household expenditure on imported or domestically produced varieties.

Panel (b) of figure 3 shows the distribution of footprints based on only imported emissions. While the distribution exhibits the same right skewed pattern also seen in panel (a) for the overall emissions, the pattern is more pronounced for imported emissions. The vast majority of the imported emissions footprints is below 10 tonnes of CO_2.

[17]Note that we exclusively look at household expenditure and emissions attributed to households. This explains the relatively low carbon emissions associated with the consumption purpose "housing": while it includes emission for a sector called "construction", these only cover maintenance and repairs, not the construction of new buildings.

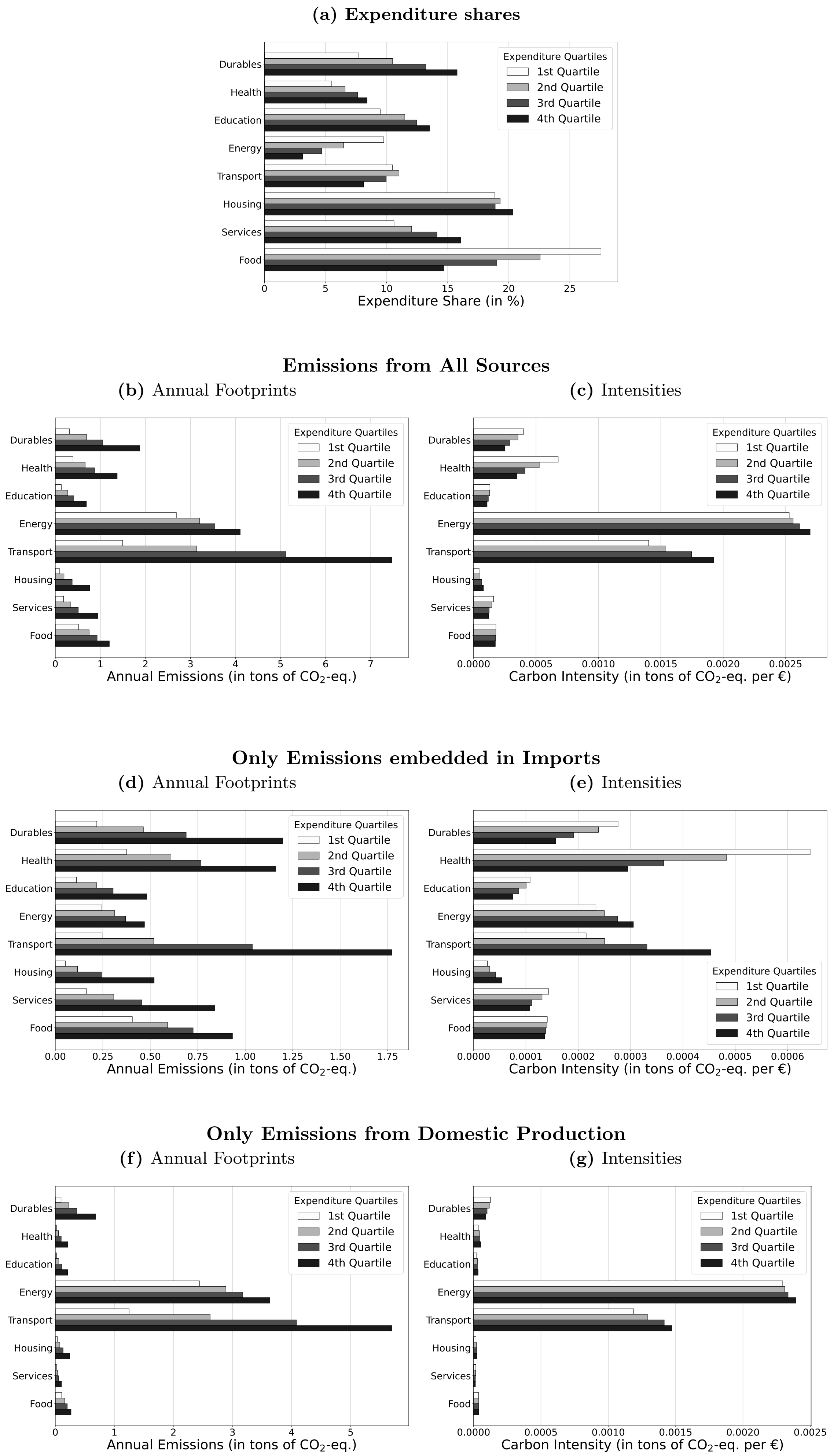


Figure 4: Equivalised expenditure shares, emissions and intensities across expenditure quartiles

Panels (d) through (g) of figure 4 show how the footprints and intensities change, when only carbon emissions embedded in imports (d and e) or domestic emissions (f and g) are considered. Decomposing the emissions in this way reveals that the high intensities and subsequently high footprints of the energy and transport sector are strongly driven by emissions embedded in domestically produced products. When only imported emissions are considered, the distribution among categories is more even, and no category clearly has highest intensities or footprints for all quartiles. As noted in section 4.3, these patterns cannot be interpreted as domestic energy being particularly emissions intensive. Because our expenditure data does not differentiate between imported and domestically produced products, we cannot rule out that the pattern is driven a comparatively large expenditure share of domestic production in the transportation and energy sectors.

Panels (d) and (e) of figure 4 show how the footprints and intensities change when only carbon emissions embedded in imports are considered. Decomposing the emissions in this way reveals that footprints and intensities are more evenly distributed between the categories when only imported emissions are considered. In contrast to panels (b) and (c), which depict all emissions, the intensities (and as a consequence also the footprints) associated with expenditure on energy and transport are not abnormally high.

4.4.3 Domestic emissions and expenditure

Panel (c) of figure 3 shows the distribution of footprints based on only domestic emissions. Compared to the graph for all emissions in panel (a), the distribution of domestic footprints is similar in shape and right-skewness, but shifted to the left. This is a direct result of the domestic emissions being a subset of the overall emissions. Compared to the distribution of footprints based on imported emissions in panel (b), higher footprints are more frequent.

Panels (f) and (g) of figure 4 show annual footprints and intensities, respectively, when only domestic emissions are considered. The pattern of extremely high intensities and subsequently high footprints of the consumption purposes "energy" and "transport" observed in panels (b) and (c) is even more pronounced here.

As noted in section 4.3, these patterns cannot be interpreted as domestic energy being particularly emissions intensive. Because our expenditure data does not differentiate between imported and domestically produced products, we cannot rule out that the pattern is driven a comparatively large expenditure share of domestic production in the transportation and energy sectors.

4.5 Current Value Added taxation

Under current legislation, products in Ireland can be taxed at four different VAT rates (or be exempt). The highest of these is the so-called "standard rate" of 23%. There is also a "reduced rate" of 13.5%, a "second reduced rate" of 9%, and a "livestock rate" of 4.8%, which is irrelevant for most households. Using a database on the website of Irish Revenue, we are able to attribute a tax rate to each of the most fine grained HBS categories.[18] The resulting data set is used to assign a rate to each of the aggregated categories by constructing the weighted average of its components VAT rates.[19] The resulting average VAT rates of the eight consumption purposes are presented in figure 5. For reference, we also include patterned bars showing the values of the four statutory VAT rates.

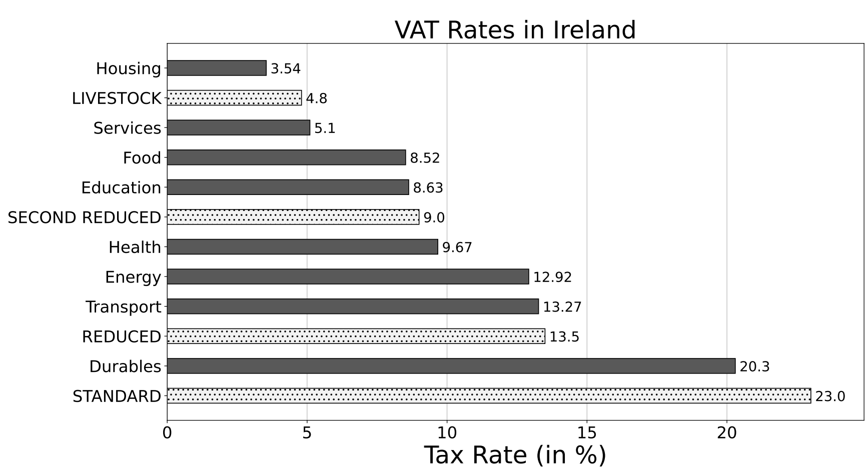


Figure 5: Aggregate VAT rates for consumption eight purposes

The data is in line with previous literature showing that despite the comparatively high standard rate, frequent exemptions and the high prevalence of the two reduced rates cause the effective Irish VAT rate to be much lower (see e.g. Borselli et al., 2012). The aggregate VAT rate for durables is by far the highest among

[18]The website can be reached at https://www.revenue.ie/en/vat/vat-rates/search-vat-rates/VAT-rates-database.aspx. It offers a search engine that produces the applicable VAT rate for products similar to the searched term.

[19]The formula for the calculation of each VAT rate is:

$$VAT_j[\%] = \sum_{k=1}^{K} VAT_k[\%] * \left(\frac{EXP_k[€]}{EXP_j[€]}\right) = \sum_{k=1}^{K} VAT_k[\%] * SHARE_{jk}$$

Here, 'k' is an index for the fine grained HBS category for which we have VAT rates from the database (or a previous aggregation) and 'j' indicates the more aggregated category which 'k' is part of. "EXP" stands for expenditure, and "SHARE" stands for expenditure share (of a commodity subcategory in a commodity category). The information on equivalences between HBS and aggregated categories is taken from table A.11.

the eight consumption categories, while housing and services are the lowest. The other categories form two clusters, around 9% and 13%, respectively. Note that the very low rates for "housing" and "services" are driven by numerous exempt commodities included in these consumption purposes, not by the livestock rate of similar magnitude.

