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Who pays for higher carbon prices? Illustration for Lithuania and a research agenda

Herwig Immervoll,

Cathal O'Donoghue,

Jules Linden,

Denisa Sologon

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Herwig Immervoll, Senior Economist, OECD
Cathal O'Donoghue (University of Galway)
Jules Linden (University of Galway, Luxembourg Institute of Socio-Economic Research)
Denisa Sologon (Luxembourg Institute of Socio-Economic Research).

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EU-SILC and HBS data are provided by Eurostat. Simulations of compensating transfers to households ("revenue recycling") draw on EUROMOD version i3.0+. Originally maintained, developed and managed by the Institute for Social and Economic Research (ISER), since 2021 EUROMOD is maintained, developed and managed by the Joint Research Centre (JRC) of the European Commission, in collaboration with Eurostat and national teams from the EU countries. We are indebted to the many people who have contributed to the development of EUROMOD.

Abstract

This paper lays out an approach, and a research agenda, for assessing the impact of carbon pricing on household budgets, and of possible compensatory government transfers that can be financed through carbon-tax revenues. It relies on a rich set of available data and policy models and combines them in a way that is informative for mapping the gains and losses at the household level in the short term as countries transition to a low-carbon economy. A particular focus is on linking information on carbon emissions and consumption patterns (which is needed for quantifying carbon-tax burdens), with income data and tax-transfer policy models (needed for assessing government policies that aim to cushion or offset carbon-tax burdens). The approach is illustrated for a carbon-tax scenario based on a recent proposal in Lithuania. Results confirm that direct burdens from higher fuel prices fall disproportionately on lower-income households. But indirect effects, from higher prices of goods other than fuel, are sizeable and broadly "flat" across the income distribution, which dampens regressivity. Low-income households are also found to respond more strongly to rising prices, reducing their burdens and, hence, regressivity. The total effect is only mildly regressive. Recycling carbon-tax revenues back to households allows considerable scope for avoiding or cushioning losses for large parts of the population, and existing policy models can be used to design compensation measures that facilitate majority support for carbon tax packages.

Résumé

Ce document présente une approche pour évaluer l'effet de la tarification du carbone sur le budget des ménages, et celui d'éventuels transferts compensatoires publics pouvant être financés sur le produit des taxes carbone. Il s'appuie sur un large ensemble de données disponibles et de modèles d'action, qu'il combine de façon à pouvoir établir une cartographie des gains et des pertes à court terme au niveau des ménages dans le contexte de la transition vers une économie bas carbone. Une attention particulière est accordée à l'articulation des informations sur les émissions de carbone et les modes de consommation (nécessaires pour quantifier la charge que représente la fiscalité du carbone) avec les données sur les revenus et les modèles de prélèvements et de transferts (nécessaires pour évaluer les politiques publiques visant à amortir ou compenser cette charge). L'approche est illustrée à l'aide d'un scénario de taxation du carbone qui repose sur une proposition présentée récemment en Lituanie. Les résultats confirment que la charge directe imposée par le renchérissement des produits énergétiques pèse de façon disproportionnée sur les ménages modestes. En revanche, l'effet indirect, dû à l'augmentation des prix autres que ceux des combustibles et carburants, est non négligeable et globalement étalé sur l'ensemble de la distribution des revenus, ce qui tempère le caractère régressif. Il apparaît en outre que les ménages modestes réagissent plus fortement à la hausse des prix, ce qui réduit la charge qu'ils supportent et, partant, la régressivité. En définitive, l'effet total n'est que modérément régressif. La redistribution des recettes de la fiscalité du carbone aux ménages offre d'importantes possibilités de prévenir ou d'atténuer les pertes pour une grande partie de la population, et il est possible de se servir des modèles d'action existants pour concevoir des mesures de compensation qui favorisent l'adhésion de la majorité aux programmes de taxation du carbone.

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Key findings

- Carbon taxes raise the cost of heating and transport fuel, and of other carbon-intensive goods and services. At levels that countries currently apply or discuss, their impact on household living costs is significant, but substantially smaller than the effects of high levels of inflation seen across the OECD during 2022. For instance, and broadly in line with other studies of the inflationary impact of carbon pricing ("greenflation"), a carbon tax at rates currently proposed in Lithuania would increase the consumer price index by less than 5% in total.[1]
- The immediate impact of carbon pricing on households' budgets depends on their reliance on different fuels for heating and transportation ("direct" effect), and on their consumption of all other goods that give rise to carbon emissions ("indirect" effect). In Lithuania, the indirect effects are in fact quantitatively somewhat more important. This result highlights that distributional assessments need to go beyond examining household spending on fuel, which sometimes dominates policy debates.
- Households react to higher prices, by rebalancing consumption towards less carbon-intensive (and less costly) products. The responsiveness to price changes differs across goods and income groups. For instance, low-income households spend large parts of their budgets on necessities, and they can be less able to escape higher prices on carbon-intensive goods. In Lithuania, adjustments of consumption patterns are estimated to reduce the net impact of carbon taxes on household expenditures by up to 16%. Results suggest that low-income households respond more strongly than higher-income groups.
- Taken together, the overall effects of carbon pricing can be broadly similar across income groups. In Lithuania, low-income households spend much large shares of their income on heating, including on cheaper and higher-emitting ("dirtier") heating fuels. But spending on motor fuels is concentrated among better-off households. Indirect effects, from higher prices of goods other than fuel, are broadly "flat" across the income distribution, which dampens regressivity. Low-income households are also found to respond more strongly to rising prices, reducing their burdens and, hence, regressivity.
- The total effect in Lithuania is only mildly regressive. Overall losses sum to about 4% of income for the bottom half of the distribution, and 3.5% for the top half. Yet, even "flat" burdens can be too much for some groups to absorb, notably at the very bottom of the distribution. Since escaping poverty requires overcoming situations of deficiency, this typically calls for consuming

[1] On "Greenflation", see e.g., (Konradt and Weder di Mauro, 2022[135]).

more, not less. Cushioning the losses can therefore be important, both for political economy and for social welfare reasons.

- Revenues from carbon taxes are substantial. Channelling them back to households allows governments considerable scope to cushion losses and shape the distributional profile as part of a broader policy package. The proposed carbon tax in Lithuania is estimated to raise about 1.3% of GDP.
- The paper considers three different options of “revenue recycling”, by distributing some or all of that carbon-tax revenue through household transfers. Paying a lump-sum transfer to everybody, akin to a “basic income”, results in a large majority (60%) who would be better off than without the carbon tax. Using revenues to increase existing government transfers results in sizeable gains for low-income groups but, overall, a slight majority would see net losses. Reducing labour taxes would benefit higher-income groups but a large majority (some 70%) would be worse off with such a policy package.
- Carbon taxes lower emissions from household consumption as intended. But given consumer preferences as represented in currently available data, reductions are relatively small. This highlights that, at existing or proposed levels, carbon taxes alone are not sufficient for meeting national and international climate commitments. A comprehensive 60 EUR/tonne carbon tax in Lithuania is estimated to reduce emissions from final consumption by between 7 and 8% (depending on the revenue recycling scenario). While the type of revenue recycling largely determines the distributional outcome of a carbon-tax package, the choice makes only a very modest difference in terms of emissions connected to household consumption. This result suggests that, in designing compensatory transfers to households, there is no major trade-off between achieving social and environmental objectives.

1 Introduction

1. As part of strategies to tackle the causes of climate change, different forms of carbon pricing, such as carbon taxes, cap-and-trade systems and phase-outs of fossil-fuel subsidies, have been introduced to shift the marginal private cost of carbon towards its marginal social cost.[2] These measures incentivise a reduction in emissions, as well as the substitution from dirtier to cleaner fuels and technologies. They are recommended for their environmental effectiveness, because they are administratively simple and economically efficient without being technologically prescriptive, and because they do not weigh on government budgets (High-level Commisssion on Carbon Prices, 2017[1]; Pigou, 1920[2]; Nordhaus, 1991[3]; Pearce, 1991[4]).

2. This paper sets out a modelling framework to simulate the distributional impact of a carbon tax on consumers in the short term, and applies it to study a prospective reform in Lithuania. The policy simulations combine micro-level information on household expenditure and income, with input-output data that allow tracing the carbon content and associated tax burdens across sectors and through different stages of production. Using this approach, it is possible to approximate the effects of a carbon tax on the price of goods across all consumption categories, not just households' direct use of carbon-rich energy products. The paper quantifies the resulting net effects of the tax on household budgets, and disentangles its key drivers, including consumption of energy and other goods, as well as consumers' responsiveness to price changes. The approach notably accounts for the effects of policies that seek to compensate selected population groups through government transfers or income-tax concessions, which can be financed through carbon-tax revenues ("revenue recycling").

3. Beyond their effect on consumption expenditures, carbon taxes and other climate-change mitigation measures also alter the incomes of the owners of the different factors of production, including natural resources, "brown industry" equity and labour (Rausch, Metcalf and Reilly, 2011[5]; Metcalf, 2021[6]). Relatedly, changing input prices and consumer demand trigger labour-market adjustments through a reallocation of jobs from high-carbon to low-carbon industries and activities and employment effects can be a specific focus in public debates. The gains and losses from labour-market adjustments can be difficult to quantify and are not reflected in the approach presented here.[3] There will clearly be employment losses in firms that see reduced demand due to carbon-intensive technologies (Dussaux, 2020[7]). While this will affect specific population groups, such as older workers, available findings suggest that the net employment impact can be limited (OECD, 2021[8]; Metcalf and Stock, 2020[9]). Estimates on the broader impact of employment changes on inequality also do not necessarily provide a clear-cut picture.[4]

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[2] (Nordhaus, 2017[128]) defines the social cost of carbon as the economic cost caused by an additional tonne of CO_2 emissions or its equivalent; it rests on the concept of internalising externalities, considering both inter- and intra-generation equity.

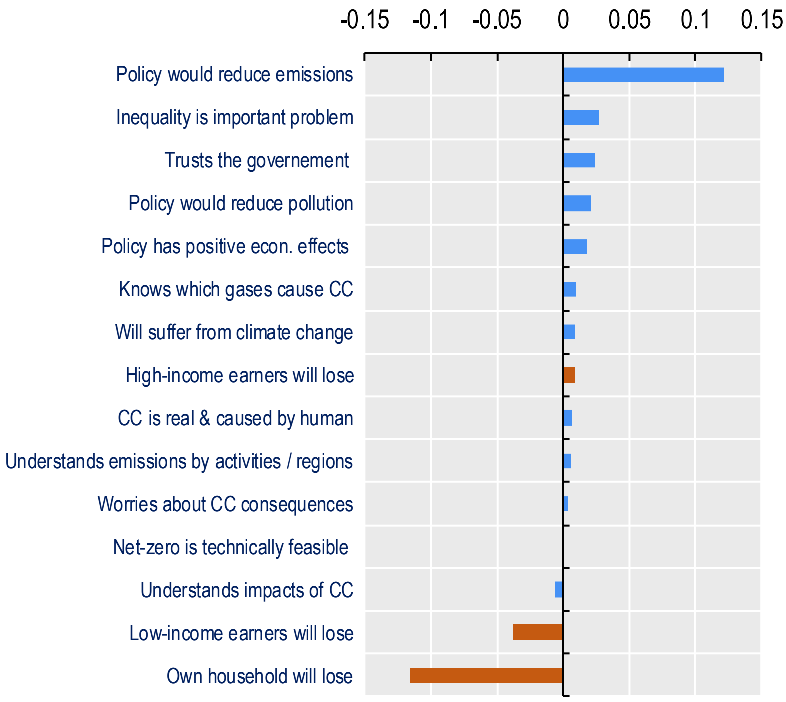
[3] Significant uncertainty about future employment shifts comes from disagreements on the likely cost and pace of green-technology adoption (Way et al., 2022[133]).

[4] Macro models that account for general equilibrium effects do not necessarily indicate that carbon taxes create greater losses for more disadvantaged labour-market groups. For instance, OECD (forthcoming[122]) suggests that

4. Across countries, current carbon prices are well below levels that are considered in line with national and international commitments, notably the targets affirmed in the Paris Agreement (OECD, 2022[10]). Numerous governments are therefore considering reforms to introduce or increase them. Yet, in the short term, there can be notable trade-offs between the intended incentives from higher carbon prices, and unintended distributional effects (Baumol and Oates, 1988[11]; Baranzini, Goldemberg and Speck, 2000[12]). The pattern of gains and losses from climate-change mitigation measures can be a key driver of public and political support for fighting climate change (Büchs, Bardsley and Duwe, 2011[13]; Tatham and Peters, 2022[14]). A recent large-scale survey of 40,000 people across 20 countries, shows that support for carbon taxes hinges on their perceived distributional impacts on lower-income households, and respondent's own assessment of their household's gains and losses (Figure 1).

Figure 1. Support for climate policies hinges on perceived gains and losses

Correlation between beliefs and support for carbon tax package with cash transfers



Note: Results of regressions of support on standardized variables measuring respondents' beliefs and perceptions. Country fixed effects, treatment indicators, and individual socioeconomic characteristics are included but not displayed. The dependent variable is and indicator variables equal to 1 if the respondent (somewhat or strongly) supports each of the main climate policies. n=40 680, R2=0.378.
Source: Adapted from (Dechezleprêtre et al., 2022[15]).

