IDB
Inter-American Development Bank

IDB WORKING PAPER SERIES Nº IDB-WP-01404

Cash transfers in the context of carbon pricing reforms in Latin America and the Caribbean

Leonard Missbach
Jan Christoph Steckel
Adrien Vogt-Schilb

Inter-American Development Bank
Climate Change and Sustainable Development Sector

November 2022

Cash transfers in the context of carbon pricing reforms in Latin America and the Caribbean

Leonard Missbach
Jan Christoph Steckel
Adrien Vogt-Schilb

November 2022

Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library
Missbach, Leonard.
Cash transfers in the context of carbon pricing reforms in Latin America and the Caribbean / Leonard Missbach, Jan Christoph Steckel, Adrien Vogt-Schilb.
p. cm. — (IDB Working Paper Series ; 1404)
Includes bibliographic references.
1. Cash transactions-Environmental aspects-Latin America. 2. Cash transactions-Environmental aspects-Caribbean Area. 3. Transfer payments-Environmental aspects-Latin America. 4. Transfer payments-Environmental aspects-Caribbean Area. 5. Climate change mitigation-Economic aspects-Latin America. 6. Climate change mitigation-Economic aspects-Caribbean Area. 7. Greenhouse gas mitigation-Economic aspects-Latin America. 8. Greenhouse gas mitigation-Economic aspects-Caribbean Area. I. Steckel, Jan C. II. Vogt-Schilb, Adrien. III. Inter-American Development Bank. Climate Change Division. IV. Title. V. Series.
IDB-WP-1404

http://www.iadb.org

OPTIONAL: Type address for correspondence

OPTIONAL: Type Authors name and eMail

Cash transfers in the context of carbon pricing reforms in Latin America and the Caribbean

Leonard Missbach, Jan Christoph Steckel, Adrien Vogt-Schilb

Abstract

One reason carbon prices are difficult to implement is that they might imply high additional costs on poor and vulnerable households. In response, studies often highlight that recycling revenues through cash transfers can render carbon pricing reforms progressive. This neglects that existing cash transfer programs target households from low-income groups often imperfectly and that impacts of a carbon price are heterogeneous within income groups. In this study we analyze the role of existing cash transfer schemes to alleviate distributional effects of carbon pricing in 16 Latin American and Caribbean countries. We find carbon pricing to be regressive in 11 countries, progressive in 5, and show that differences within income groups exceed differences between them. Beyond total household expenditures, car ownership and cooking fuel explain the variance in carbon pricing impacts. We show that households who are most affected by carbon pricing, some of them poor, do not necessarily have access to existing cash transfer programs. Governments aiming to compensate households may broaden coverage of existing cash transfer programs or consider complementing instruments such as in-kind transfers or removing existing distortionary taxes.

Keywords: Carbon Pricing; Climate Mitigation; Energy Poverty; Social Acceptability; Tax Incidence

JEL codes: C67; H23; O54; Q52; Q54

[1] Corresponding author: missbach@mcc-berlin.net; +49 30 338 5537 233; Mercator Research Institute on Global Commons and Climate Change, Torgauer Straße 12-15, 10829 Berlin, Germany; Department Economics of Climate Change, Technical University of Berlin, Berlin, Germany
[2] Mercator Research Institute on Global Commons and Climate Change, Berlin, Germany; Department Climate- and Development Economics, Brandenburg University of Technology Cottbus Senftenberg, Cottbus, Germany
[3] Inter-American Development Bank, Washington, DC, USA; avogtschilb@iadb.org

1. Introduction

Carbon pricing is often proposed as the most efficient policy instrument to reduce greenhouse gas emissions (e.g. Pigou 1920; Pearce 1991). In conjunction with other environmental taxes, the IMF estimates that an efficient carbon price could increase annual government revenues globally by almost USD 6 trillion, prevent almost 1 million air-pollution related death per year, and reduce carbon emissions by 36% (Parry et al. 2021).