5 Estimation Results

5.1 Estimation of EASI demand system

(a) Engel curve for Energy **(b)** Engel curve for Transport

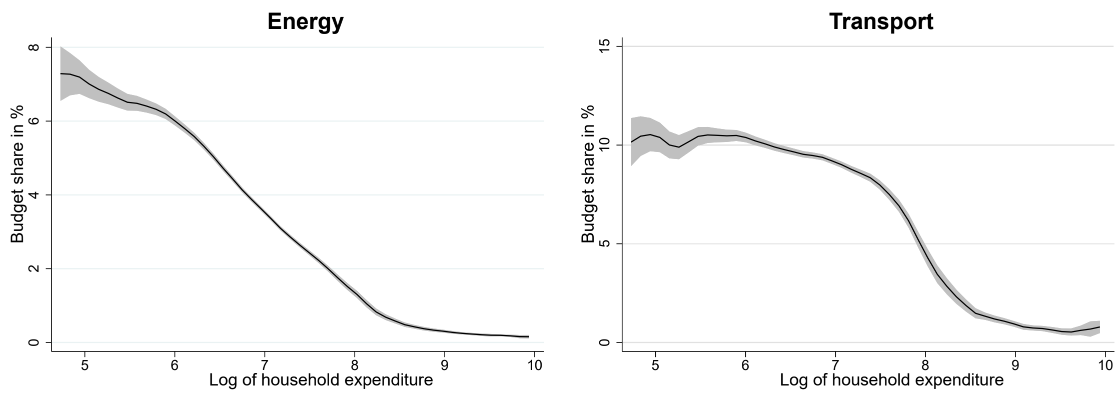


Figure 6: Engel curves based on regressing budget shares (y-axis) on income levels (x-axis, log-scale). Shaded area around each curve represents confidence band.

Figure 6 shows the Engel curves for the two consumption purposes we are most interested in, because they are associated with the highest footprint: 'energy' and 'transportation'. In both cases, the curves are nonlinear, which indicates that the budget effects would not be captured accurately by other demand systems that have been used with Irish data before (e.g. the Almost Ideal or Quadratic Almost Ideal demand system used by Savage (2016)). Like panel (a) of figure 4, the curves also show that households with lower expenditure levels tend to spend a larger share on these emissions-intense goods, which leads us to expect regressive effects of carbon taxation. Engel curves for all eight consumption purposes can be found in figure B.1 in appendix B. The non-linearity of the Engel curves is confirmed by the estimates from the EASI demand system, for which we find statistically significant and positive parameters.[20] This justifies our approach in this paper.

5.2 Labour Supply

In contrast to other studies in the literature, we do not only consider the direct effect of the simulated reforms on household incomes. Instead, we follow the approach of van der Ploeg et al. (2022) and allow for behavioural changes in response to the reform. In particular, we consider changes in labour supply in our model, which are induces by the carbon tax lowering the real consumption wage. These labour supply changes are important, as they reduce both household utility and the tax base of the income tax. We use estimates of household labour supply to simulate these changes in social welfare after the reform (for precedents of this approach, see Cremer et al., 2016; Fadlon and Nielsen, 2019).

Table A.9 includes a summary statistic for labour supply. It shows that the average weekly amount of working ours in our sample of Irish household is 49.08 hours, which amounts to nearly ten hours per day, assuming a five day work week. To estimate the labour supply schedule, we construct a log-linearised version of equation (11):

$$\log l_h = \alpha_0 + \alpha_1 \log \left(\frac{(1-t_h)W_h}{P_h^M} \right) \tag{11*}$$

Here, $\varepsilon^F = \alpha_1$ is the Frischian wage elasticity. The estimated disutility of labour is $\phi = e^{-\alpha_0/\alpha_1}$. We follow the approach outlined by Heckman (1979) to correct for selectivity bias and thus include the coefficient of the inverse Mills ratio evaluated at the mean sample in the parameter α_0.

The results of estimating equation (11*) using the GMM are presented in table A.10. The Frischian wage elasticity is estimated to be 0.305. This is a rather low elasticity, which is in line with previous results in the literature that found labour supply in Europe to be inelastic (Bargain et al., 2014). We also included socioeconomic controls in the estimation. The estimated coefficients show that urban households and households with low levels of education tend to work more hours, while single households tend to work less.

5.3 Income Tax Estimation

We use the data on total 'Income tax & social insurance deductions' provided for each household by the HBS to estimate the effective income tax schedule faced by the households. Following van der Ploeg et al. (2022), we model tax payments to be non lineal in income. We mode tax payments to depend on the first, second

[20] Parameters for socioeconomic variables are available upon request.

and third power of the households income. The resulting estimates are shown in table A.2. All coefficients are statistically significant and the model has an R-squared of 0.85, meaning it approximates the income tax schedule reasonably well. It can therefore be used to simulate the changes in tax liability faced by the households due to the reform.

5.4 Elasticities

Tables A.4 to A.7 show the own- and cross-price elasticities of the eight consumption purposes for the first to fourth expenditure quartile, respectively. Comparing the corresponding cells of the tables shows that households in the lower expenditure quartiles have lower own price elasticities for energy compared to households in the highest expenditure quartile.[21] A likely reason for this are the limited substitution possibilities of energy. Similarly, the demand for transport, education, health, durables, and food is getting more elastic from quartile to quartile. Only housing exhibits larger elasticities for smaller quartiles. Services remain at roughly the same elasticity for all quartiles, with no clear trend. Comparing our estimates of these own price elasticities (OPE) with the literature is of hard, because existing estimates were constructed with different levels of aggregation, demand systems, or both. Despite methodological differences however, our results for the consumption purposes "energy" and "transport" are broadly in line with the literature: Using German data, Pothen and Tovar Reaños (2018) find similar values for the corresponding categories in their analysis. Savage (2016) provides an estimate specifically for Ireland, and although he includes both transport and energy in the same category, his OPE does not much differ from those we arrive at in our analysis. Likewise, the weighted average of the range of results obtained by Salotti et al. (2015) for six European countries comes close to our result here, at least in terms of energy. The existing estimates for the category "transport" cover a wider range. On the lower end of the spectrum, Salotti et al. (2015) report a weighted average between six countries of 0.47. In contrast, Clements et al. (2006) study 45 countries and come up with an average OPE of 1.58 for the "transport" category. Our estimates for transport lie between these two boundaries but are concentrated at the lower end of the spectrum. The differences between the previous estimates could be a consequence of the different demand systems used. The advantage of the EASI demand system used here is its ability to capture non-linear Engel curves well. Our own price elasticities for the consumption purpose 'food' are much higher than the values between -0.1 and -0.4 estimated by Savage (2016). A possible reason for this difference is that we summarize alcohol, tobacco, and other foodstuffs under the term "food" (like is done in the COICOP classification) while Savage (2016) estimates own price elasticities for each of those three categories separately.

In the off-diagonal, we also present the cross-price elasticities for each consumption purpose in tables A.4 to A.7. The cross-price elasticities of the two consumption purposes that have the strongest environmental impact (namely transportation and energy) are of particular interest. Whenever they are statistically significant, the cross-price elasticities between the two types of transport and energy are negative, suggesting a complementary relationship between goods encompassed by these categories. The elasticities get smaller each quartile, possibly indicating that the complimentary weakens as households spend more. Note that the relation does not seem to run both ways: While we find a statistically significant negative impact of price increases in 'energy' on the consumption of 'transport' for quartiles one to three, the inverse cross-price-elasticity is statistically insignificant for all quartiles.

5.5 Simulation Results

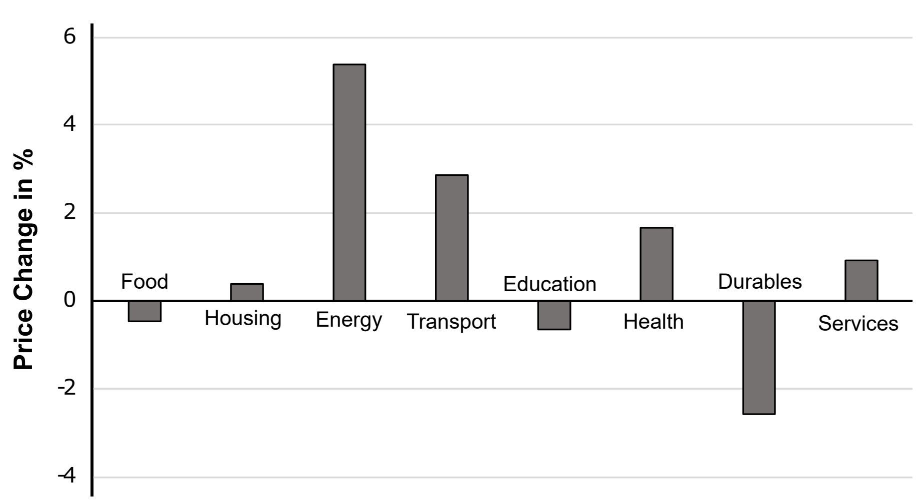


Figure 7: Percent changes in prices after the 'green VAT' reform

Figure 7 shows the percentage changes in aggregate prices of each consumption purpose after the introduction of the 'green VAT', based on the calculation described in section 2.1. The most prominent changes are strong increases of about five percent for energy, three percent or transport and just under two percent for health-related expenditures. These increases are in line with the intensities presented in panel (c) of figure 4 , which were highest for these three consumption purposes. Another notable change is a pronounced drop in the price of durables by about three percent. This is a result of this consumption purposes relatively

[21] To avoid confusion, we use the terms "lower" and "higher" to refer to absolute values when talking about elasticities. Thus an elasticity of -1 is described as being *higher* than a value of -0.5.

low carbon intensity in combination with the comparatively very high initial average VAT rate (see figure 5).

The increases in the prices of housing and services, as well as the decreases in the prices of education and food are negligible in comparison to the other four categories.

Based on these price patterns, we expect consumers to substitute consumption away from "Energy", "Transport", and "Health" towards the other consumption purposes, especially durables.

5.5.1 Emissions, work hours and inequality

	Emission	Hours	Consumption	Income tax revenue	Indirect tax revenue	GINI expenditure	GINI Income
Green VAT (GVAT)	-6.16	-0.88	-1.06	-1.53	14.80	0.48	-0.37
GVAT +Transfers(+5%)	-5.14	-0.88	-0.15	-1.52	4.41	1.96	-0.38
GVAT+ Income tax (-4%)	-5.22	-0.72	0.21	-5.22	-2.12	-0.20	-0.31

Table 2: Changes in percent under different reform scenarios

In table 2 we present the simulation results for the three scenarios in terms of percent changes in different variables. In the upper row, the results of the GVAT scenario without any revenue recycling are shown. We find that compared to the baseline of no price changes, the amount of emissions decreases, and consumption, hours worked, and the income tax revenue decrease as well. This is because in our model household income is affected by two channels. On the one hand, the higher consumption tax induces a fall in real wages, which disincentives the supply of work, reducing work hours. On the other hand, lower real wages reduces the amount of labour households are willing to supply. As a result of these two effects, household expenditure and household income fall. As for changes in the GINI index, while a progressive income tax reduces income inequality, low income households experience higher commodity prices creating more expenditure inequality.