5. From a political-economy point of view, and in a context where voter support for climate-change mitigation is needed now, the initial burdens from a carbon tax can be of particular interest. Avoiding

unemployment and wage losses resulting from a carbon tax in Lithuania may increase with worker's skills. Emerging results using micro-data do illustrate that losses for displaced workers in carbon-intensive sectors can be sizeable (Barreto, Grundke and Krill, forthcoming[121]). These studies are informative but necessarily based on past layoff events, with dismissals in "brown" sectors largely driven by globalisation and offshoring. The associated restructuring and subsequent re-employment opportunities are therefore imperfect indicators of the pattern of employment gains and losses that may result from climate-change mitigation.

transition-related losses for budget-constrained low-income households, even if temporary, is important for social welfare reasons (Budolfson et al., 2021[16]). In part, concerns about the distributional impacts of carbon taxes stem from the fact that domestic fuels in particular are, at the same time, necessities and a main source of household-level emissions. When prices go up, the poorest households may be ill-equipped to draw on savings or to cut back on other expenditures, see also (OECD, 2022[17]) and (Sologon et al., 2022[18]). As a result, low-income groups may bear a substantial burden from higher carbon taxes. A regressive impact, in turn, risks worsening key aspects of inequality, material deprivation and social exclusion, such as fuel poverty or food insecurity. The current cost-of-living crisis has dramatically heightened concerns over the economic burdens on households from rising living costs, and higher energy prices in particular.

6. Existing studies highlight that net effects of carbon taxes vary strongly between countries and policy measures, depending not only on the features of the tax and consumption patterns, but also on population characteristics and existing inequalities (Ohlendorf et al., 2020[19]). Importantly, carbon taxes and fuel prices affect not only the cost of transportation and heating but, subject to the carbon intensity in the production process, also the prices of other goods. For each household, the overall impact depends on their consumption bundle, and on their propensity and ability to adjust consumption in response to price movements.

7. Any regressive effects, or a concentration of losses among specific groups, may call for accompanying measures to compensate losers, while maintaining the fundamental price signals from carbon pricing (Carattini, Carvalho and Fankhauser, 2018[20]; World Bank, 2019[21]). For instance, the carbon tax in Ireland includes a commitment to using the resulting revenues for preventing fuel poverty and ensuring a just transition. The carbon tax that British Columbia, Canada, introduced in 2008 was accompanied by a revenue-neutral tax shift that cuts other taxes and provides for direct transfers to households (Murray and Rivers, 2015[22]). Switzerland earmarks one third of carbon-tax revenues for programmes to support a green transition and reduce energy consumption, with the remainder is redistributed through lower health insurance premiums (Bureau, Henriet and Schubert, 2019[23]).

8. Compensation should be timely and may need to be suitably targeted in order to support the political feasibility and sustainability of climate-change mitigation initiatives. Policy models in combination with rich micro-level data ('microsimulation models') allow exploring each of these mechanisms and their likely net effect on different households (Hynes and O'Donoghue, 2014[24]; Immervoll and O'Donoghue, 2009[25]; O'Donoghue, 2021[26]), complementing CGE-type approaches that estimate macro-economic effects.[5] Policy models can facilitate the assessment of alternative reform scenarios or paths, and provide timely input into policy debates, design and implementation, as carbon taxes move up the policy agenda in many countries.

9. The remainder of this paper is structured as follows. Section 2 briefly sketches the policy context for carbon taxes. Section 3 gives an overview of past assessments of their distributional impact, lays out a methodology for assessing environmental taxes in a microsimulation framework, and describes the input data that is available for Lithuania. Section 4 presents results, distinguishing between *(i)* direct effects (via fuel consumption by households), *(ii)* indirect effects (via household consumption of other goods and services with different carbon content), *(iii)* behavioural adjustments (rebalancing of consumption patterns in response to price signals), and *(iv)* revenue recycling (options for using carbon-tax revenues to compensate selected groups). The results section also presents estimates for the scope of emission reductions that can be achieved through an introduction of a carbon tax, via expected changes in consumption patterns towards less carbon intensive (and less expensive) goods.

[5] E.g. (Diamond and Zodrow, 2021[134]).

2 Carbon taxes: policy context in Lithuania and internationally

10. Carbon taxes were first introduced in Finland in 1990 and in Norway in 1991. A number of OECD countries have followed since then. In Europe, rates in 2021 ranged from 7 cent/tonne of CO2 in Poland to 116 Euro/tonne in Sweden. Other OECD countries operating an explicit carbon tax at a national level include Canada, Chile, Denmark, Estonia, Finland, France, Iceland, Ireland, Japan, Latvia, Luxembourg, Mexico, Netherlands, Norway, Portugal, Slovenia, Spain, Switzerland and United Kingdom (OECD, 2019[27]; Köppl and Schratzenstaller, 2022[28]).

11. Additional countries have announced carbon taxes or are in the process of implementing them. The OECD's (2022[29]) Tax Policy Reforms report notes that "promoting environmental sustainability has become increasingly central to the policy goals of taxing energy and vehicle use", and provides additional details on new or higher carbon taxes that are already in place or are planned for 2023 (e.g., in Austria, Canada, Iceland, Ireland, Netherlands).

12. But some governments have responded to cost-of-living concerns by recently suspending environmental tax measures. Portugal suspended its proposed increase in carbon tax until the end of the year and Austria delayed the introduction of its carbon tax until October 2022. Already at an earlier stage, the French government withdrew a planned carbon price increase, and froze any further increases for the 2019–2022 period, following strong resistance from mostly rural areas (the Yellow Vest movement) that formed in late 2018.

13. The European Green Deal, approved in 2020, is a set of policy initiatives with the overarching goal of a climate-neutral EU by 2050. In light of this ambition, the 2021 European Climate Law sets an interim emissions reduction target of 55% by 2030 (compared with 1990 levels). In order to meet this target the European Commission has developed a set of proposals, also known as the Fit for 55 package, to review and update EU legislation, putting in place new climate policy initiatives in line with the increased ambition of the green deal. The Fit for 55 package was submitted to the European Council in 2021, it is being discussed across several policy areas, such as environment, energy, transport and economic and financial affairs (European Council, 2022[30]). The package comprises numerous legislative proposals and climate policy initiatives including, but not limited to, the taxation of energy. As part of the Fit for 55 proposal, the European Union plans to extend carbon pricing to transportation and residential sectors. In addition, countries variously committed to phasing out of fossil fuel subsidies, which effectively lower carbon prices and encourage wasteful consumption (G20 Leaders Statement, 2009[31]; OECD/IEA, 2021[32]).

14. In accordance with EU-level commitments, Lithuania has targeted net-zero emissions by 2050. Achieving this will require considerable acceleration of emissions reductions, in line with the Fit for 55 package. This will rely, in particular, on reversing emissions trends in the transport sector, as emissions from private vehicles and road freight have grown steadily and fuel taxes in Lithuania are among the lowest in the EU. Lithuania's expanding domestic renewable energy production is reducing reliance on electricity imports but decarbonising the economy through electrification will also significantly increase

electricity demand. Energy efficiency is therefore key and will require a package of ambitious climate policies.

15. Currently, Lithuania does not apply an explicit carbon tax. In 2021, CO_2 emissions from energy use in Lithuania are partly priced, through the EU Emissions Trading System (ETS) and through (comparatively low) fuel excise taxes. Recently, the Lithuanian Government has proposed to phase-in a tax based on the carbon intensity of fuels from 2025. The tax would start at 10 Euros per tonne of CO_2 and rise by 10 Euro each year, rising to 60 Euros per tonne in 2030, though the carbon tax component in the current proposal does not apply to entities already subject to the EU ETS. 60 Euros per ton corresponds to a low to midpoint estimate for the social cost of carbon in 2020 (High-Level Commission on Carbon Prices, 2017[33]), though more recent studies mostly support higher values. The US government currently relies on a mean value of USD 51/tCO_2 (Interagency Working Group on Social Cost of Greenhouse Gases (IWG), 2021[34]), a recent report by the European Commission (2021[35]) suggests a central value of EUR 100/tCO_2 through to 2030, while a recent comprehensive review indicates a preferred mean estimate of USD185/tCO_2, at 2020 prices (Rennert et al., 2022[36]).

3 Distributional effects of carbon taxes: Literature review

16. Much of the literature on the distributional impact of carbon taxes focuses on their initial impact, without revenue recycling. There is a common conjecture that carbon taxation is regressive in high-income countries (Klenert and Mattauch, 2016[37]). However, home fuel and electricity taxation tends to be more regressive than fuel taxation in the transport sector (Büchs, Ivanova and Schnepf, 2021[38]), which can be progressive, especially in countries with moderate car ownership and well-developed public transport systems (Wang et al., 2016[39]).

17. Households in countries with lower GDP levels, including within the OECD area, tend to face significantly higher risks of energy affordability (Flues and van Dender, 2017[40]), which tends to render carbon taxes less regressive overall. Outside the OECD, progressive impacts are also generally more common in poorer countries, where consumption baskets tend to be less carbon intensive, energy can be more difficult to access or less affordable for large shares of the population, and home fuels can be less important for heating due to climatic conditions (Ohlendorf et al., 2020[19]; Dorband et al., 2019[41]).

18. Taxation of both direct and indirect emissions tends to be less regressive (or more progressive) than taxing direct emissions only, e.g., through excise taxes on fuel (Ohlendorf et al., 2020[19]).

19. The literature on net impacts, accounting also for revenue recycling, is smaller, though existing studies point to the quantitative importance of revenue recycling for overall distributional outcomes. This also holds for policies that raise effective carbon prices through a withdrawal of energy subsidies (Durand-Lasserve et al., 2015[42]). Notable results include the following:

1. Lump-sum transfers (such as a basic income financed through carbon taxes) are progressive and poverty reducing (Berry, 2019[43]; Klenert et al., 2018[44]; Owen and Barrett, 2020[45]);
2. Depending on their reach, social welfare payments support low-income earners and reduce inequality, while across-the-board income tax cuts benefit the top and are regressive (Callan et al., 2009[46]; Klenert and Mattauch, 2016[37]);
3. VAT tax reductions for specific goods, e.g. on public transport, can redistribute between regions (Brännlund and Nordström, 2004[47]);
4. Energy cheques reduce fuel poverty (Berry, 2019[43]), while public transport vouchers are progressive and achieve sizeable emission reductions (Büchs, Ivanova and Schnepf, 2021[38]); and
5. Support for retrofitting residential buildings tends to be progressive (Bourgeois, Giraudet and Quirion, 2021[48]).

20. Table 1 illustrates the scope of modelling frameworks used in a range of distributional studies that employ micro-data and policy simulation. Existing frameworks variously incorporate the features that are desirable or required for informative distributional analyses of carbon taxes, namely the capacity to model carbon emissions associated with different consumption goods, the distributional impact of price changes, households' behavioural response to price changes and resulting CO_2 reductions, as well as policies that can offset unintended distributional effects via revenue recycling. Existing

frameworks have generally not incorporated all these dimensions; some are stronger on distributional measures, while others incorporate more detail in relation to behavioural responses or include a comparative perspective across countries.

21. The modelling of accompanying policies to alleviate unintended distributional consequences, including through revenue recycling, has followed different approaches. The early study for the United Kingdom by Pearson and Smith (1991[49]) has used policy simulation in combination with detailed household-level information, similar to the illustration reported here. Other studies have been more approximate, without accounting for the full granularity of household information. This is, in part, due to the fact that models often either proceeded at an aggregate or semi-aggregate level, or relied on household expenditure data alone, without linking it to policy simulation models that require detailed information on household incomes. For example, Callan et al. (2009[46]) compare carbon tax payments per income decile to revenue-neutral transfers by decile, without modelling the granular incidence of carbon taxes or compensating policies on individual households.

22. The present paper integrates revenue recycling with a careful analysis of the incidence of carbon taxes themselves. The objective is threefold. First, the paper aims to further the discussion around broader policy packages in the context of climate change mitigation. Second, it seeks to facilitate the detailed assessments of gains and losses from a carbon tax at the household level and across any population group that can be of interest from a political-economy, or a distributional point of view. Third, and based on the strengths and limitations of the proposed approach, it identifies priorities for future research in this area.