Carbon pricing, where used, has been effective in reducing emissions (Leroutier 2022; Andersson 2019; Best et al. 2020) and triggering low-carbon investments (Calel 2020), but so far its impact falls short of what would be required to implement the objectives of the Paris Agreement (Rafaty et al. 2020). One reason is that carbon pricing mechanisms still suffer from limited coverage and a low nominal rate (World Bank 2021). Indeed, overcoming the political economy of high (and efficient) carbon prices can be difficult (Jenkins 2014; Vogt-Schilb and Hallegatte 2017). Notably, groups of households that expect negative effects of carbon pricing can organize effectively and block policy reforms (Olson 1965). For example, in 2018 the so-called "yellow vest movement" in France formed in response to a carbon price increase for transport fuels (Douenne and Fabre 2022); similarly, violent protests led the government of Ecuador to withdraw a formerly enacted fossil fuel subsidy reform, which would have had similar impacts on local energy prices as a price on carbon emissions (Montenegro and Ramirez-Alvarez 2022).

Governments could use complementary measures to cushion adverse impacts of carbon pricing on any group of households (Klenert et al. 2018), which may increase the political acceptability of carbon pricing and allow countries to advance social development and environmental goals in parallel (Fay et al. 2015). Recent experience suggests that implementing complementary measures for compensation can help governments succeed with fossil fuel subsidy reforms (Maestre-Andrés et al. 2019; Rentschler and Bazilian 2017). One frequently proposed option to foster the political acceptability of carbon pricing is to take advantage of cash transfer programs, because cash transfers are usually beneficial to poorer and more vulnerable households (Baranzini et al. 2017; Budolfson et al. 2021).

Many studies focus on the incidence of carbon pricing (see Ohlendorf et al. (2021) for a review). Notably, the distributional implications of carbon pricing depend centrally on how revenues would be recycled (Symons et al. 1994; Goulder 1995). One frequent approach is simulating a so-called *lump-sum cash transfer* which recycles carbon pricing revenues to households on a per capita basis (e.g., Feng et al. 2018; Garaffa et al. 2021). With lump-sum cash transfers, poorer households are usually found to be net winners of such reforms, as they receive more money from revenue recycling compared to additional carbon pricing incidence.

This study addresses two limitations of the predominant proposal to combine carbon pricing with cash transfers in the context of low- and middle-income countries. First, while lump-sum cash transfers are effective in theory and may entail several benefits for economic development (Bastagli et al. 2019), existing cash transfer programs may be imperfect instruments to channel money to households in practice: Existing cash transfer programs are imperfectly targeted (e.g., reach richer households), and suffer from imperfect coverage (e.g., do not reach all poor households) (Robles et al. 2019; Bah et al. 2019). It is therefore not clear if existing cash transfer programs can play the role in practice that lump-sum rebates play in theory (Malerba et al. 2021; Vogt-Schilb et al. 2019; Renner 2018).

Second, the public acceptability of carbon pricing might depend crucially on whether specific groups of households are heavily affected rather than on the average differences between income groups. In point of fact, beyond distributional effects between income groups, also called *vertical* effects, many studies highlight the large variability of effects *within* income groups, also called *horizontal* effects (Rausch et al. 2011; Farrell 2017; Cronin et al. 2019; Feindt et al. 2021; Fischer and Pizer 2019; Steckel et al. 2021). Large horizontal differences of carbon pricing incidence matter, because some poorer households could suffer from substantial costs, even if carbon pricing and revenue recycling would lead to progressive results on average.

Addressing such shortcomings, we investigate which households are most affected by carbon pricing and assess whether those households could receive compensation through existing governmental cash transfer programs. We consider 16 countries in Latin America and the Caribbean, a developing region that increasingly aims at contributing to international efforts to mitigate climate change (Fazekas et al. 2022), suffers from widespread economic inequality, and where all countries have established at least one cash transfer program, such as *Bolsa Familia* in Brazil, *Progresa* in Mexico, or *Juntos* in Peru (Robles et al. 2019).