The second row displays the results of the scenario 'GVAT+Transfers', in which existing transfers are increased by five percent. Compared to the GVAT scenario in the first row, the reduction in emissions is smaller. The effects on revenue from indirect taxation and consumption keep their directions but are of substantially lower magnitude. The reduction in hours worked, income tax revenue and income inequality remain largely unaffected by this method of revenue recycling. A possible interpretation of these effects is that the increased transfers boost disposable incomes of some households. This depresses income inequality but acerbates expenditure inequality. This is because transfers as modelled here (see section 2) does not reach middle income levels.

In the third row, the results of the simulation scenario in which we reduce the income tax by four percent, are shown. This method of revenue recycling leads to a reduction in emissions that is slightly higher than that in the 'GVAT+Transfers' scenario, but still smaller than the one without any revenue recycling. Both hours worked and income inequality are reduced by smaller amounts than in the previous two scenarios. Some effects even switch their signs compared to the other scenarios: consumption now increases, while indirect revenue and inequality in expenditure decrease. The results of increased consumption indicate that the income boost from the reduced income tax lifts consumption more than increased indirect taxes depress it. The simultaneous reduction in both indirect taxes and emissions suggest that consumers shift their expenditure towards less carbon intense products with lower associated tax rates. Regarding the effect on the GINI coefficients, the reduction in income taxes and its progressive nature reduce income inequality. Income cuts increases also expenditure that is allocated more equally across households.

5.5.2 Welfare effects on different household types

Using the EASI demand system, we can also look at how household's welfare is impacted, while differentiating between several household types. The panels on the left hand side of figure 8 show the impact of each of our three simulated reforms on welfare for every income decile, with one being the lowest and ten the highest expenditure levels. The welfare loss is expressed in terms of the Hicks' Equivalent Variation (HEV) as a share of total expenditure. Without any revenue recycling, all deciles experience welfare losses due to the reform. Households with higher expenditures tend to be less affected than households in lower expenditure levels. Recycling the revenue through increased transfers mitigates this effect by reducing the reform's adverse impact most for the poorest households (see panel (c)). In contrast, using reduced income taxes as a revenue recycling mechanism seems making the pattern observed in the first panel even more pronounced (see panel (e)). However, note that the level of the incidence reduces in general across households.

The panels on the right hand side of figure 8 show the welfare impact across different household types. In the absence of revenue recycling (panel (b)), couples tend to experience slightly smaller losses than single adults. In the scenario with increased transfers (panel (d)), the welfare loss gets reduced much more for elder single adults and childless couples than for the other household types. If an income tax is used to recycle additional revenue (see panel(f)), all households experience smaller welfare losses than without any recycling, but relative to other household types, single adults over 65 suffer higher welfare losses.

6 Discussion

Previous discussions of a green VAT in the academic literature have largely been limited to explaining the concept itself (see Timmermans and Achten, 2018; De Camillis and Goralczyk, 2013). In this study, we are the first to use the EASI demand system to simulate the economic and environmental effect of a green VAT reform. We find that while the policy reduces emissions, it can also have adverse distributional impacts and reduces the labour supply. In order to keep the same level of revenue as the current VAT system while imposing a minimum base VAT tax rate, as proposed in the literature, a large carbon tax has to be imposed. If additional revenue from the carbon tax is used to increase social transfers, the welfare impact on households in the lowest deciles can be mitigated, but the reduction in working hours remains unchanged. Recycling revenue by lowering income taxes instead reduces the adverse impact on labour supply, but benefits households in the low expenditure deciles relatively little. A mix of revenue recycling mechanism could potentially address both concerns.

There are many aspects of environmental VAT reform that can be further explored by future research. According to Courchene and Allan (2008) the VAT is less vulnerable to the problem of carbon leakage than other taxes. 'Carbon leakage' occurs when measures aimed to reduce emissions are circumvented by firms by moving the polluting part of the production process elsewhere (Cosbey et al. (2019); see Dechezleprêtre et al. (2022) and Fell and Maniloff (2018) for discussions of the magnitude of the problem). To stop leakage from happening, a country can try to accompany its carbon tax with a border carbon adjustment, in which a tariff or import tax is levied on imports in order to also put a price on the emissions embedded in them, thereby negating the benefits of shifting pollution abroad. Such a tariff potentially is at odds with the restrictions on barriers to international trade imposed by the World Trade Organization (WTO). Both Courchene and Allan (2008) and De Camillis and Goralczyk (2013) are optimistic that using the VAT as an environmental tax will circumvent this problem, since in the current system, imported goods are also subject to the value-added tax once they are sold in a country.

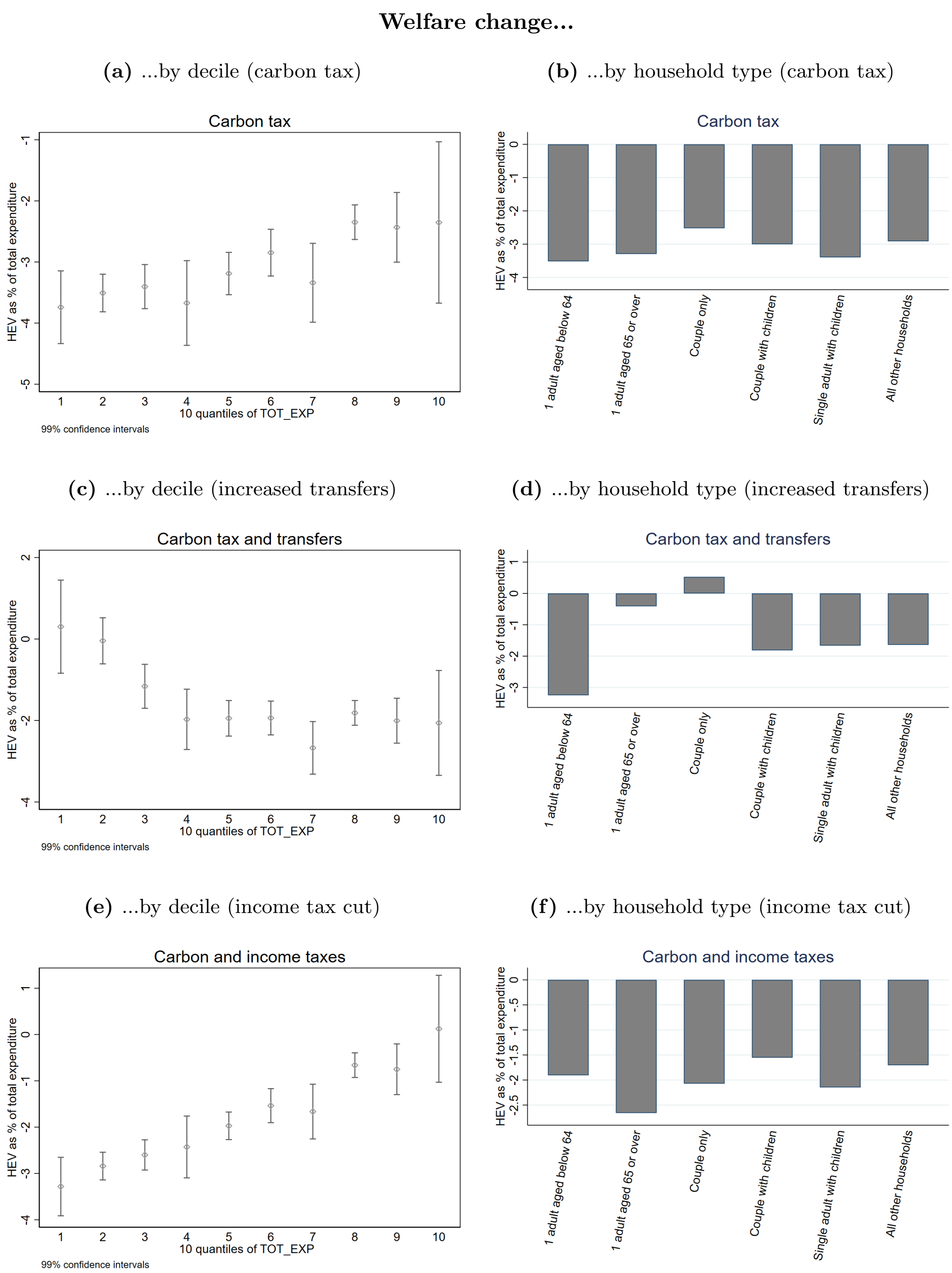


Figure 8: Welfare changes for different socioeconomic groups under different scenarios

A final possible advantage of the VAT is that the tax is potentially self enforcing, because each intermediate producer can only claim back VAT on their inputs if they are part of the VAT system. Pomeranz (2015) verifies the existence of this mechanism empirically, but stresses that it only takes effect when the tax is enforced by the standard way of audits (or at least the credible threat of audits), too. This is echoed by Waseem (2022), who concludes from his empirical analysis of the VAT regime in Pakistan that "the results suggest a complementarity between self-enforcement mechanisms built into a VAT and physical enforcement" (Waseem, 2022, p.25).

One crucial limitation of our study is that, due to data restrictions, we can only analyse tax and price changes, and thus also substitution responses, at a very aggregated level. Academic proposals for environmental VAT reforms, like Timmermans and Achten (2018) or De Camillis and Goralczyk (2013) envision using Life-Cycle-Analysis to obtain an environmental impact assessment for (ideally) every product. Some authors, like Albrecht (2006), recognize that such a level of detail is infeasible in the face of the sheer multitude of products subject to value-added taxation. But even the simplified heuristic proposed by Albrecht (2006) still differentiates between varieties of the same product (e.g. energy-efficient vs. non-efficient white goods, renovated vs. non- renovated houses, renewable vs. fossil energy, etc.). Non-academic policy proposals discuss similar patterns of tax differentiation (see e.g. Committee on Economic and Monetary Affairs, 2011; Umweltbundesamt, 2022). However, we are unable to simulate such patterns of differentiation, because we do not have data on emissions intensities on such a fine-grained level. Even the expenditure data from the HBS, which are much more detailed that the emissions data available to us, do not provide the level of detail that would be necessary for such an analysis. For example, white goods are only listed as 'dishwasher' or 'fridges and freezers' in general, without any differentiation by their level of energy efficiency (see Central Statistics Office, 2017).