Table 1. Overview of existing distributional studies using microsimulation: Scope and modelling choices

Author	Country coverage	Scope	Distributional impact	Distributional metric	CO_2 emission reduction	Taxes considered	Multi-regional IO model	Revenue recycling	Behavioural response (consumption)
(Pearson and Smith, 1991[49])	United Kingdom (some results for EU12)	country	Regressive	Expenditure	no	Carbon tax	Country IO	(1) Lump-sum; (2) lower income tax	Yes
(Symons, Speck and Proops, 2002[50])	5 EU	country	Mixed	Income	no	Direct and indirect	no	No	no
(Sterner, 2012[51])	7 EU	country	Progressive	Income and expenditure	no	Transportation fuel	no	No	yes
(Flues and Thomas, 2015[52])	21 OECD	20 country average, country	Mixed	Income and expenditure	no	Home heating, motor fuel and electricity	no	No	no
(Dorband et al., 2019[41])	87 low and middle-income	country	Progressive	Income	no	Transportation fuel	yes	No	yes
(Vogt-Schilb et al., 2019[53])	Latin America & Caribbean	Cross-country	Progressive	Expenditure	no	Direct and indirect	yes	(1) Higher cash-transfers, (2) Higher coverage	no
(Büchs, Ivanova and Schnepf, 2021[38])	27 EU	EU-level	Regressive across EU	Income	yes	Direct and indirect	yes	(1) fuel rebates; (2) green vouchers + infrastructure	Average elasticities by EU quintile
(Feindt et al., 2021[54])	23 EU	EU-level, country	Progressive across country/ regressive across EU	Expenditure	no	Direct and indirect	yes	(1) National / EU lump sum; (2) Targeted to poor	Average elasticities across countries
(Steckel et al., 2021[55])	8 Asian	Cross-country	Progressive	Expenditure	no	Direct and indirect	yes	Lump-sum	no
(Budgetdienst, 2022[56])	Austria	Country	Progressive	Income	no	Carbon tax	Country IO	Lump-sum, differentiated by region	no
(Zhao et al., 2022[57])	China	Country	Regressive	Income	Yes, set to achieve 1.5 degree target	Carbon tax	Yes	(1) Tax exemptions, (2) Subsidies	yes

Note: See also Box 1

4 Methodology and data

23. This section situates microsimulation modelling in relation to carbon taxes and environmental policies more broadly. It then presents the data for the present analysis, which is constructed from three main sources, the World Input-Output Database (WIOD), Household Budget Survey (HBS), and the European Union Statistics of Income and Living Conditions (EU-SILC). The section starts by describing WIOD and the input-output analysis underpinning carbon-intensity estimates for each product category. WIOD is then combined with HBS data to estimate carbon-tax burdens at the household level. It also describes the consumption model used to derive households' behavioural responses. The final steps consist of imputing expenditure patterns into the EU-SILC data and simulating selected revenue-recycling measures, drawing on the Lithuania module of the EUROMOD tax-benefit model (which requires EU-SILC as input).

24. There is a growing literature on modelling the distributive impact of environmental taxes, see Box 1. All models abstract from the full complexity of the real world. This paper makes a number of modelling choices to keep the empirical illustration transparent and tractable:

1. In addition to the introduction of carbon taxes, other climate-change mitigation measures are usually planned or introduced in parallel. These include changes in excise duties and changes in the parameters or scope of the Emissions Trading System (ETS). In order to identify the differential distributional impact of the carbon tax, it was decided to model this change in isolation. As there are limited interactions with these other measures, this arguably contributes to a better understanding of the carbon tax specifically.
2. In its current version, the carbon-tax proposal in Lithuania does not cover installations that are already subject to emissions trading, and it does not yet feature a carbon tax (carbon border adjustment) for imported goods. The calculations in this paper ignore this variation and relate to a uniform carbon tax across all sectors and products. Although the multi-regional input-output data makes it possible to account for tailored carbon-tax scenarios, a uniform carbon tax is arguably a useful first step when illustrating the approach. It is also informative as ETS does not yet include the transport and buildings sectors, where the effects of carbon taxes on prices are expected to be especially sizeable. Furthermore, by 2030, carbon prices will, to varying extents, also rise for ETS sectors, even if not through explicit carbon taxes. An average carbon price of 60 EUR/tonne of CO_2 probably presents a reasonable lower-bound value.
3. The reference period of the policy introduction and simulation is relevant, as household circumstances, consumption patterns and prices change over time, as do preferences, including for consumption. Modelling relies on the latest available microdata including on household expenditures (HBS 2015) and incomes (EU-SILC 2018). Income and price data are updated and reflect the large recent price changes (see Annex A5). However, although the simulated carbon tax is to be introduced over a period up until 2030, a decision was made not to project household characteristics forward to 2030, but model them on the basis of 2022. The inflationary situation, in particular, is highly volatile and both prices and incomes therefore do not lend themselves to reasonably certain medium-term forecasts. Given this context, it appears more informative to rely on granular information on current or recently observed prices, consumption patterns and living standards, than to make speculative assumptions about the medium-term future. This choice

should be kept in mind when interpreting results. The EUR 60/tonne carbon tax is therefore simulated as if it were implemented in the present (with data limitations as described above), rather than in 2030.

4. Relatedly, observed income levels are uprated uniformly via price and income inflators (for 2021), as is standard in the literature, rather than through more ambitious now-casting approaches (Sologon et al., 2022[58]; O'Donoghue and Loughrey, 2014[59]; Immervoll, Mustonen and Riihelä, 2005[60]). Now-casting of microdata can be informative when the objective is to approximate broader or aggregate measures of inequality. They involve a range of data adjustments, however, which can be problematic when the resulting data are used as input into further modelling or analysis. Essentially, extensive data manipulations can obscure the results from the policy modelling exercise that are of primary interest.

25. Annex A provides details on each of the steps in the modelling process and how it was implemented in the context of this paper. It describes, in turn:

- the input-output model, which captures carbon emissions by sector and allows quantifying the pass-through of carbon taxes from inputs to the price of final consumer products and services (Annex A1);
- the matching of input-output data with a household expenditure survey, which is needed to compute the carbon footprint from household consumption (Annex A2);
- a consumption model that quantifies households' behavioural responses to carbon-tax related price changes (Annex A3);
- the linking of expenditure information (from household budget surveys) with other characteristics needed for distributional analysis (from the EU-SILC survey), Annex A4;
- data adjustments to approximate the situation in the 2022 baseline year with earlier data (2015 for the household budget survey), Annex A5; and
- the simulation of options for recycling carbon-tax revenues, drawing on output from the EUROMOD tax-benefit model (Annex A6).

Box 1. Assessing the distributive impact of environmental policy using microsimulation

Microsimulation models can disentangle complexity that governments routinely confront when designing public policy interventions (O'Donoghue, 2021[26]). Sources of complexity include policy design, population structure and behaviour. In each of these areas, models aim at incorporating key policy and empirical mechanisms, as well as the heterogeneity of socio-economic circumstances as captured in available micro-data. As simulation tools, the resulting models allow quantifying likely effects in advance of reform rollout, improving policy design prior to committing major expenditure.

Hynes and O'Donoghue (2014[24]) provide a broad review of the use of microsimulation models to inform environmental policy. The distributional implications of carbon taxes have been analysed by Casler and Rafiqui (1993[61]) and Mathur and Morris (2014[62]) in the USA, Hamilton and Cameron (1994[63]) in Canada, Pearson and Smith (1991[49]), Symons et al. (1994[64]) and Symons et al. (2002[65]) in the United Kingdom, Cornwell and Creedy (1997[66]) and Creedy and van de Ven (1997[67]) in Australia, Callan et al. (2009[46]) and O'Donoghue (1997[68]) in Ireland, Bach et al. (2002[69]) and Bork (2006[70]) in Germany, Kerkhof et al. (2009[71]) in the Netherlands, Poltimäe and Võrk (2009[72]) in Estonia, Labandeira and Labeaga (1999[73]), Labandeira et al. (2009[74]) and Garcia-Muros et al. (2017[75]) in Spain, Bureau (2011[76]) and Berry (2019[43]) in France, Vandyck and Van Regemorter (2014[77]) in Belgium, Yusuf & Resosudarmo (2015[78]) in Indonesia, and Rosas-Flores (2017[79]) in Mexico.

Microsimulation has also been used to explore distributional effects of other environmental policies, such as tradable emissions permits, taxes on methane emissions from cattle (Hynes et al., 2009[80]) and taxes on nitrogen emissions (Berntsen et al., 2003[81]). Doole et al. (2013[82]) examine the distributional impact of a cap-and-trade strategy on dairy farms. Occasionally, distributional impact analyses took the form of 'what if' simulations of given policy scenarios assuming alternative consumption patterns. For example, Alfredsson (2004[83]) utilised a microsimulation model to undertake a life-cycle analysis of 'greener' consumption patterns that incorporates energy use and CO_2 emissions connected with the entire production process, up to the point of purchase.

In large parts, environmental microsimulation is similar to an indirect-tax model, containing input expenditure data from household budget surveys (HBS), a policy calculator and the consumption behavioural response. In addition, however, it incorporates a further component to model pollution, both directly in terms of polluting activities by households, and indirectly, through the polluting activities in the value chains of the goods consumed (captured through an input-output model).

5 Results

26. At carbon tax levels that countries currently apply or discuss, the impact on household living costs can be significant, as can be their distributional effects. At the outset, it is useful to put the resulting burdens into context, however. In Lithuania, the impact on living costs would be much smaller than the effects of high inflation rates seen across the OECD over recent months. A carbon tax at 60 EUR/tonne as currently discussed would increase the consumer price index by less than 5% in total, and over a period of several years (see Annex Figure A1).

Consumption patterns across the income spectrum

27. The impact on different population groups depends upon a number of factors including notably the distribution of expenditures across the income spectrum. Carbon taxes affect household budgets directly through fuel consumption, and indirectly via the consumption of other goods and services that give rise to CO_2 emissions during the production process.

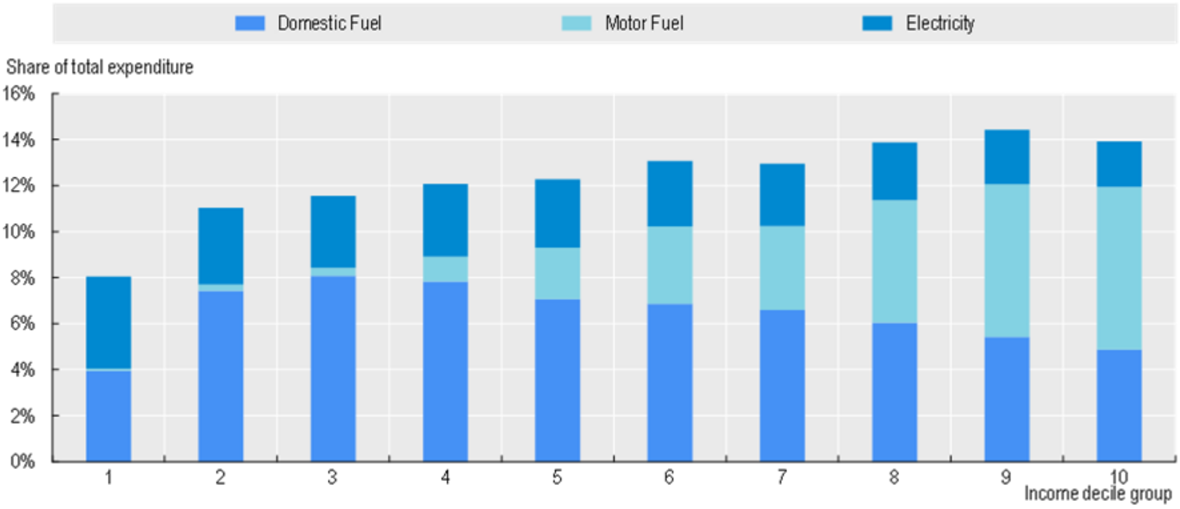
28. The direct incidence of carbon taxes across households is shaped by the pattern of fuel expenditures. Domestic heating fuels are necessities, i.e. people will buy them regardless of income. Low-income households therefore devote larger shares of their total income and expenditures to heating fuels than better-off households. An opposite pattern can emerge for motor fuels, reflecting higher rates of car ownership among middle and higher-income households.

29. Figure 2 describes the distributional shape of fuel expenditure patterns in Lithuania, along with electricity. Spending shares for heating fuel are highest in income deciles 2, 3 and 4. Overall, spending on heating fuels is quite regressive, with a large difference in shares between the bottom and the top. Nevertheless, shares are lowest in the poorest 10%, which may be related to budget constraints and the poorest households needing to prioritise other essentials over adequate heating. Expenditures on electricity are substantially lower than for heating fuel in all but the bottom decile, and it follows a mildly regressive pattern overall. Spending on motor fuels is very top-heavy, with almost no spending on this item in the bottom 30% but a higher share than heating fuels at the top. Taken together, *overall* fuel expenditure is clearly progressive relative to income in Lithuania, which is increasingly unusual in international comparisons. When adding electricity, patterns are still progressive but less so than for fuel.[6]

[6] These consumption patterns are a snapshot at a single point in time. It should be noted that Lithuania has changed very significantly in terms of its economic and consumption structure over recent years. It is likely that Lithuania will continue to converge towards European patterns over the planning period for the Carbon Tax which may affect medium term conclusions.