We build our analysis on detailed national household surveys and input-output (IO) modelling. The data provides representative information for 547 million households including consumption expenditures and access to existing cash transfer programs. We model the carbon price incidence in each country by calculating sectoral carbon intensities from multi-regional input-output data, mapping the sectoral carbon intensities to country-specific household budget items and related expenditures. We simulate the first-order impact of carbon pricing and analyze it conjointly with information of access to governmental transfer programs. Then, we assess which household characteristics correlate with especially high carbon pricing incidences. Among others, we include total expenditures, car ownership, electricity access, cooking fuel use, and socio-demographic variables. We test their relevance for explaining variance in carbon pricing incidence using different techniques: OLS regression, regression-based inequality decomposition, and logit regression. Our results are robust to the choice of the model.

We show that, in Latin America and the Caribbean, there are discrepancies between households which are most affected by carbon pricing, those who are relatively poor, and those who are currently recipients of cash transfer programs. Poorer households are not necessarily most affected by carbon pricing: comparing impacts across expenditure quintiles, we find that carbon pricing is regressive in eleven countries but progressive in five countries. More importantly, horizontal differences (within expenditure quintiles) are substantial and exceed vertical differences (across expenditure quintiles) in all countries. In addition, carbon pricing incidences tend to be more heterogeneous among poorer households: horizontal differences are more pronounced among the poorest expenditure quintile than among the richest expenditure quintile in 13 countries. As a result, some poor households would face large impacts from carbon pricing, even if revenues were rebated as lump-sum cash transfers which would render the reform progressive on average.

Households who bear high costs from carbon pricing are not necessarily those who benefit from existing governmental transfer programs. For example, in Paraguay, as few as 5.5% of households who experience relatively high costs could receive compensation through existing cash transfers. Across countries, car ownership, the use of cooking fuels (e.g., LPG or firewood), and access to electricity predict which households would face particularly high additional costs, even after recycling revenues to households. Living in urban or rural settings, ethnicity and household size can also matter, albeit differently in different countries.

Our findings show that existing cash transfer programs would provide an imperfect measure to protect households from Latin America and the Caribbean from high costs of carbon pricing. Beyond expanding the scope of existing transfer programs, governments can consider in-kind transfers or targeted subsidies to cushion the unequal cost burden on the population. Taking country-specific characteristics into consideration could help promote efficient, yet politically acceptable environmental policy targeted to each country's circumstances.

We proceed as follows: First, we introduce the data and method that allows for our microsimulation of carbon pricing incidence at the household-level in 16 countries of Latin America and the Caribbean. Second, we analyze the determinants of heterogeneity in carbon pricing incidence, namely differences between expenditure quintiles (vertical distributional effects), differences within expenditure quintiles (horizontal distributional effects), and differences in factors beyond household expenditures. Third, we exhibit gaps between those segments of the population which would face high additional costs, and those which could be compensated through existing transfer programs. Fourth, we discuss our results before we conclude in our last section.

2. Data

For our empirical analysis, we build on and combine two different types of data: household budget surveys and multi-regional input-output (MRIO) data. Household budget survey data allows us to identify household characteristics and household-specific consumption patterns; we use MRIO data to compute sectoral embedded carbon intensities, reflecting carbon emissions that we attribute to the consumption of specific goods and services on the country-sector-level.

The GTAP database (Aguiar et al. 2019) includes data on trade relationships and emissions of several greenhouse gases in the year 2014. We convert the data into a multi-regional input-output table $\mathrm{Z} \in \mathrm{R}^{(\mathrm{r} \cdot \mathrm{s}) \times (\mathrm{r} \cdot \mathrm{s})}$ expressing inter-regional, inter-sectoral monetary flows in USD for 141 different countries (regions) r and 65 different sectors s (Peters et al. 2011). We choose data from GTAP since it provides the opportunity to draw on homogenized data across countries and regions and includes detailed data for all countries of interest in this study.