7 Conclusion

In this paper, we take expenditure data from the Irish Household Budget Survey and combine them with data on consumption-based emissions. We aggregate the data into eight consumption purposes: food, housing, energy, transportation, education, health, durables and services. For each of these, we end up with a household specific carbon intensity (emissions per Euro spend on the consumption purpose). Summary statistics and graphical representations of the data show that the consumption purposes 'transport' and 'energy' are particularly emissions intensive. Regarding the distribution of footprints across household, we find that there is a long upper tail: While the average annual footprint was 11.51 tons of CO_2, roughly 1.5% of Irish households have a footprint of more than 40 tons.

Using the combined emissions and expenditure data, we construct new 'green' VAT rates for eight consumption purposes. The GVAT consists of a uniform base rate of four percent and a strong carbon tax of 120 Euro per ton of CO_2. Since the new tax rates vary according to a consumption purposes emissions intensity, the prices of 'energy' and 'transport' rise substantially, while there is a moderate drop in the price of 'durables', because of its high VAT rate in the existing VAT system. We subsequently use the EASI demand system to simulate the effects of the introduction of such the new system in Ireland. We consider three scenarios: one with just the GVAT, but no revenue recycling mechanism for any additional revenue, one with the GVAT and five percent higher state transfers and one with the GVAT and an income tax cut of four percent. We find that while the tax itself increases inequality and tends to burden lower expenditure households most, the combined carbon tax and transfer increase are shield some of the households with the lowest expenditure levels from the burden. The income tax cut mostly benefits households with middling to high expenditures and limits the reduction in working hours present in the other two scenarios. Both revenue recycle mechanisms weaken the estimated reduction in emissions slightly.

Our study reveals which broad product groups are likely to be most impacted by a comprehensive environmental reform of the value-added tax system in Ireland. However, due to data limitations we are not able to disaggregate our calculated footprints so much that we can simulate the much more limited kinds of environmental VAT rate differentiation that are currently discussed within the EU. Further research is needed to assess the impact of these specific reforms.

References

Albrecht, J. (2006). The use of consumption taxes to re-launch green tax reforms. *International Review of Law and Economics*, 26(1):88–103. Twenty-First Annual Conference of the European Association of Law and Economics.

Asatryan, Z. and Gomtsyan, D. (2020). The Incidence of VAT Evasion. *CESifo Working Paper*.

Bahn-Walkowiak, B. and Wilts, H. (2015). Reforming the EU VAT system to support the transition to a low-carbon and resource efficient economy. In Kreiser, L., editor, *Carbon pricing : design, experiences and issues*, pages 111 – 126. Elgar, Cheltenham.

Bahn-Walkowiak, B., Wilts, H., Meyer, M., and Distelkamp, M. (2017). Conceptualising a tax policy mix for resource efficiency: selected results from a three-transition pathways approach. In *The Green Market Transition*. Edward Elgar Publishing, Cheltenham, UK.

Bargain, O., Orsini, K., and Peichl, A. (2014). Comparing labor supply elasticities in europe and the united states: New results. *The Journal of Human Resources*, 49(3):723–838.

Böhringer, C., Landis, F., and Tovar Reaños, M. A. (2017). Economic Impacts of Renewable Energy Production in Germany. *The Energy Journal*, 38(KAPSARC Special Issue).

Borselli, F., Chiri, S., and Romagnano, E. (2012). Patterns of reduced VAT rates in the European Union. *International VAT monitor*, pages 13–21.

Central Statistics Office (2017). Household Budget Survey (HBS), 2015-2016. [dataset]. URL: www.ucd.ie/issda/hbs. 1st Edition. Irish Social Science Data Archive. SN: 0022-06.

Chen, Z.-M., Ohshita, S., Lenzen, M., Wiedmann, T., Jiborn, M., Chen, B., Lester, L., Guan, D., Meng, J., Xu, S., et al. (2018). Consumption-based greenhouse gas emissions accounting with capital stock change highlights dynamics of fast-developing countries. *Nature communications*, 9(1):1–9.

Clements, K. W., Wu, Y., and Zhang, J. (2006). Comparing international consumption patterns. *Empirical Economics*, 31(1):1–30.

Committee on Economic and Monetary Affairs (2011). Report on the future of VAT. URL: https://www.europarl.europa.eu/doceo/document/A-7-2011-0318_EN.pdf. Accessed: 2022-02-16.

Cosbey, A., Droege, S., Fischer, C., and Munnings, C. (2019). Developing guidance for implementing border carbon adjustments: Lessons, cautions, and research needs from the literature. *Review of Environmental Economics and Policy*, 13(1):3–22.

Council of the European Union (2022). Council Directive (EU) 2022/542 of 5 April 2022 amending Directives 2006/112/EC and (EU) 2020/285 as regards rates of value added tax. *Official Journal of the European Union*, L 107:1–12.

Courchene, T. J. and Allan, J. R. (2008). Climate change : the case for a carbon tariff/tax. *Policy Options*, 29.

Crawford, I., Keen, M., and Smith, S. (2010). Value added tax and excises. In for Fiscal Studies, I., editor, *Dimensions of tax design: the Mirrlees review*, pages 275–362. Oxford University Press, Oxford.

Creedy, J. and Sleeman, C. (2006). Carbon taxation, prices and welfare in New Zealand. *Ecological Economics*, 57(3):333–345.

Cremer, H., Lozachmeur, J.-M., Maldonado, D., and Roeder, K. (2016). Household bargaining and the design of couples' income taxation. *European Economic Review*, 89(C):454–470.

Davis, S. J. and Caldeira, K. (2010). Consumption-based accounting of CO_2 emissions. *Proceedings of the National Academy of Sciences*, 107(12):5687–5692.

de Bruin, K. and Yakut, A. M. (2021a). Construction of the Energy Social Accounting Matrix for Ireland, v2.0. *ESRI Survey and Statistical Report Series 108*.

de Bruin, K. and Yakut, A. M. (2021b). Technical Documentation of the I3E Model, V4. 0. *ESRI Survey and Statistical Report Series Number 109*.

De Camillis, C. and Goralczyk, M. (2013). Towards stronger measures for sustainable consumption and production policies: proposal of a new fiscal framework based on a life cycle approach. *The International Journal of Life Cycle Assessment*, 18(1):263–272.

Dechezleprêtre, A., Gennaioli, C., Martin, R., Muûls, M., and Stoerk, T. (2022). Searching for carbon leaks in multinational companies. *Journal of Environmental Economics and Management*, 112:102601.

Drupp, M. A., Nesje, F., and Schmidt, R. C. (2022). Pricing Carbon. *CESifo Working Paper*.

Eisenbarth, S. (2017). Is Chinese trade policy motivated by environmental concerns? *Journal of Environmental Economics and Management*, 82:74–103.

European Commission (2012). *Policies to encourage sustainable consumption : full report*. Publications Office.

European Commission (2021). Press release: New rules on VAT rates offer Member States more flexibility while supporting the EU's green, digital and public health priorities. URL: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_6608. Accessed: 2022-07-28.

Fadlon, I. and Nielsen, T. H. (2019). Household labor supply and the gains from social insurance. *Journal of Public Economics*, 171:18–28. Trans-Atlantic Public Economics Seminar 2016.

Fell, H. and Maniloff, P. (2018). Leakage in regional environmental policy: The case of the regional greenhouse gas initiative. *Journal of Environmental Economics and Management*, 87:1–23.

Fremstad, A. and Paul, M. (2019). The Impact of a Carbon Tax on Inequality. *Ecological Economics*, 163:88–97.

Fullerton, D., Leicester, A., and Smith, S. (2010). Environmental Taxes. In for Fiscal Studies, I., editor, *Dimensions of tax design: the Mirrlees review*, pages 275–362. Oxford University Press, Oxford.

Goulder, L. H. (1995). Environmental taxation and the double dividend: A reader's guide. *International Tax and Public Finance*, 2:157–183.

Heckman, J. J. (1979). Sample selection bias as a specification error. *Econometrica*, 47(1):153–161.

Hubacek, K., Chen, X., Feng, K., Wiedmann, T., and Shan, Y. (2021). Evidence of decoupling consumption-based CO2 emissions from economic growth. *Advances in Applied Energy*, 4:100074.

Karydas, C. and Zhang, L. (2019). Green tax reform, endogenous innovation and the growth dividend. *Journal of Environmental Economics and Management*, 97:158–181. SURED 2016: Dynamic and strategic aspects of environmental economics.

Klenert, D., Schwerhoff, G., Edenhofer, O., and Mattauch, L. (2018). Environmental Taxation, Inequality and Engel's Law: The Double Dividend of Redistribution. *Environmental and Resource Economics*, 71(3):605–624.

Leahy, E., Lyons, S., and Tol, R. S. J. (2011). The Distributional Effects of Value Added Tax in Ireland. *The Economic and Social Review*, 42(2):213–235.

Lewbel, A. (1989). Identification and Estimation of Equivalence Scales under Weak Separability. *The Review of Economic Studies*, 56(2):311–316.

Lewbel, A. and Pendakur, K. (2009). Tricks with Hicks: The EASI Demand System. *American Economic Review*, 99(3):827–63.

Muszyńska, J., Szczepaniak, M., and Wedrowska, E. (2021). Income inequalities in ireland and poland: The role of taxes and social transfers. *The Economic and Social Review*, 52(4, Winter):375–396.

Oosterhuis, F., Rayment, M., Varma, A., Jantzen, J., van der Woerd, H., Mudgal, S., Tinetti, B., Gerdes, H., Neubauer, A., Stocker, A., Dodoková, A., and Greño, P. (2008). *The use of differential VAT rates to promote changes in consumption and innovation.* Number R-08/10 in IVM Report. Instituut voor Milieuvraagstukken, Vrije Universiteit.