Figure 2. High-income households spend large shares of their budgets on energy

Lithuania, approximations for 2022

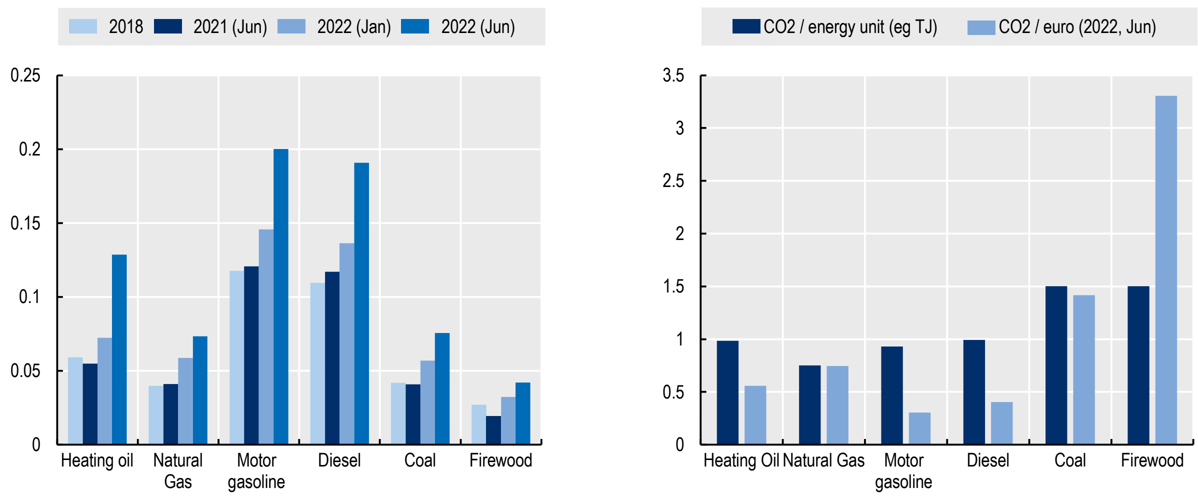


Note: Domestic fuel includes expenditure on gas (natural gas and town gas), liquified hydrocarbons, liquid fuels, heat energy, coal and other solid fuels. Motor fuels includes expenditure on diesel and petrol for transportation.
Source: Household budget survey, combined with 2022 price data.

Figure 3. Fuel prices and CO_2 emissions

A. Prices in Lithuania, EUR per kWh

B. CO_2 emissions, tonnes per unit, 1=average



Note: Firewood includes also wood waste.
Source: Author calculations using UNFCCC, Eurostat, EC Weekly Oil Bulletin.

30. Fuel *prices* and the specific composition of fuel consumption are additional factors that drive distributional outcomes. Population groups that use higher emitting “dirtier” fuels will see a greater absolute impact of carbon taxes on prices. The relative price change depends also on initial prices, with cheaper fuels affected more strongly by a given amount of carbon tax per unit. As is commonly the case, motor fuels in Lithuania are more expensive (due to higher taxation) than domestic fuels (Figure 3, Panel A). As a result, the energy usage and emissions per unit of fuel expenditure are higher for domestic fuels (which

account for a large share of spending for low-income people) than for motor fuels (which are mostly consumed by higher-income groups). Domestic fuels include high shares of solid fuels (coal, coke, firewood), which have much higher emission than liquid fuel. Emission factors are lower for natural gas (Figure 3, Panel B).

31. Like the direct effects from fuel expenditure, the distribution of the indirect burden from carbon taxes on everything else is also driven by a range of factors, and their net effect is difficult to anticipate. Budget shares for goods other than fuel can be comparatively "flat", with similar shares of total expenditures across income groups. But since poorer household save less, they spend a higher proportion of their income than better-off households. A relatively flat indirect impact of carbon taxes across households with low and high levels of total *spending* can therefore translate into a distributionally regressive impact across the *income* spectrum (with carbon tax burdens making up a larger share of income for low-income groups). Figure 2 illustrates this for electricity, which is a particularly sizeable category of non-fuel expenditure.

Budget shares and households' responses to price changes in comparative perspective

32. Along with budget shares, behavioural responses to carbon taxes are central determinants of both distributional results and CO_2 emission reductions. This paper accounts for behavioural changes by estimating a full demand system, including budget elasticities (expenditure changes for a specific good category in response to variations in total expenditure), a broad set of (own- and cross-) price elasticities (expenditure changes for a specific good category in response to price variation), and allowing for different elasticities across expenditure items and household types, see Annex A3. Results for Lithuania are presented below, along with comparisons against existing estimates for other European countries. Across all countries, estimates show households' responsiveness based on preferences that are implicit in the budget surveys that were available for this analysis (2015). The five countries (Finland, Hungary, Ireland, Luxembourg, Portugal) were chosen as relevant data and consistent estimates are available as part of recent related work (see source of Figure 4).

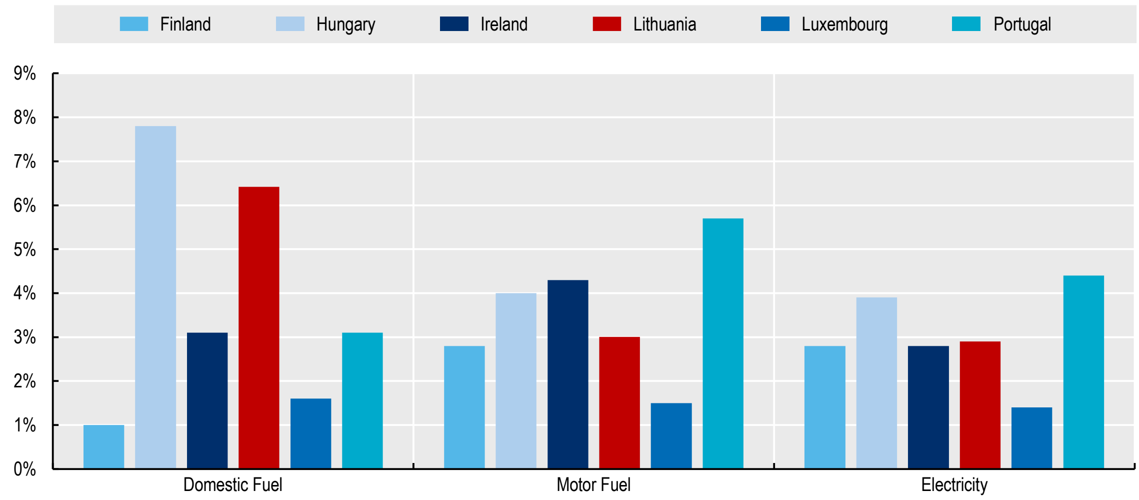
33. Budget shares for domestic fuels are higher in Lithuania (ca. 6.4%) than in four of the comparator countries and slightly lower than in Hungary (Figure 4, Panel A). Budget shares for electricity and motor fuel vary less across countries, and Lithuania's share is around 3% in both these categories, which is close to the country average. The Lithuanian shares for motor fuels are however lower than in most countries, except Finland and Luxembourg, where incomes are substantially higher. This is in part explained by very low usage at the bottom of the distribution. Overall patterns broadly resemble Hungary's though spending on all three types of energy is somewhat lower in Lithuania.

34. Published estimates of *price elasticities* of the demand of fuel vary markedly across countries and studies (Box 2). In a comparison of results using a cross-nationally consistent estimation method, Lithuania's price elasticities are in a plausible range (Figure 4, Panel B). Households in Lithuania are comparatively responsive to changes in the price of domestic fuel, though the elasticity still ranks mid-way between the other countries. Consumption of motor fuel is more responsive to price changes than domestic fuel, and electricity consumption somewhat less so. For both electricity and motor fuel, elasticities are lower than in Hungary, but higher than in the other countries.

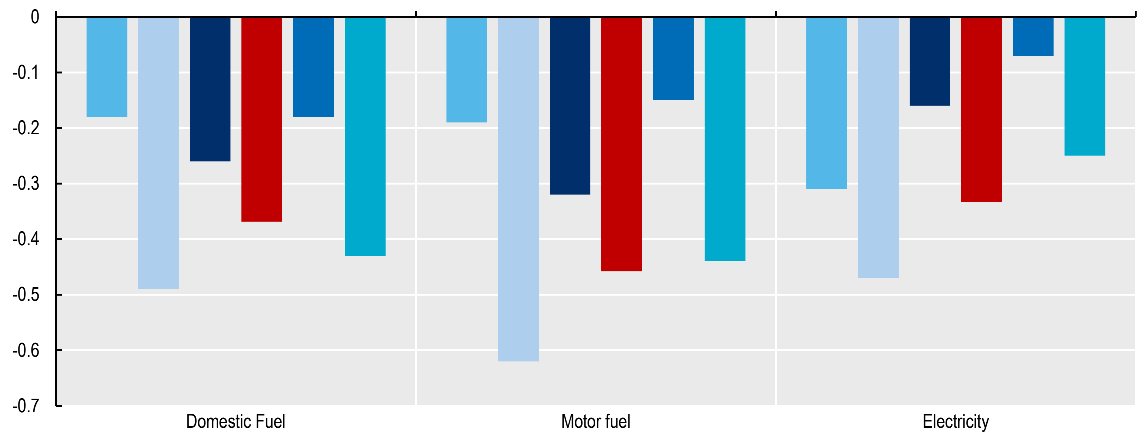
35. Lithuania's *budget elasticities* for domestic fuels and electricity rank mid-way between the five other countries (Figure 4, Panel C). Consistent with the large observed differences in expenditure shares for motor fuels between the bottom and top end of the income distribution, the estimated budget elasticity for motor fuel is significantly higher than for domestic fuel and electricity.

Figure 4. Average budget shares and behavioural response: Lithuania and other countries

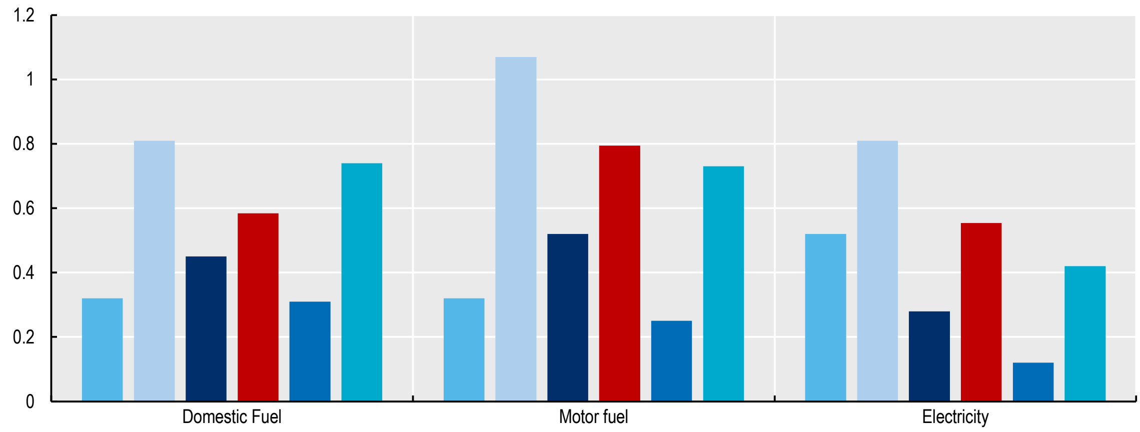
A. Budget shares, % of total household expenditure



B. Price elasticity (% change in consumption for a 1% price increase)



C. Budget elasticity (% change in consumption for a 1% increase in total household budget)



Note: Annex A3 provides details on the method used for estimating a demand system, including price and cross-price elasticities, and budget elasticities. Domestic fuel includes expenditure on gas (natural gas and town gas), liquified hydrocarbons, liquid fuels, heat energy, coal and other solid fuels. Motor fuels includes expenditure on diesel and petrol for transportation.
Source: Own calculations and (Sologon et al., 2022[18]).

Box 2. Responsiveness of fuel demand to price changes: estimates and driving factors

Published estimates of price elasticities of the demand of fuel vary markedly across studies, as demonstrated by available meta-analyses (Labandeira, Labeaga and López-Otero, 2017[84]; Dahl, 2012[85]). These results therefore provide limited direct guidance for individual country studies, and any particular estimate is unlikely to apply straightforwardly in the context and scope of the present paper.

Indeed, the wide interval of estimates is not only related to different empirical methods but also to a range of country characteristics (e.g., fuel demand would typically be more elastic in densely populated areas and those that are well-served by public transport, than in rural communities or suburbs). Time horizons also play an important role (longer-run elasticities tend to be higher as consumption falls not only due to reduced travel, but also due to substitution of more fuel-efficient vehicles for less economic ones).

It is common for studies (including the present one) to focus on short-run elasticities and to broadly assume that the responsiveness to price changes is independent of the initial price level. Elasticities are, however, likely to differ over time. For instance, when changing behaviour requires major adjustments in personal housing and transport assets, an individual may reduce consumption in the short run, while medium-term reaction may incorporate more substitution. There are also both theoretical and empirical reasons for expecting demand to become more responsive as prices go up (Hössinger et al., 2017[86]). In the present paper, this is to some extent captured indirectly via the inclusion of the budget share within the formula to produce price elasticities. Nevertheless, as prices are both on a longer-term upwards path and exceptionally volatile at present, the associated patterns of behavioural responses are of particular interest in the context of climate change, and should be a focus of future work (see Section 5).