We complement the MRIO data with household budget survey data for 16 countries of Latin America and the Caribbean. We include datasets in our analysis, if they meet all of the following criteria: The household budget survey is nationally representative; it was conducted in 2010 or later, but before 2020 (to exclude effects from measures against the spread of Covid-19; with the exception of Mexico), and includes information on consumption expenditures at the level of consumption items. If country-specific data was available in multiple years, we include the most recent survey. Table 1 provides an overview of household budget survey data used in this study.

Data from household budget surveys encompasses information on socio-demographic household characteristics, such as age, education and occupation of household members, ethnicity, location, and asset ownership. We also include information on fuels used for cooking, lighting, and heating. In a first step, we homogenize the data on household characteristics across countries; Table A1 lists summary statistics for each country-specific survey dataset.

Table 1: Overview of household data: This table shows information on household budget survey data used in this study.

Country	**Dataset**	**Year**	**Households**	**Population**

Argentina	Encuesta Permanente de Hogares	2017	21,539	40,348,583
Barbados	Barbados Survey of Living Conditions	2016	2,434	205,843
Bolivia	Encuesta de Hogares	2019	11,859	11,525,284
Brazil	Pesquisa de Orcamentos Familiares	2017	57,889	207,049,069
Chile	Ecuesta de Presupuestos Familiares	2017	15,237	11,094,041
Colombia	Encuesta Nacional de Presupuestos de los Hogares	2016	87,166	48,013,649
Costa Rica	Encuesta Nacional de Ingresos y Gastos de los Hogares	2018	6,924	4,896,294
Dominican Republic	Encuesta Nacional de Gastos e Ingresos de los Hogares	2018	8,884	10,295,064
Ecuador	Encuesta Condiciones de Vida	2013	28,950	15,950,676
El Salvador	Encuesta De Hogares De Propositos Multiples	2016	23,622	6,455,437
Guatemala	Encuesta Nacional de Condiciones de Vida	2014	11,534	16,001,402
Mexico	Encuesta Nacional de Ingresos y Gastos de los Hogares	2020	88,899	126,715,250
Nicaragua	Encuesta Nacional de Hogares Sobre Medicion de Nivel de Vida	2014	6,851	6,268,100
Paraguay	Enuesta de Ingresos y Gastos y de Condiciones de Vida	2011	5,410	6,535,195
Peru	Encuesta Nacional de Hogares	2019	35,542	32,659,982
Uruguay	Encuesta Nacional de Ingresos y Gastos de los Hogares	2016	6,888	3,496,155
Total			**419,628**	**547,510,024**

In each country-specific dataset, we correct outliers at the item-level by setting the top expenditure percentile of all non-zero expenditures to the item-level median. We also track and remove duplicates, i.e., households which report the same expenditures on each individual item as another household does. We separate real expenditures from consumption that stems from home production, gifts or as remuneration for labor. We thereby aim to provide an accurate estimate on household-level costs that could potentially increase if an upstream carbon price was implemented.

We extrapolate weekly and monthly expenditures to yearly expenditures to obtain an approximation of total yearly household expenditures on the item-level. We thereby neglect seasonal patterns in the consumption of frequently purchased consumption items such as food. We expect the resulting bias to be small, since statistics offices usually collect consumption survey data over the course of multiple months. In a last step, we remove imputed expenditures which for instance represent a theoretical rent of dwelling owners. This is necessary, since the inclusion of imputed rental payments is likely to be skewed towards richer households, thereby introducing bias to the calculation of total household expenditures.

Since data from GTAP refers to the year 2014, we inflate or deflate expenditures from each survey to 2014 using consumer price indices (IMF 2020). Then we convert local currencies to international dollar using exchange rates from the World Bank (2020).

The collected data includes information for many different consumption items – up to 8,560 items in the case of Brazil. We aggregate country-specific item-level data to 65 sectors s from the GTAP database. In addition, we extract information on expenditures on energy items (such as electricity, solid and liquid fuels) and on broader consumption categories (energy, food, goods, and services)[1]. Table A2 lists average household expenditures and average expenditure shares for each country and each expenditure quintile.