Pendakur, K. (2009). EASI made Easier. In Slottje, D. J., editor, *Quantifying Consumer Preferences*, pages 179–206. Emerald Group Publishing Limited.

Pigou, A. C. (1920). *The Economics of Welfare*. London: Macmillan.

Pomeranz, D. (2015). No Taxation without Information: Deterrence and Self-Enforcement in the Value Added Tax. *American Economic Review*, 105(8):2539–69.

Pothen, F. and Tovar Reaños, M. A. (2018). The Distribution of Material Footprints in Germany. *Ecological Economics*, 153:237–251.

Salotti, S., Montinari, L., Amores, A. F., and Rueda-Cantuche, J. M. (2015). Total expenditure elasticity of non-durable consumption of European households. In *JRC Technical Report EUR 27081 EN*, page 2015. European Union.

Savage, M. (2016). Indirect tax reform and the specification of demand: the case of Ireland. *International Tax and Public Finance*, 23(2):368–399.

Stiglitz, J. E. (2013). Sharing the Burden of Saving the Planet: Global Social Justice for Sustainable Development. Lessons from the Theory of Public Finance. In Stiglitz, J. E. and Kaldor, M., editors, *The Quest for Security: Protection Without Protectionism and the Challenge of Global Governance*, pages 161–204. Columbia University Press.

Tiezzi, S. and Verde, S. F. (2016). Differential demand response to gasoline taxes and gasoline prices in the u.s. *Resource and Energy Economics*, 44:71–91.

Timmermans, B. and Achten, W. M. (2018). From value-added tax to a damage and value-added tax partially based on life cycle assessment: principles and feasibility. *The International Journal of Life Cycle Assessment*, 23(11):2217–2247.

Tovar Reaños, M. A. and Lynch, M. A. (2022). Are fuel poverty metrics fit for purpose? An assessment using behavioural microsimulation. *Sustainable Cities and Society*, 81:103817.

Tovar Reaños, M. A. and Lynch, M. A. (2022). The benefits of action on implementing carbon taxation in Ireland: a demand system approach. *Journal of Environmental Planning and Management*, pages 1–25.

Tovar Reaños, M. A. and Wölfing, N. M. (2018). Household energy prices and inequality: Evidence from German microdata based on the EASI demand system. *Energy Economics*, 70:84–97.

Umweltbundesamt (2022). Vorschläge des Umweltbundesamtes für eine umweltorientierte Reform der Mehrwertsteuer [Proposal for a environmental reform of the Value-Added Tax of the German Environmental Agency]. URL: https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2022-05_factsheet_umweltorientierte-reform-mehrwertsteuer.pdf. Accessed: 2022-08-08.

van der Ploeg, F., Rezai, A., and Tovar Reaños, M. (2022). Gathering support for green tax reform: Evidence from German household surveys. *European Economic Review*, 141:103966.

Varian, H. R. (1992). *Microeconomic analysis*. W.W. Norton.

Waseem, M. (2022). The Role of Withholding in the Self-Enforcement of a Value-Added Tax: Evidence from Pakistan. *The Review of Economics and Statistics*, 104(2):336–354.

Wood, R., Moran, D. D., Rodrigues, J. F., and Stadler, K. (2019). Variation in trends of consumption based carbon accounts. *Scientific data*, 6(1):1–9.

Appendix A - Additional Graphs

Table A.1: Summary statistics. Demand system

Variable	Mean	Std. Dev.	Min.	Max.
Commodity budget shares				
Budget share food	0.222	0.097	0.01	0.44
Budget share housing	0.146	0.109	0.001	0.393
Budget share energy	0.041	0.026	0.001	0.119
Budget share transport	0.09	0.051	0.002	0.22
Budget share education	0.155	0.144	0.004	0.71
Budget share health	0.061	0.047	0.001	0.197
Budget share durables	0.1	0.078	0.001	0.313
Budget share services	0.184	0.131	0.007	0.704
Commodity price indices				
Price index food	71.873	15.645	11.205	117.726
Price index housing	30.475	11.866	0.231	85.687
Price index energy	47.04	16.014	9.245	119.065
Price index transport	42.656	16.705	6.236	121.482
Price index education	49.722	35.55	0.162	179.524
Price index health	36.896	16.568	0.183	108.693
Price index durables	53.098	25.5	12.627	214.257
Price index services	21.827	14.427	0.23	84.176
Socioeconomic characteristics				
Total expenditure	1132.184	1189.917	113.153	20711.527
Income	966.889	924.571	0	16621.551
Rural household	0.338	0.473	0	1
Dwelling age group 1	0.24	0.427	0	1
Dwelling age group 2	0.253	0.435	0	1
Dwelling age group 3	0.316	0.465	0	1
Surveyed in quarter 1	0.239	0.427	0	1
Surveyed in quarter 2	0.252	0.434	0	1
Surveyed in quarter 3	0.255	0.436	0	1
Central heating (gas)	0.336	0.472	0	1
Central heating (other fuel)	0.538	0.499	0	1
Washing machine in household	0.985	0.12	0	1
Dishwasher in household	0.646	0.478	0	1
Car in household	0.917	0.277	0	1
N		12738		

Table A.2: Polynomial for income taxation. Dependent variable: Tax paid

Variable	Coefficient
Income	0.139***
	0.003
Income^2	4×10^{-5}***
	(0.000)
Income^3	-0.1.92$\times10^{-9}$***
	(0.00)
Constant	-10.836***
	(2.111)
Observations	12,738
R-squared	0.815

Table A.3: Results of the EASI demand system estimation. Iterated 3SLS, 3 digits

Regressor:	Dependent variable: budget share for ...						
	Food	Housing	Energy	Transport	Education	Health	Durables
Polynomial coefficient:							
y1	0.189*	0.041	0.041	-0.089	-0.723***	-0.045	-0.067
	(0.099)	(0.120)	(0.025)	(0.056)	(0.140)	(0.059)	(0.096)
y2	-0.089**	0.019	-0.041***	0.026	0.293***	0.037	0.041
	(0.043)	(0.052)	(0.011)	(0.024)	(0.060)	(0.026)	(0.041)
y3	0.012	-0.011	0.009***	-0.005	-0.042***	-0.009**	-0.008
	(0.008)	(0.010)	(0.002)	(0.004)	(0.011)	(0.005)	(0.008)
y4	-0.000	0.001*	-0.001***	0.000	0.002**	0.001**	0.001
	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
Household types:							
z1	-0.087***	-0.015	-0.017***	-0.011	0.022	0.025***	0.038***
	(0.014)	(0.017)	(0.003)	(0.008)	(0.020)	(0.008)	(0.013)
z2	-0.069***	-0.026	-0.020***	0.003	0.058**	0.077***	0.022
	(0.018)	(0.022)	(0.004)	(0.010)	(0.025)	(0.011)	(0.017)
z3	-0.033*	-0.008	-0.007	-0.008	0.033	0.015	0.053***
	(0.018)	(0.022)	(0.004)	(0.010)	(0.026)	(0.011)	(0.018)
z4	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)	(.)	(.)	(.)
z5	-0.011	-0.074***	-0.005**	-0.002	0.066***	0.017***	0.011
	(0.010)	(0.012)	(0.002)	(0.005)	(0.014)	(0.006)	(0.010)
z6	0.004	-0.055***	-0.003	0.005	0.018	-0.003	0.023***
	(0.008)	(0.010)	(0.002)	(0.005)	(0.012)	(0.005)	(0.008)
Interaction term:							
yz1	0.012***	0.008	0.003***	0.002	-0.002	-0.012***	-0.012***
	(0.005)	(0.006)	(0.001)	(0.003)	(0.007)	(0.003)	(0.004)
yz2	0.005	-0.008	0.005***	-0.005	-0.007	-0.022***	-0.002
	(0.007)	(0.008)	(0.002)	(0.004)	(0.009)	(0.004)	(0.006)
yz3	0.005	0.001	0.003*	0.002	-0.002	-0.004	-0.012**
	(0.006)	(0.008)	(0.002)	(0.003)	(0.009)	(0.004)	(0.006)
yz4	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)	(.)	(.)	(.)
yz5	0.001	0.015***	0.001	0.001	-0.017***	-0.007***	-0.003
	(0.003)	(0.004)	(0.001)	(0.002)	(0.004)	(0.002)	(0.003)
yz6	0.006**	0.007**	0.001	0.003**	-0.004	-0.002	-0.005**
	(0.002)	(0.003)	(0.001)	(0.001)	(0.003)	(0.001)	(0.002)
Interaction between price and expenditure ($b_{i,j}$):							
ynp1	-0.035***	-0.008**	0.002*	-0.002	0.044***	-0.007***	0.002
	(0.004)	(0.003)	(0.001)	(0.002)	(0.003)	(0.002)	(0.003)
ynp2	-0.008**	0.002	-0.000	0.007***	0.004	0.001	-0.001
	(0.003)	(0.005)	(0.001)	(0.002)	(0.004)	(0.002)	(0.003)
ynp3	0.002*	-0.000	-0.008***	0.001	0.003***	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
ynp4	-0.002	0.007***	0.001	-0.016***	0.008***	0.002	-0.000
	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
ynp5	0.044***	0.004	0.003***	0.008***	-0.062***	0.013***	0.023***
	(0.003)	(0.004)	(0.001)	(0.002)	(0.005)	(0.002)	(0.003)
ynp6	-0.007***	0.001	0.001	0.002	0.013***	-0.011***	-0.002
	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.003)	(0.002)
ynp7	0.002	-0.001	0.000	-0.000	0.023***	-0.002	-0.026***
	(0.003)	(0.003)	(0.001)	(0.002)	(0.003)	(0.002)	(0.003)
Price parameter ($a_{i,j,l}$):							
np1	0.141***	-0.001	-0.009**	-0.006	-0.097***	0.010	-0.016*
	(0.014)	(0.011)	(0.004)	(0.007)	(0.010)	(0.008)	(0.009)
np2	-0.001	0.025	-0.001	-0.026***	-0.010	-0.006	-0.008
	(0.011)	(0.017)	(0.004)	(0.008)	(0.012)	(0.008)	(0.009)
np3	-0.009**	-0.001	0.040***	-0.007*	-0.011***	-0.005	-0.004
	(0.004)	(0.004)	(0.005)	(0.004)	(0.003)	(0.004)	(0.003)
np4	-0.006	-0.026***	-0.007*	0.077***	-0.018***	-0.014**	-0.004
	(0.007)	(0.008)	(0.004)	(0.008)	(0.007)	(0.006)	(0.006)
np5	-0.097***	-0.010	-0.011***	-0.018***	0.100***	-0.033***	-0.041***
	(0.010)	(0.012)	(0.003)	(0.007)	(0.017)	(0.007)	(0.009)
np6	0.010	-0.006	-0.005	-0.014**	-0.033***	0.056***	0.003
	(0.008)	(0.008)	(0.004)	(0.006)	(0.007)	(0.010)	(0.007)
np7	-0.016*	-0.008	-0.004	-0.004	-0.041***	0.003	0.082***
	(0.009)	(0.009)	(0.003)	(0.006)	(0.009)	(0.007)	(0.010)
	(0.009)	(0.009)	(0.004)	(0.007)	(0.008)	(0.011)	(0.008)
Household characteristics:							