Distribution of carbon tax burdens across income groups

36. The overall incidence of the carbon tax is shaped by *(i)* the distributional patterns of households' fuel expenditures, *(ii)* the indirect effects of a 60 EUR carbon tax on the cost of other goods, based on emissions released during production in different parts of the value chain, and *(iii)* households' behavioural responses to the resulting price changes.

37. To aid transparency, it is useful to first consider results without behavioural responses (Figure 5). On this basis, the carbon-tax burden on domestic fuels (ca. +1.3% of household income on average across all income groups) is much higher than for motor fuels (+0.3% on average). This reflects the higher expenditure on heating, as well as the higher emissions per unit of domestic fuel. In line with fuel expenditure profiles, the *direct* carbon tax burden for domestic fuels is concentrated in the bottom half (regressive), while carbon taxes on motor fuels are progressive. The direct burden on households from overall fuel expenditures is regressive, though burdens are higher for deciles 2-5 than for the bottom 10%.

38. At close to +2.0% of household income on average, the costs from *indirect* emissions related to the production of other goods and services are higher than the direct effects (1.6% on average). This highlights the quantitative importance of accounting for all consumption categories, and a careful Input-Output analysis. The scale of the indirect effect is partly driven by spending on electricity, and the carbon intensity of electricity generation. Although the lowest-income households spend greater shares of total

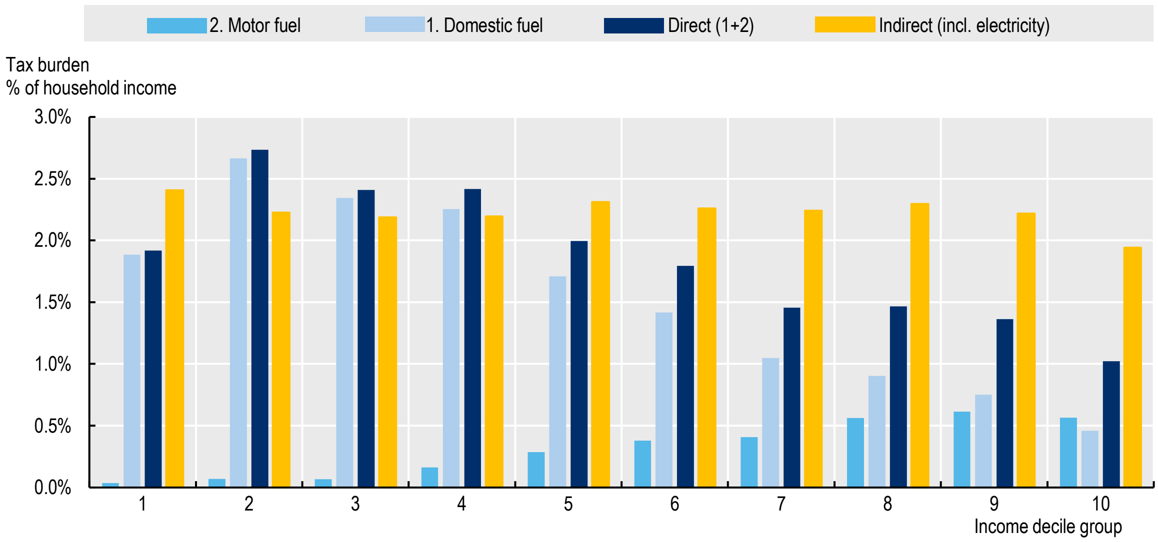
expenditure on electricity than higher-income groups (Figure 2), the carbon content of electricity is lower than for other energy sources, and overall indirect effects are essentially flat as a share of income.[7]

39. As households respond to the incentives from higher prices and rebalance expenditures towards less carbon intensive products, behavioural adjustments reduce effective tax burdens. Estimates indicate a reduction by up to 16% (Figure 6).[8] Consumption responses lead to a bigger reduction in carbon-tax burdens in the bottom half of the distribution, as prices of cheaper goods (and dirtier fuels) are more strongly affected by a given carbon tax than expenditure categories with significant shares of more expensive and luxury products. Reductions are, however, smaller for the poorest 10%, who are likely to have fewer margins for adjusting consumption without cutting into essentials (compare distance between the results with and without behavioural response).

40. Overall losses for households are remarkably flat, with around 4% of income for the bottom half of the distribution, and 3.5% for the top half. The largest burdens are found for decile 2, and the smallest for decile 10. The "flatness" is arguably a striking finding given the granularity of the analysis, accounting for 56 sectors, 35 expenditure categories, and the full heterogeneity of consumption patterns found in the HBS micro-data. As discussed above, multiple drivers and country idiosyncrasies shape this result for Lithuania. There is no a-priori reason to expect it to apply more generally and carry over to other country settings.

Figure 5. Incidence of a EUR 60/t carbon tax, without behavioural response

Share of household income



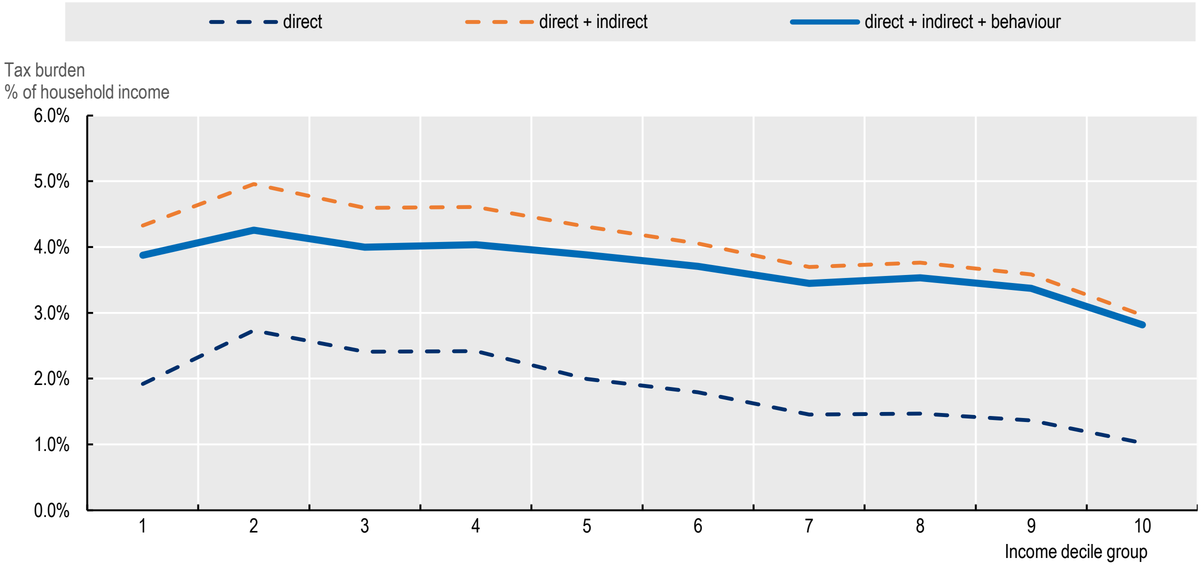
Source: Authors' calculations using data on household expenditure, emission levels and industry inputs and outputs. See main text for details.

[7] As for all goods except fuel, carbon tax payments for electricity are calculated using the WIOD input-output data, see Annex A1. This computes CO_2 emissions per euro for 24 expenditure categories and apply the 60 Euro/tonne tax accordingly. The WIOD accounts for Lithuania's use of nuclear, gas, coal and renewable in 2014. The carbon intensity of electricity generation changed since then, but by less than 10% (227 gCO_2/kwh in 2014, 209 gCO_2/kwh in 2021).

[8] It is worth noting that the reduction of carbon-tax burdens in Figure 6 exceeds the adjustment one would obtain through a straight price elasticity. The reason is an assumption of unchanged savings; in the context of a price increase, unchanged savings imply a fall in consumption over and above the pure price elasticity. The suitability of this assumption can be questioned, especially in the very short term, where dissaving can provide a cushioning mechanism for households confronted with rising prices. The present version assumes unchanged savings, as the methodology cannot reliably incorporate inter-temporal decision making in relation to savings.

Figure 6. Incidence of a EUR 60/t carbon tax, with and without behavioural response

Share of household income



Source: Authors' calculations using a consumption model in conjunction with data on household expenditures, emission levels, industry inputs and outputs. See main text for details.

Revenue recycling

41. The carbon tax generates revenue, which can be used to shape its overall distributive impact via revenue recycling. This section illustrates the scope for redistribution measures as part of a broader carbon-tax policy package, and analyses the resulting gains or losses for different income groups.

42. Each revenue recycling option has strengths and weaknesses (Nachtigall, Ellis and Errendal, 2022[87]). In what follows, three stylised compensation measures are considered. All three are budget-neutral and can thus be fully financed through the carbon tax. In addition to the options considered here, there are clearly many other possible uses of carbon-tax revenues, including those that do not immediately benefit households but may do so indirectly and in later periods (such as increasing investment or paying off public debt).

43. **Option (1)** is a stylised lump-sum transfer, paid at the same individual rate to all residents (same rate for adults and children). Similar to a universal basic income, a lump-sum payment is often less redistributive than established social transfers. When conceived as a standalone benefit that replaces other transfers, a basic income is difficult to finance without a substantial tax increase (Browne and Immervoll, 2017[88]). However, in the context of a carbon tax, lump-sum compensation can be an attractive option, as it is built around a novel revenue source, and can be introduced "on top of" existing transfers, without needing to substitute for them. It is also simple to communicate and, as everyone receives a recurring payment, it may act as a signal that the carbon tax aims to alleviate climate change, without creating an additional overall burden for households. The universal lump-sum payment to everybody is indeed sometimes argued to be the optimal revenue recycling option (Klenert et al., 2018[44]).

44. Alternatively, carbon-tax revenues can be used to compensate households more selectively, e.g. by adapting/expanding existing transfers or introducing new targeted support payments. The specific reform considered here is a proportional increase of all social benefits **(Option 2)**. A uniform increase can be attractive if existing social transfers are seen as a suitable vehicle for targeting support to those in need.

The approach has similarities to strategies that seek to alleviate the impact of price increases by indexing benefits for inflation (OECD, 2022[17]).

45. **Option (3)** is a cut in labour taxes (all income taxes and workers' social insurance contributions). Like option (2), taxes are reduced by the same proportion for everybody. Packaged with a carbon tax, this type of scenario is commonly discussed under the heading of "environmental tax reform" (Metcalf, 1999[89]). A common argument for environmental tax reforms is that they may create a "double dividend", by simultaneously improving environmental and economic conditions, through lowering harmful emissions and distortionary labour taxation (Pearce, 1991[4]; Ekins et al., 2011[90]; Antosiewicz et al., 2022[91])

For each option, Figure 7 reports different measures of gains/losses by income group:

- Average gain or loss of a carbon tax with revenue recycling;
- Average gain or loss after accounting for households' consumption responses to the carbon-tax package (including revenue recycling);
- Share of individuals with net gains.

46. In addition to income, further distributional dimensions can be equally important as patterns by income level (e.g., differences by age, region, gender or labour-market status). These can be explored in future work.

47. Two types of behavioural response enter the results. First, and similar to the earlier analysis, the price response stems from the price change triggered by the carbon tax. Second, the income change from revenue recycling induces a change in expenditures on different items, in line with the estimated budget elasticities.[9]

48. Figure 7, Panel A first shows losses without any compensating transfers as a baseline, to facilitate assessing the impact of revenue recycling. The results are the same as those shown earlier in Figure 6,and can be interpreted as a scenario where the government does not spend the carbon-tax revenue. The overall revenue from the carbon tax amounts to around 1.35% of GDP, after accounting for consumers' responses to higher prices. The exact scale of these resources will depend on the implementation details of the carbon tax, and will be smaller if it is not applied uniformly (see Section 3). It is clear, however that the revenues are sizeable and provide the government with considerable scope to cushion losses and shape the distributional profile as part of a broader policy package. In addition, knock-on effects on other taxes, such as VAT, can create significant additional revenue effects, which are not currently included in the estimates.[10]

49. When all carbon-tax revenues are channelled back to individuals via a lump-sum transfer (Figure 7, Panel B), most people are better off than without the carbon-tax package. Revenues are sufficient for financing a per-capita lump-sum of 22 Euros per month. All households in the bottom decile gain, and at least half do throughout deciles 1 to 7. Low-income households pay smaller absolute amounts in carbon tax than better-off, because they spend less. With everybody receiving the same flat-rate payment, the overall carbon-tax package creates a sizeable income boost at the very bottom. As a percentage of household income, gains then quickly decline as one moves up the income spectrum.

50. Average gains do not turn negative until the 8th decile (i.e., well above the income of the "median voter"). Even for high-income earners in the top decile, the lump-sum payment cuts the average net carbon-tax burdens in half (compare Panels A and B). The lump-sum scenario examined here is very simple and its distributional properties could be further tailored, e.g. by making it taxable. Instead of a uniform per-

[9] The expenditure changes for each consumption category are calculated assuming that households spend the entire additional income that they receive from revenue recycling, i.e. savings remain unchanged, in line with footnote 8.