To assess whether households are in principle capable of accessing governmental reimbursement payments, we keep track of all monetary income from governmental organizations in households, such as pensions, (conditional and unconditional) cash transfer programs, or stipends (see also Table A3).

Our final dataset comprises homogenized data for 419,628 households that represent 547 million people. For each household, we draw on detailed socio-demographic information as well as on yearly expenditure information in 65 unified sectors.

3. Method

We conduct a microsimulation of carbon pricing reform to assess the distributional impact of carbon pricing. In our model, we derive the incidence of carbon pricing from households' carbon footprints building on household-level consumption data and multi-regional input-output data. Next, we analyze characteristics of households with especially high additional costs using different statistical methods. We deploy three different techniques, namely OLS regression, regression-based inequality decomposition, and logit-regression and compare outcomes systematically. Each technique helps to gain insights into three different questions of interest.

3.1. Micro-Simulation of Carbon Price Incidence

The incidence of carbon pricing at the household-level expresses the carbon intensity of household consumption. Households who spend a larger share of expenditures on goods and services which are more emissions-intensive than others will also face larger additional costs from carbon pricing in comparison to total household expenditures.

We derive sectoral carbon intensities at the national level using detailed multi-regional input-output data (see also Dorband et al. (2019) and Steckel et al. (2021)). $Z \in R^{(r\cdot s)\times(r\cdot s)}$ represents the inter-industry flow matrix with countries r and sectors s. Entries of Z reflect the total monetary value (in USD) of flows from sector s_1 in region r_1 to sector s_2 in region r_2. Analogously, the final demand vector $Y \in R^{s\cdot r\times r}$ with entries $y_{r_1,s_1}^{r_2}$ expresses the sum of all monetary flows from sector s_1 of region r_1 into final consumption (demand) of region r_2. We compute the total output vector $O \in R^{r\times s}$ with entries

$$o_{r_1,s_1} = \sum_s \sum_r (z_{r_1 s_1}^{r,s}) + \sum_r y_{r_1,s_1}^{r} \quad (1)$$

Drawing on the total output vector O, we next derive the technology matrix $A \in R^{(r\cdot s)\times(r\cdot s)}$, which describes the amount of input from each region r_1 and sector s_1 that is required for one unit of output in sector s_2 in region r_2, with entries

$$a_{r_1 s_1}^{r_2 s_2} = z_{r_1 s_1}^{r_2 s_2} / o_{r_2,s_2} \quad (2)$$

Using the technology matrix A, we calculate the Leontief inverse L, which accounts for all interlinkages in the production chain and expresses the amount of inputs that are embedded in final production of any sector in any region.

[1] Detailed matching tables are available in a separate online repository.

$$L = (I - A)^{-1} \tag{3}$$

With the Leontief inverse L we calculate the total amount of carbon emissions that can reasonably be attributed to household consumption. Those embedded carbon emissions consist of direct emissions from fossil fuel use and indirect emissions. We denote direct emissions by $E^{dir}_{r_1 s_1}$ which stem from GTAP. Indirect emissions $E^{indir}_{r_1 s_1}$ are derived as follows:

$$E^{indir}_{r_1 s_1} = \sum_{r'} \sum_{s'} \sum_{r} f_{r',s'} L^{r,s_1}_{r',s'} y^{HH,r_1}_{r,s_1} \tag{4}$$

with $y^{HHr_1}_{r,s_1}$ expressing the total household consumption in region r_1 of goods or services from sector s_1. By $f_{r',s'}$ we denote the total amount of carbon emissions released by sector s in region r. For the purpose of our analysis, we exclude international emissions, which is equivalent to the assumption of absent carbon border adjustment mechanisms. Both, $y^{HHr_1}_{r,s_1}$ and $f_{r',s'}$ originate from the GTAP database: vector $f_{r',s'}$ covers carbon emissions from fossil fuel use, but not methane or nitrous oxide from agriculture or emissions from deforestation. We also treat the use of biomass (such as firewood) as carbon-neutral, since it would be difficult to tax in practice. We next turn to a vector of national and sectoral carbon intensities $CI_{r,s}$ which expresses the total amount of carbon emissions that are embedded in the consumption of one output unit (in USD) in sector s and region r.