Continued on next page

TableA.3 (continued from previous page)

Regressor:	**Dependent variable: budget share for ...**						
	Food	Housing	Energy	Transport	Education	Health	Durables
Rural household	0.004**	-0.023***	0.002***	0.009***	-0.006**	-0.001	0.002
	(0.002)	(0.002)	(0.000)	(0.001)	(0.002)	(0.001)	(0.002)
Dwelling age group 1	0.023***	-0.063***	0.003***	-0.005***	0.023***	0.003**	-0.006***
	(0.002)	(0.003)	(0.001)	(0.001)	(0.003)	(0.001)	(0.002)
Dwelling age group 2	0.023***	-0.075***	0.003***	-0.005***	0.027***	0.001	-0.001
	(0.002)	(0.003)	(0.001)	(0.001)	(0.003)	(0.001)	(0.002)
Dwelling age group 3	0.020***	-0.053***	0.001**	-0.003**	0.018***	-0.001	-0.001
	(0.002)	(0.002)	(0.000)	(0.001)	(0.003)	(0.001)	(0.002)
Surveyed in quarter 1	-0.002	0.005**	0.005***	0.002*	0.008***	-0.001	-0.017***
	(0.002)	(0.002)	(0.000)	(0.001)	(0.003)	(0.001)	(0.002)
Surveyed in quarter 2	-0.000	0.007***	0.003***	0.000	0.004	0.000	-0.012***
	(0.002)	(0.002)	(0.000)	(0.001)	(0.003)	(0.001)	(0.002)
Surveyed in quarter 3	0.003	0.000	-0.002***	0.001	0.010***	0.000	-0.012***
	(0.002)	(0.002)	(0.000)	(0.001)	(0.003)	(0.001)	(0.002)
Central heating (gas)	-0.007***	0.010***	-0.002***	-0.004***	0.003	0.005***	-0.001
	(0.002)	(0.003)	(0.001)	(0.001)	(0.003)	(0.001)	(0.002)
Central heating (other fuel)	-0.001	-0.011***	-0.000	0.002**	0.004	0.004***	0.002
	(0.002)	(0.003)	(0.001)	(0.001)	(0.003)	(0.001)	(0.002)
Washing machine in household	0.004	-0.021***	0.005***	-0.002	-0.015*	0.004	0.003
	(0.006)	(0.007)	(0.001)	(0.003)	(0.008)	(0.003)	(0.006)
Dishwasher in household	-0.005***	-0.003*	0.003***	-0.000	-0.004**	0.006***	0.000
	(0.002)	(0.002)	(0.000)	(0.001)	(0.002)	(0.001)	(0.002)
Car in household	-0.016***	-0.031***	0.002***	0.011***	-0.004	0.006***	0.015***
	(0.003)	(0.003)	(0.001)	(0.002)	(0.004)	(0.002)	(0.003)
Constant	0.147*	0.229**	0.082***	0.228***	0.659***	0.040	0.095
	(0.084)	(0.102)	(0.022)	(0.048)	(0.119)	(0.051)	(0.082)
N	12738						
R-squared	0.411	0.298	0.544	0.341	0.450	0.146	0.119
adjusted R2	413						

*p<0.10, ** p<0.05, *** p<0.01

Table A.3 presents the full estimation results of the model parameters based on equation (4).

A.1 Own- and Cross-price elasticities

Table A.4: Elasticities for First Quartile

	Food	Housing	Energy	Transport	Education	Health	Durables	Services
Food	-0.704***	0.025***	0.013***	0.008	0.033***	0.03***	0.01	0.013**
	(-0.017)	(-0.008)	(-0.005)	(-0.007)	(-0.006)	(-0.005)	(-0.008)	(-0.006)
Housing	-0.025	-0.826***	-0.014	-0.043***	-0.045***	-0.002	-0.032**	0.161***
	(-0.028)	(-0.02)	(-0.008)	(-0.013)	(-0.013)	(-0.009)	(-0.015)	(-0.014)
Energy	0.163***	0.062***	-0.445***	-0.008	-0.021**	0.01	0.021	0.025***
	(-0.021)	(-0.014)	(-0.015)	(-0.013)	(-0.01)	(-0.008)	(-0.011)	(-0.009)
Transport	-0.013	-0.043***	-0.036***	-0.504***	-0.023**	-0.035***	-0.066***	0.027***
	(-0.024)	(-0.016)	(-0.008)	(-0.018)	(-0.009)	(-0.008)	(-0.012)	(-0.01)
Education	-0.296***	-0.231***	-0.12***	-0.151***	-1.001***	-0.063***	-0.076***	-0.01
	(-0.04)	(-0.029)	(-0.011)	(-0.015)	(-0.027)	(-0.012)	(-0.015)	(-0.024)
Health	-0.152***	-0.126***	-0.078***	-0.155***	-0.079***	-0.828***	-0.099***	-0.105***
	(-0.031)	(-0.022)	(-0.009)	(-0.016)	(-0.017)	(-0.023)	(-0.018)	(-0.015)
Durables	-0.225***	-0.157***	-0.067***	-0.158***	-0.044**	-0.059***	-0.692***	-0.102***
	(-0.041)	(-0.024)	(-0.011)	(-0.017)	(-0.017)	(-0.013)	(-0.028)	(-0.02)
Services	-0.161***	0.105***	-0.054***	-0.038***	0.071***	-0.022**	-0.041***	-1.108***
	(-0.036)	(-0.023)	(-0.008)	(-0.013)	(-0.016)	(-0.008)	(-0.014)	(-0.02)

Significance levels **p<0.05, ***p<0.01. Standard errors are included in brackets.

Table A.5: Elasticities for Second Quartile

	Food	Housing	Energy	Transport	Education	Health	Durables	Services
Food	-0.774***	0.041***	0.018***	0.015**	0.039***	0.033***	0.031***	0.015***
	(-0.013)	(-0.009)	(-0.003)	(-0.006)	(-0.006)	(-0.004)	(-0.007)	(-0.005)
Housing	0.03	-0.816***	-0.005	-0.018**	-0.024***	0.005	-0.009	0.139***
	(-0.017)	(-0.013)	(-0.004)	(-0.008)	(-0.008)	(-0.005)	(-0.01)	(-0.009)
Energy	0.188***	0.071***	-0.432***	-0.013	-0.029***	0.008	0.015	0.023***
	(-0.019)	(-0.012)	(-0.012)	(-0.012)	(-0.009)	(-0.007)	(-0.009)	(-0.008)
Transport	0.006	-0.033***	-0.032***	-0.575***	-0.011	-0.024***	-0.059***	0.019**
	(-0.015)	(-0.012)	(-0.006)	(-0.015)	(-0.007)	(-0.006)	(-0.009)	(-0.008)
Education	-0.231***	-0.227***	-0.092***	-0.121***	-1.043***	-0.041***	-0.059***	-0.04**
	(-0.025)	(-0.021)	(-0.006)	(-0.01)	(-0.016)	(-0.008)	(-0.013)	(-0.016)
Health	-0.043**	-0.094***	-0.049***	-0.101***	-0.023	-0.925***	-0.058***	-0.041***
	(-0.021)	(-0.019)	(-0.006)	(-0.012)	(-0.013)	(-0.016)	(-0.015)	(-0.012)
Durables	-0.13***	-0.139***	-0.053***	-0.129***	-0.021	-0.039***	-0.839***	-0.083***
	(-0.025)	(-0.016)	(-0.006)	(-0.012)	(-0.012)	(-0.009)	(-0.019)	(-0.014)
Services	-0.155***	0.04**	-0.048***	-0.048***	0.036***	-0.014**	-0.04***	-1.089***
	(-0.021)	(-0.016)	(-0.004)	(-0.008)	(-0.012)	(-0.006)	(-0.01)	(-0.015)

Significance levels **p<0.05, ***p<0.01. Standard errors are included in brackets.

Table A.6: Elasticities for Third Quartile

	Food	Housing	Energy	Transport	Education	Health	Durables	Services
Food	-0.827***	0.038***	0.022***	0.021***	0.046***	0.039***	0.049***	0.015***
	(-0.013)	(-0.01)	(-0.003)	(-0.007)	(-0.007)	(-0.004)	(-0.007)	(-0.005)
Housing	0.051***	-0.788***	-0.003	-0.009	-0.006	0.009	0.001	0.144***
	(-0.016)	(-0.014)	(-0.003)	(-0.008)	(-0.01)	(-0.006)	(-0.011)	(-0.01)
Energy	0.227***	0.06***	-0.418***	-0.016	-0.033***	0.013	0.008	0.025***
	(-0.02)	(-0.013)	(-0.017)	(-0.014)	(-0.01)	(-0.007)	(-0.01)	(-0.008)
Transport	0.024	-0.033***	-0.028***	-0.632***	0.005	-0.013**	-0.05***	0.013
	(-0.014)	(-0.011)	(-0.005)	(-0.016)	(-0.008)	(-0.006)	(-0.01)	(-0.007)
Education	-0.158***	-0.174***	-0.065***	-0.085***	-1.09***	-0.028***	-0.027**	-0.031**
	(-0.02)	(-0.015)	(-0.003)	(-0.008)	(-0.016)	(-0.006)	(-0.011)	(-0.013)
Health	0.005	-0.068***	-0.031***	-0.062***	0.008	-0.985***	-0.027**	-0.01
	(-0.015)	(-0.015)	(-0.004)	(-0.01)	(-0.011)	(-0.012)	(-0.011)	(-0.009)
Durables	-0.064***	-0.117***	-0.042***	-0.104***	0.007	-0.028***	-0.935***	-0.069***
	(-0.019)	(-0.015)	(-0.004)	(-0.01)	(-0.011)	(-0.008)	(-0.018)	(-0.012)
Services	-0.15***	0.003	-0.041***	-0.055***	0.016	-0.017***	-0.043***	-1.086***
	(-0.016)	(-0.013)	(-0.003)	(-0.007)	(-0.011)	(-0.005)	(-0.008)	(-0.013)

Significance levels **p<0.05, ***p<0.01. Standard errors are included in brackets.