[10] For illustration purposes, it was decided to limit revenue recycling to the carbon tax itself, also because additional revenues from other taxes may be more difficult to earmark in practice.

capita amount for all, the compensation could also feature differentiation by age, or provide supplements to those with higher energy needs, see e.g., the “climate bonus” recently introduced in Austria (Budgetdienst, 2022[56]).

51. A pro-rata increase of all existing social transfers (Figure 7, Panel C) redistributes the entire carbon-tax revenue to benefit recipients only. Because carbon taxes are paid by everybody and then distributed to a smaller group, average gains would be large for recipients of existing benefits. Lithuania currently spends about 9.2% of GDP on (cash) social benefits, including pensions. Carbon-tax revenues are therefore sufficient to finance a benefit increase of around 16%, well in excess of the adjustment that would result from straight inflation indexing of social transfers (below 5%, see annex Figure A.1). The gains are spread across fewer beneficiaries than in the lump-sum scenario, and gains are more concentrated among the bottom deciles, which comprise most benefit recipients.

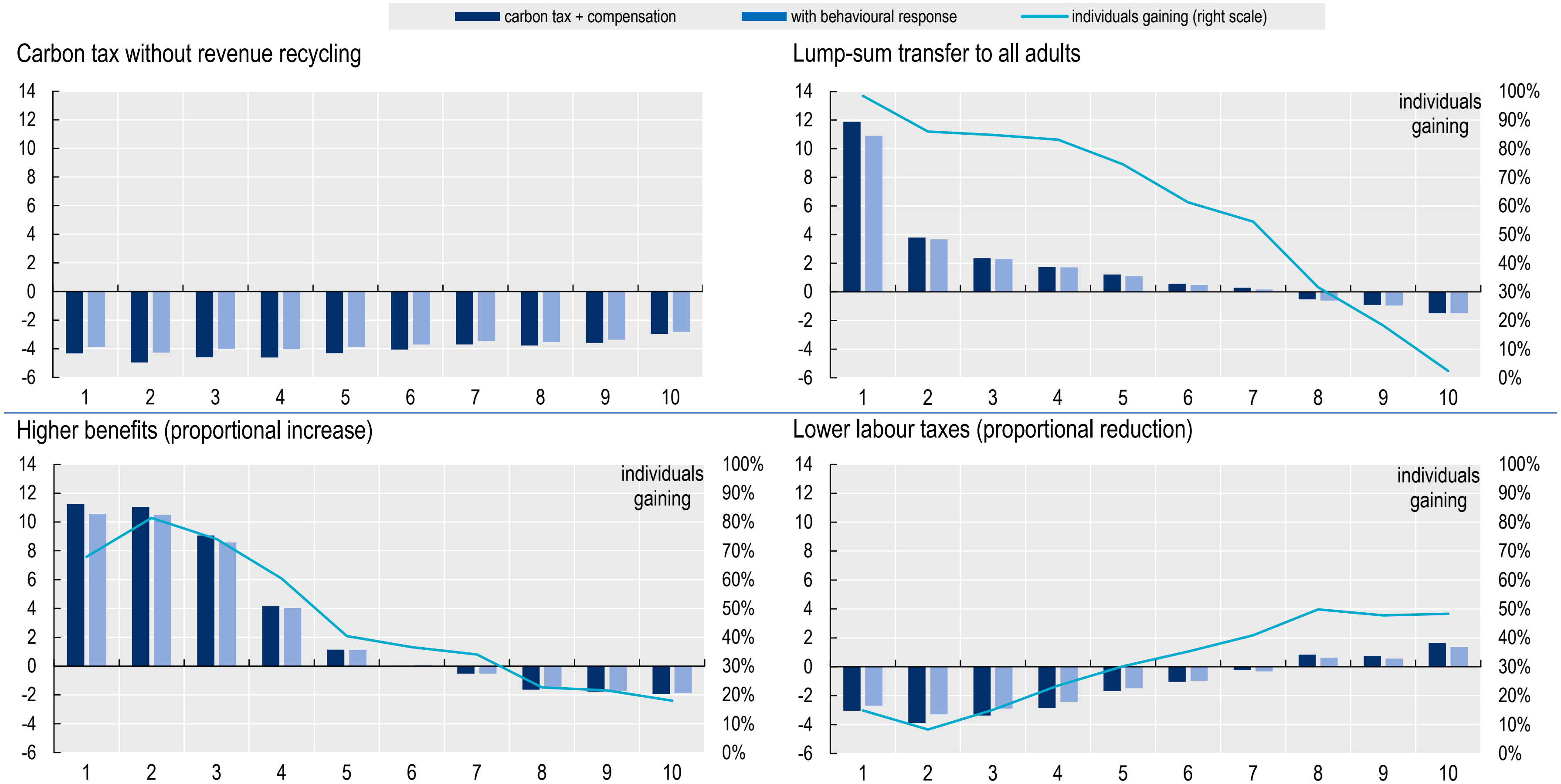
52. Unlike in the lump-sum scenario, not all poor households are better off. This reflects coverage gaps in the existing benefit system and, in particular, the commonly high degree of non-takeup of means-tested benefits. Both these factors explain the substantial share (>30%) of net losers in the bottom decile. Furthermore, and also in contrast to the lump-sum compensation, even the highest-income group includes some people (ca. 18%) who are better-off than without a carbon tax package. While there are fewer recipients of social benefits among high-income households, benefit entitlements (e.g. from pensions) among some of them are sufficiently large to ensure that a pro-rata increase outweighs their carbon-tax burden, resulting in a net gain. Across all middle and upper-income deciles, however, fewer than half gain from such a carbon-tax package. This is relevant when considering political support for such a policy. Without accompanying measures, significantly higher benefits for lower-income earners may also weaken work incentives.

53. Lowering taxes on labour (Figure 7, Panel D) has the opposite effect of a benefit increase, with net gainers concentrated at the top of the distribution. Lower labour taxes can strengthen work incentives (the “double dividend” argument). Tax reductions provide support for low-income groups, by easing income tax burdens for some of them, and reducing losses from the carbon tax itself (compare Panels A and D). But more than 85% of the poorest third of Lithuania’s population would be worse off with such a carbon-tax package. . By contrast, close to half of the top 30% would gain from the reform package. Even for high-income groups, gains are modest in percentage terms, however (<2%). Compared with the other two revenue-recycling scenarios, the patterns of gains and losses for the labour tax reduction therefore appear less favourable for building strong voter support.

54. From a broader inclusiveness point of view, the carbon tax combined with additional social transfers reduces inequality. The redistributive effect is stronger for the proportional increase of existing benefits (a reduction by 2 Gini points) than for the lump-sum transfer (a reduction by 1 point). The package with lower labour taxes is regressive (an increase by 0.5 points), though without accounting for possible positive employment effects.

Figure 7. Carbon tax package with revenue recycling

Different scenarios for revenue recycling: Gains and losses by income group (deciles)



Source: Authors' calculations using a consumption and tax-benefit model, in conjunction with data on household expenditure, emission levels and industry inputs and outputs. See main text for details.

Environmental Impact

55. Greenhouse gas (GHG) emissions in Lithuania declined steeply between 1990 and 2000 but have since stabilised at around 20 $MtCO_2eq$, which accounted for around 0.55% of total EU emissions in 2019 (Jensen, 2021[92]), and around 0.04% of global emissions (Global Carbon Project, 2021[93]). Although emissions per capita are increasing, they remain below the OECD average. Emissions have largely decoupled from economic growth, with emissions intensity per unit of GDP decreasingly steadily since 2005 (OECD, 2021[94]). Transport, agriculture and industry make up two thirds of Lithuanian GHG emissions. The transport sector in particular is the biggest and fastest growing contributor to total emissions, accounting for over 30% of emissions in 2019, up from less than 20% in 2005 (OECD, 2021[94]).

56. The estimated adjustments of household consumption, in response to the carbon tax and revenue recycling, can be translated into equivalent changes of CO_2 emissions. This approach applies the same input-output model that was used to trace carbon emissions, and the resulting carbon tax, from different stages of production to consumer goods. Reversing this approach gives emission reductions from re-balanced final household consumption of around 9.5% as a result of price changes alone. This estimate relates to emissions released in all parts of the value chain, including foreign production of goods and inputs that are imported into Lithuania. But it is limited to the direct consequences of changing final household consumption.[11]

57. Revenue recycling increases household income and spending in line with estimated budget elasticities and, hence, lowers emission reductions somewhat. Altogether, and depending on the revenue recycling scenario, overall emission reductions are estimated to range between 7 and 8% for carbon-tax policy packages that redistribute tax receipts back to households.[12]

58. The policy implications from these findings are twofold. First, at current consumer preferences and the tax rates currently considered, emission reductions are relatively modest, even for a comprehensive carbon levy that does exempt specific industries or products. At existing or proposed levels, carbon taxes alone are not sufficient for meeting national and international climate commitments.

59. Second, the type of revenue recycling strongly shapes the distributional outcome of a carbon-tax package, but the choice makes only a very modest difference in terms of environmental objectives. This suggests that, in the design of compensating transfers to households, there is no major immediate trade-off between achieving social and environmental objectives.

60. However, the sizeable share of gainers in some of the revenue recycling scenarios implies that it may be possible to limit direct compensation measures to less than the total carbon tax revenue. This could allow financing other forms of government expenditures. Some authors have explored combining transfers with scaling back other distortionary taxes, in line with the “double dividend” arguments (García-Muros, Morris and Paltsev, 2022[95]). An alternative would be scaling up of programmes that

[11] Noting that the model keeps the savings rate constant (see footnote 8). Using a pure price elasticity (with overall savings allowed to respond to prices, and expenditure shares increasing when prices go up) would result in a smaller reduction in emissions, though differences are likely to be minor (perhaps less than 0.5 percentage points).

[12] It is therefore lower than recent estimates of more encompassing emission reductions from higher carbon prices (D’Arcangelo et al., Forthcoming[124]). Those estimates point to a reduction of 3.7% per 10 EUR increase on average across countries. Their scope is quite different, however, as they rely on a large cross-country dataset, look at long-term reductions for the economy as a whole, notably including technological adjustments on the production side. They also consider carbon taxes alongside other forms of carbon pricing, and do not account for revenue recycling.

support and accelerate a green transition. This includes measures that tackle households' underinvestment in energy efficiency, e.g., through subsidies for home insulation or installations such as heat pumps (D'Arcangelo et al., 2022[96]), or that facilitate a reallocation of jobs towards less carbon-intensive production (unemployment insurance and active labour-market policies).

6 Who pays for higher carbon prices? Knowledge gaps and a research agenda

61. There is broad consensus that setting a price for carbon is a necessary part of urgent strategies to avert catastrophic climate change. Carbon pricing is economically efficient, as it promotes emission reductions in a cost-effective way that leverages, rather than hinders, entrepreneurship, markets and innovation. At the same time, there is a view that public support for carbon taxes and other forms of carbon prices is limited, largely because of perceived welfare losses and distributional concerns. Yet, granular evidence on the distributional effects of carbon pricing is either not readily available or remains difficult to compare across countries and policy settings. The current period of exceptionally high and volatile energy prices highlights the need for careful distributional analyses that support policy design, as well as communication on the benefits and costs of a green transition.

62. This paper illustrates an approach for assessing the impact of carbon taxes on household budgets, and considers the effects of possible compensatory government transfers that can be financed through carbon-tax revenues. It relies on a rich set of available data and policy models and combines them in a way that is informative for mapping the gains and losses at the household level in the short, as countries seek to transition to a low-carbon economy. A particular focus is on linking information on carbon emissions and consumption patterns (which is needed for quantifying carbon-tax burdens), with income data and tax-transfer policy models (needed for assessing government policies that aim to cushion or offset carbon-tax burdens).

63. Results, using data for Lithuania, are intended as input into the debate of programme designs and trade-offs in a specific policy and country context. In addition, the discussion of the approach, its limitations and its empirical application point to conceptual and data-related opportunities and challenges, and suggest several priorities for the broader research agenda on this topic:[13]

1. **Application in further country contexts.** The data sources and tools were chosen for their potential to support comparative analyses across countries. The input-output data, the CO_2 emission vector for different industry outputs, the household budget survey and the EUROMOD tax-benefit model all cover a significant number of OECD and non-OECD countries. Similar or equivalent data and tools are available for additional countries. Adapting the approach to other country contexts will often be straightforward and can inform national policy debates. Comparative assessments will also deepen the understanding of the drivers of gains and losses, of resulting policy challenges and of the political economy of carbon pricing.

[13] Beyond the points listed below, there are also data quality issues, which may be best analysed and addressed in specific country contexts, see e.g. the informative discussion of HBS reporting issues in Belgium by Lévay et al. (2021[136]).