$$CI_{r_1 s_1} = \frac{E^{indir}_{r_1 s_1} + E^{dir}_{r_1 s_1}}{y^{HH,r_1}_{r,s_1}} \tag{5}$$

The carbon pricing incidence reflects – first – differences in emissions intensities between sectors s in region r and – second – differences in sectoral expenditure shares on the household-level. That is, households from different countries which are identical with respect to sectoral expenditure shares might consume with a different carbon intensity, if sectoral carbon intensities differ across countries.

We compute the carbon intensity of consumption of household i, which we denote as CIC_i, as

$$CIC_i = \frac{\sum_s Exp^i_{r_1,s} * CI_{r_1,s}}{\sum_s Exp^i_{r_1,s}} \tag{6}$$

where $Exp^i_{r_1,s}$ are annual expenditures of household i on goods and services from sector s in region r_1. Variable CIC_i expresses the amount of carbon emissions that can reasonably be attributed to one unit of consumption of household i [tCO_2/USD]. It accounts for differences in household consumption and country-level industry characteristics (see also supplementary Figure A1).

An economy-wide price on carbon emissions would lead to additional costs to any household, which would reflect each household's carbon intensity of consumption. As it is common in the literature (e.g., Feindt et al. 2021; Vogt-Schilb et al. 2019; Steckel et al. 2021), we therefore derive the incidence of carbon pricing by multiplying CIC_i with a carbon price t = USD 40/tCO_2, which is likely to be at the lower bound of carbon prices that are consistent with the Paris Agreement (Stiglitz et al. 2017). We are mostly interested in differences in carbon pricing incidence between households within single countries, not in the exact magnitude of additional costs. Our main results are therefore not sensitive to differing carbon prices t'.

Our variable of interest is the additional cost (i.e., the incidence) of carbon pricing AC_i, which expresses the total required additional expenditures to household i (in relation to total household expenditures, expressed in percent).

$$AC_i = CIC_i * t \quad (7)$$

AC_i allows for interpretation as the additional budget that any household would require to maintain pre-tax consumption levels, if a carbon price t was implemented and fully passed through to household consumption. By design, AC_i represents an upper-bound first-order effect, neglecting dynamic behavior of consumers and producers[2].

We group households into expenditure quintiles to demonstrate differences in carbon price incidence across income groups. Total household expenditures per capita serve as a proxy for income, which is necessary, since income from labor might fluctuate or suffer from misreporting. In contrast, total expenditures are usually a valid representation of lifetime income (Poterba 2016). We show the distribution of AC^j for each expenditure quintile j with the help of boxplots in Figure 1 (see also Table A4).

In a first step of our empirical analysis, we systematically compare differences between and within expenditure quintiles. We show differences between quintiles (*vertical distribution)* by inspecting differences in $\overline{AC}_r^j$ which be the median of quintile j in region r. We refer to differences within expenditure quintiles as *horizontal distribution* which we compute as the spread between the 5th and the 95th percentile in each expenditure quintile, denoted by H_r^j.

To facilitate the comparison of differences between vertical and horizontal distributional effects within and across countries, we normalize $\overline{AC}_r^j$ and H_r^j for each expenditure quintile j by using $\overline{AC}_r^5$ and H_r^5 as a denominator, i.e., $\widehat{AC}_r^j = \frac{\overline{AC}_r^j}{\overline{AC}_r^5}$ and $\widehat{H}_r^j = \frac{H_r^j}{H_r^5}$, respectively.