Table A.7: Elasticities for Fourth Quartile

	Food	Housing	Energy	Transport	Education	Health	Durables	Services
Food	-0.974***	0.009	0.038***	0.026**	0.167***	0.029***	0.086***	0.024**
	(-0.025)	(-0.018)	(-0.005)	(-0.013)	(-0.016)	(-0.007)	(-0.013)	(-0.012)
Housing	0.06**	-0.691***	0.003	0.018	0.107***	0.012	0.01	0.186***
	(-0.024)	(-0.028)	(-0.005)	(-0.013)	(-0.023)	(-0.011)	(-0.018)	(-0.023)
Energy	0.333***	0.028	-0.565***	-0.019	0.03	0.004	-0.031	0.027
	(-0.036)	(-0.028)	(-0.042)	(-0.029)	(-0.024)	(-0.014)	(-0.027)	(-0.021)
Transport	0.047	-0.014	-0.016	-0.748***	0.102***	0.003	-0.031	0.009
	(-0.026)	(-0.02)	(-0.009)	(-0.028)	(-0.018)	(-0.011)	(-0.019)	(-0.014)
Education	0.029	-0.052***	-0.02***	-0.006	-1.237***	0.02***	0.07***	-0.013
	(-0.019)	(-0.015)	(-0.003)	(-0.008)	(-0.022)	(-0.006)	(-0.012)	(-0.018)
Health	0.013	-0.062***	-0.017***	-0.022	0.117***	-1.052***	0.002	0.031**
	(-0.02)	(-0.022)	(-0.005)	(-0.013)	(-0.02)	(-0.018)	(-0.015)	(-0.015)
Durables	0.019	-0.117***	-0.033***	-0.071***	0.12***	-0.018	-1.146***	-0.06***
	(-0.023)	(-0.023)	(-0.006)	(-0.014)	(-0.019)	(-0.01)	(-0.026)	(-0.018)
Services	-0.134***	-0.057***	-0.028***	-0.063***	-0.078***	-0.025***	-0.05***	-1.092***
	(-0.013)	(-0.011)	(-0.002)	(-0.006)	(-0.015)	(-0.005)	(-0.008)	(-0.017)

Significance levels **p<0.05, ***p<0.01. Standard errors are included in brackets.

Table A.8: Income Elasticities by Expenditure Quartile

	Food	Housing	Energy	Transport	Education	Health	Durables	Services
First quatile	0.571***	0.826***	0.194***	0.693***	1.948***	1.623***	1.503***	1.249***
	(0.036)	(0.085)	(0.041)	(0.059)	(0.144)	(0.088)	(0.114)	(0.123)
Second quartile	0.582***	0.698***	0.169***	0.709***	1.853***	1.334***	1.431***	1.318***
	(0.03)	(0.053)	(0.037)	(0.042)	(0.1)	(0.065)	(0.075)	(0.082)
Third quartile	0.597***	0.602***	0.133***	0.711***	1.66***	1.169***	1.353***	1.373***
	(0.03)	(0.051)	(0.04)	(0.037)	(0.075)	(0.048)	(0.056)	(0.069)
Fourth quartile	0.596***	0.296***	0.193**	0.649***	1.207***	0.989***	1.306***	1.526***
	(0.048)	(0.081)	(0.081)	(0.054)	(0.069)	(0.057)	(0.063)	(0.067)

Significance levels **p<0.05, ***p<0.01. Standard errors are included in brackets.

Table A.9: Summary statistics for labour supply

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
Income	1150.409	896.577	3.03	16618.23	9486
Working hours	49.08	21.406	1	120	9486
Urban household	0.681	0.466	0	1	9486
Low education	0.603	0.489	0	1	9486
Dependent children	0.394	0.489	0	1	9486
Single household	0.114	0.318	0	1	9486

Table A.10: Labour supply estimates using logarithmic form of equation (11). Dependent variable is hours worked.

Variable	**Coefficient**	**Std. Dev.**
Elasticity (ϵ)	0.305***	(0.046)
Inverse Mills Ratio (IMR)	-0.488***	(0.0262)
Urban	0.0152	(0.0135)
Low education	0.079***	(0.021)
Dependent children	0.009	(0.014)
Single households	-0.394***	(0.016)
year_0	0.130***	(0.024)
year_1	0.011***	(0.022)
year_2	0.018***	(0.024)
Constant	4.156***	(0.025)

Table A.11: Overview of equivalences between commodity classification systems

Purpose	Bridge grouping	HBS	Input-Output	Name (Input-Output)
DURABLES	Repairs of appliances	H07_15	ADS	Admin and support services
	Small tools	H07_20	BFM	Basic fabricated metals
	Cutlery & kitchen utensils	H07_17, H07_18		
	Electronic household items	H07_05, H07_06, H07_07, H07_08, H07_09, H07_10, H07_11, H07_12, H07_13, H07_14, H07_15, H07_45	HTP	High-tech products
	Electronic accessories	H07_19, H07_21, H07_22		
	Lawnmowers & home ICT	H07_29, H07_30 , H07_31, H07_32, H07_33, H07_36, H07_37, H07_44		
	Garden accessories	H07_43	OIN	Other industrial products
	Decorative goods & mirrors	H07_46	ONM	Other non-metallic minerals
	Glassware, china & pottery	H07_16		
	Furniture repairs	H07_02	OSE	Other services
	Repairs of home ICT	H07_38		
	Furniture	H07_01, H07_42	OTM	Other manufacturing
	Software products	H07_34, H07_35	TEL	Telecommunication services
	Clothing	H03_01, H03_02, H03_03, H03_04, H03_05, H03_06, H03_07, H03_08, H03_09, H03_10, H03_11, H03_12, H03_13, H03_14, H03_15	TEX	Textile
	Footwear	H03_16, H03_17, H03_18		
	Bedroom textiles	H07_03		
	Other household textiles	H07_04		
	Vehicles purchases	H08_01	TRE	Transportation equipment
EDUCATION	Holiday expenditure	H09_09	ACC	Accommodation and hotel services
	Charges for sports & leisure	H09_04	ADS	Admin and support services
	Education expenditure	H09_07	EDU	Education
	Gambling	H09_05	OSE	Other services
	Games & toys	H09_08_01	OTM	Other manufacturing
	Equipment for sports	H09_08_02, H09_08_03		
	Reading materials	H09_06	TEL	Telecommunication services
	Internet, phone & TV fees	H09_03		
ENERGY	Electricity	H04_01	ELC	Electricity
	Liquid Fuels (eg heating oil)	H04_03	KRS	Kerosene
	Gas	H04_02	NGS	Natural gas

Continued on next page

Table A.11 – *Continued from previous page*

Purpose	Bridge grouping	HBS	Input-Output	Name (Input-Output)
	Solid Fuels	H04_04	PEA	Peat
FOOD	Alc. drinks consumed out	H02_02	ACC	Accommodation and hotel services
	Restaurant & takeout meals	H01_01_16, H01_02		
	Fish	H01_01_10	AGR	Agriculture
	Fruit	H01_01_11		
	Vegetables	H01_01_12		
	Alc. drinks at home	H02_01	FBT	Food, beverage, and tobacco
	Bread	H01_01_01, H01_01_02, H01_01_03, H01_01_04, H01_01_08		
	Dairy products	H01_01_05, H01_01_06, H01_01_07		
	Meat	H01_01_09		
	Non-alcoholic beverages	H01_01_15		
	Other food items	H01_01_14		
	Sugar	H01_01_13		
	Tobacco	H02_03		
HEALTH	Cosmetics & related products	H06_08, H06_09, H06_010	BPP	Basic pharmaceuticals
	Spectacles and lenses	H09_01_10		
	Prescription medication	H09_01_01		
	OTC medical products	H09_01_02, H09_01_03		
	Bathroom & cleaning products	H06_01, H06_03, H06_04, H06_05, H06_06, H06_07	CHE	Chemical products
	Hospital & lab services	H09_01_08, H09_01_09	HHS	Health
	Doctor services	H09_01_04, H09_01_05, H09_01_06, H09_01_07		
	Personal goods	H09_15_03, H09_15_04	OSE	Other services
	Professional grooming	H09_14		
	Therapeutic equipment	H09_01_11	OTM	Other manufacturing
	Baby utensils	H09_16_02		
	Jewellery, clocks and watches	H09_15_01		
	Household & care services	H09_17	PSE	Professional services
	Leather and travel goods	H09_15_02	TEX	Textile
	Prams & baby seats	H09_16_01	TRE	Transportation equipment
	Central heating maint.	H05_12, H05_16, H05_18	ADS	Admin and support services
	Dwelling maintenance	H05_15, H05_17, H05_19	CON	Construction
	Mortgage & home insurance (Second dwelling)	H05_06	FSR	Financial services
	Primary dwelling insurance	H05_08		