2. **Tailoring policy scenarios.** The illustration in this paper relates to a uniform carbon tax without exemptions and set at a specific level. In practice, carbon pricing schemes typically cover only a certain fraction of national emissions, and currently exclude all, or the majority, of emissions from the production of imported goods. While there are advantages to broad-based carbon pricing, available input-output data in principle allow for assessments of real-world reforms or proposals and their effects on different population groups. With future data on emissions other than CO_2, the policy scope can also be extended to additional GHG, such as methane released during food production. In addition, real-world policy packages may involve other forms of direct and indirect taxes, as well as knock-on effects, notably on VAT burdens and revenues. The simulation framework is well-suited for assessing reforms that involve multiple policy levers, and inter-linkages between them.
3. **Capturing additional heterogeneity of emissions per unit spent.** Using presently available data allows tracing CO_2 emissions using a comparatively granular breakdown by industries (e.g., 56 different categories in this paper), countries of origin (44) and household expenditure types. The result is one single emission intensity each for 24 different consumption categories, expressed in CO_2 per Euro spent. Averaging across all products in a category ignores that the relationship between CO_2 content and spending will generally not be proportional. The paper partly accounts for this by distinguishing between different fuel types, which are a particularly important driver of carbon emissions (see Section 4). Carbon content per spending unit can be expected to vary by price level for other (non-fuel) goods (e.g. budget versus luxury restaurants) but possibly less so for others (e.g. budget versus luxury holiday travel). Future work should analyse these patterns. It may also be possible to achieve greater granularity of carbon content with existing data (e.g., for housing, using proxies such as family size or region). Relatedly, and subject to the evolution of the circular economy, actual emission intensities will also be affected by the balance of spending on new versus used goods.
4. **Enriched modelling of behavioural responses.** Carbon pricing and other climate-change mitigation measures explicitly aim at altering behaviour. Yet, distributional assessments do not always account for behavioural responses. This paper estimates consumption behaviour with respect to prices and incomes, based on the preferences that are implicit in a specific cross-section of household spending data. The implementation is reasonably granular, distinguishing between 19 expenditure categories and 8 household types. However, in line with much of the existing empirical literature, demand elasticities are estimated in a linear fashion, i.e. irrespective of the initial price levels and the size of price changes. The expenditure system is designed to model responses at the intensive margin (e.g., the amount of fuel consumed), but not at the extensive margin (e.g., switching from using the car to using a bicycle). In practice, consumers may react more strongly once prices reach a certain "threshold of pain", notably because adjustments may involve costs (say, new windows, an electric bicycle or efforts to shorten commuting distance). Future modelling exercises could include behaviour at the extensive margin (perhaps drawing on the literature on the indirect taxation of tobacco). The current period of large price swings represents a valuable opportunity for studying these aspects more closely.
5. **Medium-term evolution of gains and losses.** Climate-change mitigation is a medium-term agenda and its costs and benefits will affect current and future generations. Its urgency, the political-economy implications of perceived gains and losses, and the current cost-of-living crisis, mean that evidence on short-term impacts can be critical for initiating or accelerating policy action. Beyond the immediate impact of price changes, however, adjustments in all parts of the economy will keep altering the distribution of carbon-tax burdens over the medium term. One way to account for these is to link the micro-modelling illustrated in this paper, with CGE-

type macro models that quantify likely changes of key prices and volumes.[14] This would also allow accounting for variations in the economic incidence of carbon taxes on consumers and producers.

6. **Timeliness.** A more urgent priority is to move to input data sources that are as timely as possible. This paper uses available input-output data from 2014 and household budget surveys from 2015, combining them with the most recent information on CO_2 emissions and product prices. Recent price changes have been extraordinarily sizeable, however, and will have affected both households' consumption decisions, and the technologies employed by producers. The forthcoming 2020 wave of the European household budget survey will be strongly impacted by the COVID crisis and associated lock-downs, and it may be therefore even less representative of contemporary consumption patterns than earlier data. A number of European and non-European countries, already collect household budget surveys at frequent intervals, e.g., annually.[15] Where collections at short intervals are considered too costly, there may be opportunities to "nowcast" key moments of these data. Nowcasting could rely on modelling and/or build on information from statistical agencies, such as in Canada, France and United Kingdom, who have experience with real-time updating of CPI expenditure weights (OECD, 2021[97]).
7. **Encompassing distributional assessments.** Public debates about the distributional consequences of carbon taxes frequently focus on differences by income level, and this is also the focus of the present paper. Additional distributional aspects may be of equal interest. Indeed, studies sometimes document a sizeable heterogeneity of effects within income groups (Cronin, Fullerton and Sexton, 2019[98]; Budgetdienst, 2022[56]), and this is also reflected in this paper's findings on the shares of gainers/losers in a given decile. Examining the co-variates of these gains and losses is of interest both from a welfare point of view, and for political-economy reasons (Young-Brun, 2022[99]). As this paper's approach incorporates the full heterogeneity represented in household microdata, it enables analyses of differences by generation/age, region, type of housing, family type, and many other individual or household characteristics. A full assessment of welfare losses or gains should also go beyond changes in income or expenditure. Behavioural adjustments involve costs, and the micro-perspective adopted in this paper provides the necessary ingredients for quantifying them in an encompassing welfare analysis using metrics such as compensating variation.
8. **A knowledge base, and community of practice.** There are numerous measurement and methodological choices that can make a quantitative or qualitative difference for distributional assessments of carbon pricing. Different approaches can be appropriate in different contexts, and some choices can be dictated by data availability. There are, however, benefits to establishing a set of baseline data and methods as a public good for the research and policy community. Building on existing data sources, such as those used in this paper, a knowledge base and/or "algo bank" could facilitate necessary linkages between industry, household and environmental data, on one hand, and models of household behaviour and tax-benefit policies on the other. A set of baseline methods would promote replicability, improve transparency, speed up the production of distributional assessments when they are needed, and may facilitate the dissemination of results. The knowledge base could be complemented by a community of practice, which would establish a platform among exchange for researchers, policy analysts and practitioners, and ensure that the information and methods that make up the knowledge base remain state-of-the art.

[14] See the related approach adopted by Vandyck et al. (2021[138]).

[15] E.g., Czech Republic, Denmark, Germany, France, Italy, Japan, Mexico, Spain, United Kingdom, United States, see Causa et al. (2022[137]).

The research agenda for distributional assessments is also closely linked to the broader evolving evidence on the economic impact of climate change, and of policies to avert it. A key question concerns the counterfactual that is adopted in distributional studies. While the status quo can be a natural starting point, any losses also need to be compared to the cost of *inaction* or, vice versa, the benefits of mitigation that are the very rationale for climate-change mitigation (Tovar Reaños and Lynch, 2022[100]). The scale of economic damages from climate change remains uncertain (Auffhammer, 2018[101]; Howard and Sterner, 2022[102]). They are, however, by definition of the same order of magnitude as carbon prices that internalise the negative externalities of greenhouse-gas emissions.

Annex A. Modelling framework and its implementation

A1. Input-Output analysis

Modelling the level of CO_2 emissions from household consumption requires economy-wide data that capture carbon emissions by sector, and production linkages between sectors.

Multi-region input-output (MRIO) tables extend the Input-Output (IO) methodology introduced by (Leontieff, 1951[103]) by adding linkages between regions, which can be especially important for small, open economies and in the European context of high degrees of integration in terms of production and trade. An extensive treatment of IO analysis is provided by (Miller and Blair, 2009[104]). Briefly, MRIO datasets consist of a matrix mapping the monetary flows between *m* sectors and *n* regions, $Z \in \mathbb{R}^{(m\cdot n)(m\cdot n)}$, with single entries $z_{s1,r1}^{s2,r2}$ representing the monetary flows from sector 1 in region 1 into sector 2 in region 2, and a final demand vector $Y \in \mathbb{R}^{(m\cdot n)(m\cdot n)}$. In a *m* sector economy, the final demand for sector *i* in region 1 is denoted by f_{i1} and sector *i*'s output in region 1 is x_{i1}. Intermediate inputs from sector 1 in region 1 into sector 2 in region 2 are denoted by $z_{s1,r1}^{s2,r2}$, and $a_{s1,r1}^{s2,r2}$ is the input coefficient from sector 1 in region 1 into sector 2 in region 1, given by $a_{s1,r1}^{s2,r2} = z_{s1,r1}^{s2,r2}/o_{s2,r2}$, where $o_{s2,r2} = \sum_s \left(\sum_r z_{s1,r1}^{s,r} + \sum_r z_{s2,r2}^{s,r}\right)$.

The technology matrix, $A \in \mathbb{R}^{(m\cdot n)(m\cdot n)}$, contains all input coefficients for all sectors in all regions and enables the calculation of the Leontief inverse matrix, $L = (I - A)^{-1}$, which gives the economy-wide input requirements of output *x*, $x = \mathrm{f}(I - A)^{-1}$. In other words, *A* gives the input needed by a sector in one region from every other sector in all regions to produce one (monetary) unit of output. This can be written as $x = f\,(I + A + A^2 + \cdots + A^n)$ and gives the output per sector as a component of final demand *f*.

Environmentally extended MRIO (EE-MRIO) models link products to the indirect carbon emissions that occur in the course of production. (Kitzes, 2013[105]) provides a short introduction to EE-MRIO. Briefly, let $F \in \mathbb{R}^{(1\cdot n)}$ $F \in \mathbb{R}(1\cdot n)$ denote emissions where F_n refers to emissions produced in sector *n*. For each household, we add direct and indirect emissions to get final CO_2 emissions from household consumption:

$$F_{HH} = F_{Dir} + F_{ind}$$

Dividing *F* entry-wise by the corresponding sector's output F_{ind} gives the level of CO_2 emissions per monetary unit of the sector's output vector. Direct emissions F_{dir} are released through households' consumption of motor and domestic fuels. They are computed for one euro worth of fuels using data from Eurostat and the European Commission Weekly Oil Bulletin.[16]

[16] Direct emissions are assessed using the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006[132]). With the exception of natural gas, all other domestic fuel is assumed to have the same emission factors as heating oil, providing us with a lower bound estimate. CO_2 emissions per euro were calculated using 2015 fuel prices adjusted for inflation at the CPI-relevant fuel price index

A2. Matching input-output data with household expenditures

To approximate the carbon footprint from households' consumption, it is necessary to match WIOD with information on household expenditure as reported in HBS. HBS data commonly reports households' consumption expenditure across different consumption purposes (COICOP). WIOD tables report household final consumption expenditure in industry outputs terms (NACE rev 2). The integration of HBS data into multi-sectoral models is described in Mongelli et al. (2010[106]) and Cazcarro et al. (2020[107]). Matching information from WIOD tables to HBS data involves translating goods by expenditure purpose into industry outputs using a bridging matrix, which maps the use of a product to satisfy a consumption purpose, so that the i^{th} element of matrix $B = [b_{ij}]$ represents the use share of industry product *j* for consumption purpose *i*. As COICOP categories from HBS do not correspond directly to NACE sectors as recorded in WIOD, the matching procedure involves a crosswalk from COICOP to CPA (Classification of products by activity) to NACE. Our approach consists of four steps:

1. Transform COICOP to CPA ;
2. Match budget shares to CPA categories by aggregating COICOP categories into budget shares and calculating the weighted sum of CPA contributions to budget shares;
3. Match CPA categories to WIOD using national supply tables that link CPA inputs to each industry output; and
4. Assign the relative contribution of each sector in the country to the appropriate consumption good / budget share.

Step 1 calculates the contribution of each CPA category to each COICOP category, using a bridging matrix (Cai and Vandyck, 2020[108]). We group COICOP categories into expenditure headings, as commonly done in expenditure modelling (Deaton and Muellbauer, 1980[109]). Step 2 constructs CPA contributions to household expenditure categories. We construct a matrix $C \in \mathbb{R}^{(p)(b)}$, $C \in \mathbb{R}(p)\cdot(b)$ for the country, where p is the number of CPA categories and b is the number of budget shares, and single entries represent the contribution of a CPA category p to one monetary unit of consumption in expenditure category b. Step 3 matches CPA categories to WIOD sectors (in ISCI Rev. 4), using the fixed product sales structure assumption (Model D, Box 12.3 in UN, 2018) and the 2014 national supply tables published on the WIOD website.[17] Finally, step 4 constructs a matrix B, $B \in \mathbb{R}^{(b)(m \cdot n)}$, where b is the number of budget shares, and $(m \cdot n)$ contains the contribution of each WIOD sector's output in country m to a budget share, i.e. the composition of any expenditure category in terms of WIOD sector outputs. The procedure is straightforward when expenditure categories match exactly into one WIOD sector. Where CPA categories in expenditure groups b match to s WIOD, vector b of matrix B will contain $(s \text{ x } m)$ non-zero entries, one for each contributing sector and country.

A3. Consumption model: Behavioural responses to price changes

Modelling households' behavioural response to price changes requires a demand system that captures the relationship between prices, incomes and consumption. The estimates of behavioural adjustments,

to bring it to 2022 values. When prices go up, emissions per euro of consumption go down if volume remains constant.

[17] Where more than 60% of products in country A are imported, we swap the column of country A (industry input to CPA product) for the column of the country with the highest contribution to household final demand in country A. For example, the "Basic Metals" industry in Lithuania contributes only approximately 11,7% of industry output consumed. China supplies the largest part of any one country. We thus use the column for "Basic Metals" from the China supply table, which is the same as assuming that all "Basic Metals" consumed in Lithuania are produced using the China's input mix in that industry.

and the resulting distributional impacts, are those under current technologies and incentives once consumers had a chance to respond to the prices. For example, a consumer may not be able to immediately respond, e.g., because they cannot vary fuel use quickly, but in time they will be able to adjust.

We estimate a linear expenditure system (LES, Stone,1954), following the approach described in Cornwell and Creedy (1997[66]) and applied recently by Sologon et al. (2022[18]). Powell (1974) provides an extensive discussion of linear demand systems. In the context of the available HBS data, a key advantage of this method is that it can be estimated on cross-section data, drawing on observed consumption differences between households. This is achieved by imposing prior theoretical restrictions, rather than deriving price elasticities from observed price changes. It should be noted that the approach is relatively stylised. We assume that the price elasticities derived from the estimation dataset remain constant over time. We also assume, when updating the model to account for price changes, that savings rates remain constant and that budget shares also remain constant. This is unlikely to be fully realistic when prices change as rapidly as they have done recently. But there is no straightforward and reliable way of uprating model base datasets in volatile circumstances. We therefore prefer to follow much of the literature by maintaining the underlying distributional structure of the data and wait for more recent data, instead of modifying key information on expenditure levels and patterns, through anything other than known price indices.

We estimate income and price elasticities for 19 expenditure categories i, separately for multiple household types.[18] Budget shares are defined as w_i, p_i indicates the price and C is total consumption or expenditure, so that $w_i = (p_i c_i) / C$, where $\sum i \; w_i = 1$. The LES approximates own and cross-price elasticities in terms of income elasticities (η_i), budget shares (w_i) and "Frisch" marginal utility of income parameters (ξ) (Frisch, 1959[110]). The starting point is Stone (1954[111]), who describes an estimable system of equations, with expenditure on good i a linear function of price p_i and income M, such that

$$p_i q_i = p_i \gamma_i + \beta_i \left(M - \sum_{j=1}^{n} p_j \gamma_j \right)$$

where q_i is the quantity consumed of good i, j denotes all goods other than i and γ_i is the minimum quantity consumed of good, also referred to as subsistence consumption.

The remainder of income not spent on subsistence consumption, $\left(M - \sum_{j=1}^{n} p_j \gamma_j\right)$ is referred to as supernumeracy income. A fraction of supernumeracy income, β_i, is spend on good i, so that β_i gives the share of an additional Euro in supernumeracy income that is spent on good i. Estimating the LES requires estimating Engel functions (which trace out product demand for different levels of income) for each expenditure category. We estimate the LES for multiple household types to allow for population heterogeneity in behavioural responses. Total expenditure elasticities can be derived from the equation for Engel curves (see Annex A4):

$$\eta_{ih} = 1 + \frac{dw_{ih}}{dC_h} \frac{dC_h}{w_{ih}} + 1 + \frac{\beta_i + 2\gamma_i . lnC_h}{w_{ih}}$$

[18] Single-person household (working-age and old-age), single parent, couple (working-age) with and without children, couple (at least one old-age) with and without children. Expenditure categories are Food and Non-alcoholic beverages, Alcoholic beverages, Tobacco, Clothing and footwear, Heating fuels, Electricity, Rents, Household services, Health, Private transport, Public transport, Communication, Recreation and culture, Education, Restaurants and hotels, Other goods and services, Childcare costs, Motor fuels, Durable goods.

where η_i is the budget elasticity, subscript h indicates the household type, *d* indicates a change, lnC_h is the average of the logarithm of total expenditure of households of type h, and w_{ih} is the average budget share of commodity group *i*.

The set of own- and cross-price elasticities, η_{ii} and η_{ij}, can be computed using a result established by Frisch (1959). Using the Frisch parameter, Frisch showed that the cross-price elasticities can be described as follows:

$$\eta_{ij} = -\eta_{ih} w_{jh} \frac{1 + \eta_{jh}}{\xi}$$

Own-price elasticities η_{ii} can be described as:

$$\eta_{ij} = -\eta_{ih} w_{jh} \frac{1 + \eta_{jh}}{\xi} + \frac{\eta_{ih}.\delta_{ij}}{\xi}$$

where δ_{ij} is Konneker's delta, which equals 1 if $i = j$, and 0 otherwise.

The Frisch parameter relies on external information as it is not possible to estimate it directly. (Deaton, 1974[112]) provide a review of Frisch parameters. Our sensitivity analysis shows that price elasticities are relatively stable with respect to changes in the parameter value within the commonly used range and we use a value of -1.5.

The LES method imposes two specific limitations. First, it is based on the Stone-Geary utility function, which assumes additive utility, i.e. the utility derived from the consumption of one product is independent of the consumption of other products. This excludes complementary goods and inferior goods. Powell (1974[113]) and Creedy and van de Ven (1997[67]) argue that when the LES is estimated on aggregated/grouped expenditure categories, complementary goods likely fall into the same expenditure category, making the lack of complements and inferior goods acceptable to overcome data limitations. Second, the LES assumes proportionality between income and price elasticities, large income elasticities, characterising luxury goods, are associated to large price elasticities, i.e. households respond more strongly to price changes in luxuries than necessities. Clements (2019[114]) finds empirical support for such proportionality.

A4. Linking expenditure information with other characteristics needed for distributional analysis: Imputing expenditures into EU-SILC

Estimating the distributional impacts of options for recycling carbon tax revenues requires a model that jointly considers the impact of direct and indirect taxation on household incomes which, in turn, requires information on household consumption patterns, incomes, employment situation and demographics. HBS contain information on consumption patterns, total income, and some demographic characteristics. EU-SILC contains detailed information on household incomes and labour market status of each household member. We impute expenditure into EU-SILC data using parametrically estimated Engel curves, which show the relationship between income and expenditure, and capture consumption patterns along the income distribution (Engel, 1895[115]). To make the estimation statistically feasible, we aggregate product categories as recorded in HBS into 19 broader expenditure groups (see footnote 18).

Comparing four imputation methods, Decoster et al. (2011[116]) select parametric Engel curves as a preferred approach.[19] There are two important issues when imputing expenditure data utilizing

[19] For a detailed discussion refer to Banks et al. (1997[129])

parametric Engels curves. First, disposable income definitions often differ between data sources, which can cause estimates to be biased. To alleviate this potential problem, we drop observations with negative disposable incomes and calibrate HBS household incomes to EU-SILC levels. Second, zero expenditure by some households for some commodity groups (e.g. alcohol, tobacco, education, motor fuels) may lead to significant bias in imputed expenditures, as estimated regression coefficients fail to reproduce zero values. We address this by following a two-stage approach. First, we estimate and impute the likelihood of positive expenditures using a logit model. We then rank households according to this likelihood and assign positive expenditure to the highest ranked households until the target share of households with positive expenditure is reached. Second, we estimate and impute budget shares using a conditional demand equation.[20]

Using HBS data, we first estimate total expenditure as a function of household disposable income and a set of demographic characteristics. We then use the estimated parameter to impute total expenditures into the SILC dataset, using household disposable income and selected demographic characteristics that are common to both data sources. To estimate total expenditure, we use the functional form, reflecting the common log-normal distribution of income and consumption:

$$lnx = a + \beta lny + \delta o + u$$

Where x is total consumption expenditure, o is a vector of demographic and household characteristics, and u represents an error term. We generate a normally distributed error term, reproducing the mean and variance of the error term in the HBS. Our definition of total expenditure is closest to the concept of "strictly monetary expenditure", which excludes the value of home production, debt payments, social insurance contributions and other insurance payments, in-kind benefits and value of gifts received.

To introduce consumption categories into the SILC data, we subsequently estimate Engel curves for each commodity group, using:

$$w_i = a + \beta_i lnx + \gamma lnx^2 + \delta_i o + u$$

where w_i is the budget share for commodity group *i*.

Based on these categories, we would not be able to differentiate between products falling *within* a given category. This is relevant in the context of environmental taxation. For instance, Farrell (2017[117]) shows that low-income households rely more heavily on more polluting ("dirtier") sources of energy. To address this, we subdivide energy-related expenditure categories and impute subcategories following the same procedure as described above. For home fuels, we differentiate between natural gas and other sources of heating fuel. For motor fuels, we differentiate between diesel and petrol.

A5. Data adjustments to account for population, income and price changes

Currently available HBS data are from 2015. While consumption patterns have changed since then, notably due to COVID and the cost-of-living crisis, this is the most recent information available and the one that we use as the basis for the analysis in this paper. We can, however, make adjustments to bring population totals and structure up to a more recent period, and to account for price and income changes:

2020 is the most recent year for which **population** totals are available and we use this information to account for changes as shown in Table A.1. Even though the 2015-2020 time interval is quite short, population changes for some age groups are substantial. Relevant drivers of these changes in Lithuania are ageing as well as historical and current migration patterns. Lithuania has fewer than 3 million

[20] This approach is broadly in line with (De Agostini et al., 2017[130]), who impute the likelihood of positive expenditure for some selected expenditure groupings.

residents, its population is decreasing and projected to decline by 200,000 by 2030 (OECD, 2021[118]). Historically, migration remained outward, with young people, in particular, leaving Lithuania. This trend has reversed recently, with net positive migration flows since 2019 (OECD, 2021[94]). From 2015 to 2020, most working age groups declined while most older age cohorts aged (60+) expanded, with greater relative increases for older groups. To approximate 2022 population totals, we subsequently apply twice the average annual growth rate over the 2015-2020 period. The resulting factors are used to reweight observations in the micro-data depending on their age group.

Total **inflation** over the 2015-22 period was 41%, with 2021-2022 accounting for more than half (29 percentage points) of this change (Figure A.1). Food, drink and tobacco, fuels, restaurants and transport increased at a higher rate than the mean. To put the impact of the planned carbon tax into perspective, we have shown an estimate of its impact on the average consumption basket (see Figure notes for how this was done). The impact is comparatively small; price increase observed over the 2021-2022 period were almost six times as high as the increase that would result from a carbon tax of EUR 60/tonne, using May 2022 price levels as reference.

Nominal incomes grew faster than prices between 2015 and 2021 (by 29%, a real increase of 15%). We uprate all disposable incomes by a uniform factor reflecting this average change. In reality, some of the change in disposable income will have been due to market income changes among workers, some due to employment changes and some due to changes in policy, notably those that impact on pensions and other government transfers. Although it is possible to approximately account for this granularity, it is beyond the scope of this project. More up-to-date HBS data was collected in 2020 and will be available in 2023. It is preferable to await new data rather than attempting to undertake complex, cumbersome and potentially in-transparent adjustments of the rich income distributions captured in the data. Relatedly, given the uncertainty in relation to income changes in 2022, we have chosen not to implement any income adjustments for 2021-2022.

Table A.1. Population change, Lithuania 2015-2020

	2015	2020	Change
0 – 4	150984	145590	0.964
5-9	139381	144512	1.037
10-14	134240	132642	0.988
15 – 19	166270	130926	0.787
20 – 24	201515	154360	0.766
25 – 29	195615	185376	0.948
30 – 34	178111	187446	1.052
35 – 39	176352	171793	0.974
40 - 44	197732	174252	0.881
45 - 49	207820	195470	0.941
50 - 54	225192	201308	0.894
55 - 59	213239	217731	1.021
60 - 64	170639	196708	1.153
65 - 69	145259	154540	1.064
70 - 74	131531	126480	0.962
75 - 79	120539	110410	0.916
80 - 84	85932	90739	1.056
85 - 89	47321	51559	1.090
90 - 94	14902	18624	1.250
95 - 99	1978	3364	1.701
100 +	358	639	1.250
Total	**2904910**	**2793986**	**0.962**

Source: United Nations.

Figure A.1. Change in cost of average consumption basket

Note: The impact of the EUR 60/t carbon tax on the cost of an average consumption basket is found by estimating the resulting price increases, relative to May 2022 prices, in 19 separate expenditure categories (they are listed in footnote 7). These price changes are applied to each household given their expenditure weights as per HBS, and the cost increases are then averaged across all households.

A6. Simulating options for recycling carbon-tax revenues

The direct tax and benefit payments by and to households are calculated using the EUROMOD tax-benefit microsimulation model (Sutherland, Immervoll and O'Donoghue, 1999[119]; Immervoll and O'Donoghue, 2009[25]; Sutherland and Figari, 2013[120]). EUROMOD combines a tax and benefit calculator with detailed and partly harmonised micro data, based on EU-SILC, on income, earnings, labour force participation, as well as many demographic variables. For any set of household characteristics and country, EUROMOD is able to calculate the amount of benefits the household is entitled to and the taxes it should pay.

In this application, EUROMOD is used to compute household disposable income, calculated as the sum of households market income plus cash transfers minus income taxes and social insurance contributions that are payable by household members. Incomes in the baseline scenario without revenue recycling relate to 2017 tax-benefit rules, and similar calculations are possible for later years subject to the availability of data and EUROMOD updates for that year.

As is standard in EUROMOD, calculated revenue recycling options assume full take-up of benefit and no tax evasion or income under-reporting. For population groups for whom non-takeup of benefits or tax evasion are relevant, the calculated impact of revenue recycling on household income may overstate the true impact.

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