Continued on next page

Table A.11 – *Continued from previous page*

Purpose	Bridge grouping	HBS	Input-Output	Name (Input-Output)
	TV & audio equipment	H07_23, H07_24, H07_25, H07_26, H07_27, H07_28	HTP	High-tech products
	Repair of major durables	H07_41	OSE	Other services
	Musical instruments Indoor durables (e.g. rugs)	H07_39 H05_23, H07_40	OTM	Other manufacturing
	Mortgage & home purchase Rent (primary dwelling)	H05_04, H05_05, H05_07 H05_01, H05_02, H05_03	RES	Real estate services
	Home improvement materials	H05_14, H05_20, H05_21, H05_22, H05_24	RUP	Rubber and plastic
	Refuse/sewage collection Water charges	H05_11 H05_10	WAT	Water and sewerage
	Paint, wallpaper& timber	H05_13	WWP	Wood and wood products
	Local property tax	H05_09	nc	
SERVICES	Catering services	H09_19_02	ACC	Accommodation and hotel services
	Estate agents & room hire	H09_12_04, H09_19_04	ADS	Admin and support services
	Plants, seeds & fertilisers	H09_13	BPP	Basic pharmaceuticals
	Banking services Insurance/pension premiums	H09_12_07, H09_12_08, H09_12_09 H09_10	FSR	Financial services
	Phone purchase & repair	H09_02_01, H09_02_02	HTP	High-tech products
	Donations Other services	H09_18_05 H09_12_03, H09_19_01, H09_19_03, H09_19_07, H09_19_08, H09_19_09, H09_19_10, H09_19_11	OSE	Other services
	Postage	H09_19_05	OTR	Other transportation
	Legal services Pet costs	H09_12_01, H09_12_12, H09_19_06 H09_11	PSE	Professional services
	Official certificate fees	H09_12_10, H09_12_11	PUB	Public services
	Phone account payments	H09_02_03, H09_02_04, H09_02_05	TEL	Telecommunication services
	Banking services	H09_12_06	nc	
	Money to children	H09_18_01, H09_18_02, H09_18_03, H09_18_04	nc	
	Professional fees & fines	H09_12_02, H09_12_05	nc	
TRANSPORT	Air travel	H08_06_02, H08_06_03	ATS	Air transportation
	Diesel	H08_02_02	DIE	Diesel
	Vehicle insurance	H08_03_01, H08_03_02	FSR	Financial services
	Petrol	H08_02_01	GAL	Gasoline

Continued on next page

Table A.11 – *Continued from previous page*

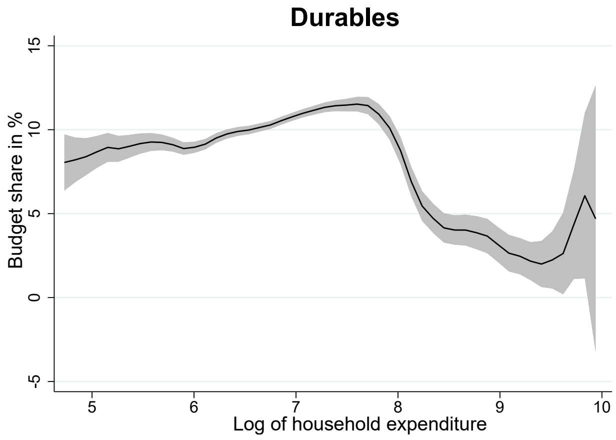
Purpose	**Bridge grouping**	**HBS**	**Input-Output**	**Name (Input-Output)**
	Public transport & taxis	H08_05, H08_06_04	LTS	Land transportation
	Other transport fuels	H08_02_03	OPP	Other petroleum products
	Fees from vehicle use (e.g. driving lessons, parking fees)	H08_04_09, H08_04_10, H08_04_11, H08_04_12, H08_04_13	TRD	Trade
	Delivery charges	H08_06_01		
	Vehicle maintenance	H08_04_04, H08_04_05, H08_04_06, H08_04_07, H08_04_08		
	Vehicle parts	H08_04_01, H08_04_02, H08_04_03		
	Vehicle tax	H08_03_03, H08_03_04	nc	

Source: Authors' table based on de Bruin and Yakut (2021b), Central Statistics Office (2017) and own categorization.

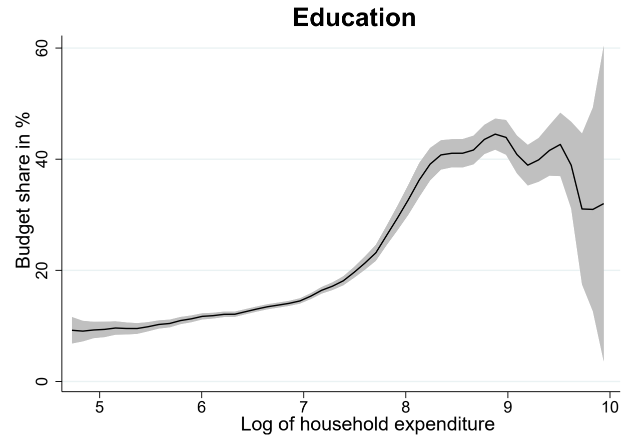
COA	Coal
CRO	Crude oil
FUO	Fuel-oil
LPG	Liquid petroleum gas
OMN	Other mining
WTS	Water transportation

Appendix B - Additional Graphs

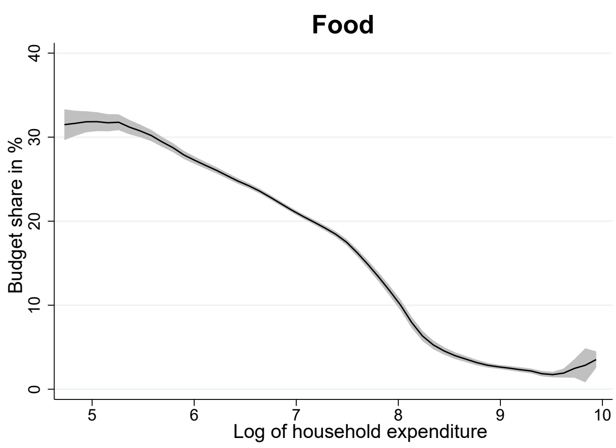
(a) Engel curve for Durables



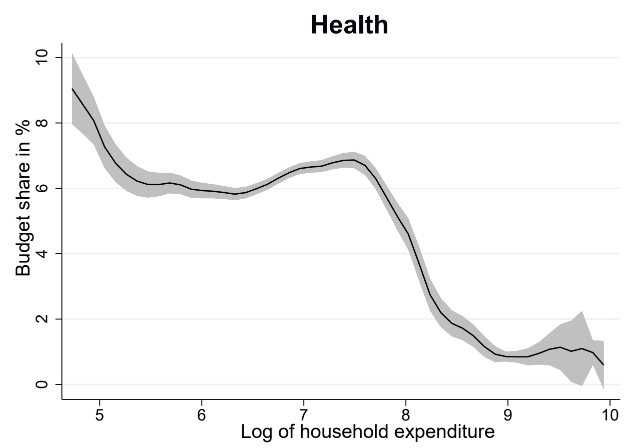
(b) Engel curve for Education



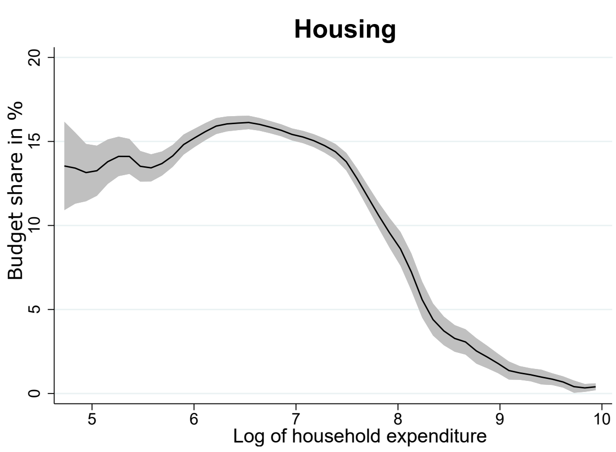
(c) Engel curve for Food



(d) Engel curve for Health



(e) Engel curve for Housing



(f) Engel curve for Services

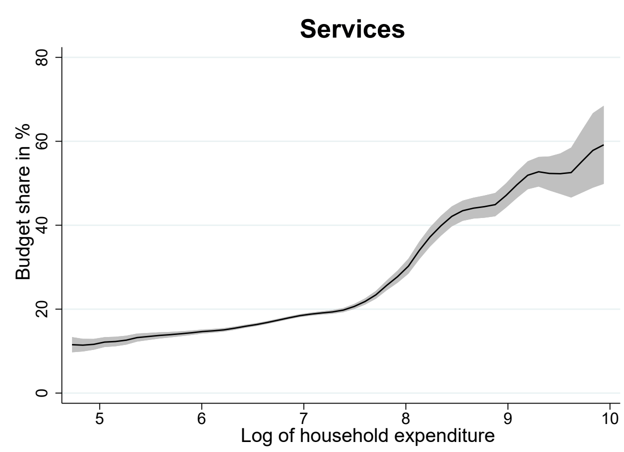


Figure B.1: Engel curves based on regressing budget shares (y-axis) on income levels (x-axis, log-scale)

Appendix C - Additional Proofs

C.1 Derivation of the marginal cost of Utility

Equation (4) implies that

$$\frac{\partial w_{ih}}{\partial x_h} = \left[\sum_{r=1}^{R} b_{ir} r \log(y_h)^{r-1} + \sum_{j=1}^{J} b_{ij} \log(p_j) + \sum_{l=1}^{L} g_{il} z_l \right] \frac{d \ \log(y_h)}{dx_h}$$

and from (3) we get

$$\frac{d \ \log(y_h)}{dx_h} = \left(x_h \left\{ 1 + \sum_{j=1}^{I} \log(p_{hj}) \left[\sum_{r=1}^{R} b_{ir} r \log(y_h)^{r-1} + \sum_{j=1}^{J} b_{ij} \log(p_j) + \sum_{l=1}^{L} g_{il} z_l \right] \right\} \right)^{-1}$$

This can be plugged into the derivation of the equation for the marginal cost of utility in footnote 8, where it can be transformed into the rightmost term.

C.2 Derivation of the VAT revenue

The term reflecting the VAT revenue in the governments budget constrain in equation 12 is constructed the following way: The VAT revenue for a commodity can be calculated by multiplying the VAT rate with the product of the number of units sold and the pre-tax price per unit. The number of units sold is $\frac{x_{h,i}}{p_i}$, the total amount of spending on the product divided by the tax-inclusive price. The tax free price is given by $\frac{p_i}{1+VAT_i^t}$. The total revenue is the sum of the VAT payments from all consumption purposes and all households:

$$\sum_{h=1}^{H} \sum_{i=1}^{I} VAT_i^t \frac{x_{h,i}}{p_i} \frac{p_i}{1+VAT_i^t} = \sum_{h=1}^{H} \sum_{i=1}^{I} VAT_i^t \frac{x_{h,i}}{1+VAT_i^t}$$