We systematically compare vertical and horizontal distributional effects within and across countries by inspecting $\widehat{AC}_r^1$ and $\widehat{H}_r^1$, thereby comparing median incidence and differences between the 5th and 95th percentile for the first (i.e., the poorest) and the fifth (i.e., the richest) expenditure quintile. $\widehat{AC}_r^1 > 1$ indicates regressive distributional effects, i.e., median carbon price incidences are higher for poorer households than for richer households. To the contrary, $\widehat{AC}_r^1 < 1$ expresses progressive distributional effects. $\widehat{H}_r^1 > 1$ points to horizontal effects in the first quintile exceeding those from the fifth quintile, i.e., carbon price incidences are more heterogeneous among poorer households than among richer households. $\widehat{H}_r^1 < 1$ represents more heterogeneous carbon price incidences in the richer quintile compared to the poorest quintile. In addition, the comparison of $\widehat{AC}_r^1$ and $\widehat{H}_r^1$ facilitates the analysis of whether differences in vertical or horizontal heterogeneity are more pronounced in any country. If $\widehat{AC}_r^1 > \widehat{H}_r^1$, we interpret vertical differences to outweigh horizontal differences in country r and vice versa. Our approach addresses the methodological challenge to systematically compare differences in distributional outcomes across different groups (see Cronin et al. (2019) or Steckel et al. (2021)). We show $\widehat{AC}_r^1$ and $\widehat{H}_r^1$ in Figure 2 and Table A5. Supplementary Figure A2 presents a visual representation of a sensitivity analysis indicating that $\widehat{H}_r^1$ is robust to changes in computing the horizontal differences within expenditure quintiles.

[2] We argue that it is first-order ('overnight') effects which correlate with political support for a specific policy, i.e., households with a larger AC_i are more likely to express strong sentiments against a carbon price than others do.

Since we expect the carbon pricing incidence AC_i of household i to reflect household-specific consumption patterns, we show Pearson correlation coefficients for AC_i and the share of total household expenditures on broader consumption categories (namely energy, goods, services, and food) and detailed energy items (namely electricity, firewood, charcoal, kerosene, petrol, diesel, LPG, gas, and other biomass, such as dung or animal waste). We inspect cross-country differences in correlation coefficients visually (Figure 3, see also Table A6 and Table A7). Figure A3 presents a supplementary factor decomposition analysis of carbon pricing incidence.

3.2. OLS regression

We identify factors correlating with carbon pricing incidence AC_i in household i by estimating the following specification on the household-level for each country r:

$$AC_i^r = \alpha_0^r + \beta_o^r exp_i^r + \beta'^r X'^r_i + \varepsilon_i^r \quad (8)$$

α_0^r is the intercept, ε_i^r captures the error term of household i. exp_i^r expresses log-transformed total household expenditures (in USD). X'^r_i is a set of country-specific explanatory variables including household size, location (urban vs. rural), education of the household head, or ethnicity. X'^r_i also captures binary variables indicating the most frequently used cooking fuel (such as LPG, kerosene, electricity, firewood or charcoal), electricity access and car ownership – factors, which we expect to correlate with carbon pricing incidence. We estimate the regression separately for each country r and for each expenditure quintile j_r at the country-level and report results in Table A8 to Table A23.

Coefficients from this regression can help identify factors, which drive the carbon price incidence AC on a country-level. This might facilitate the formulation of nuanced tax regimes or efficient reimbursement strategies. If for instance, the use of LPG for cooking would correlate strongly with the carbon price incidence, an exclusion of LPG from taxation might be a solution to mitigate unintended excessive costs.

3.3. Inequality decomposition

Estimates of β_0^r and β'^r, which are statistically different from zero, do not allow for inquisition of whether the related covariates exp_i^r and elements of X'^r_i explain much of the variation in AC_i^r. We therefore turn to advances in regression-based inequality decomposition techniques to distill the factors, which account for the largest part of variance in AC_i^r. Our approach builds on work by Fields (2003) and by Shorrocks (1982) and finds frequent application in many fields of economics (Cowell and Fiorio 2011; Morduch and Sicular 2002), including environmental economics (Duro et al. 2017) and development economics (Lambert et al. 2014; Cain et al. 2010). Sager (2019) and Farrell (2017) use the approach in the context of carbon pricing incidence analysis. Starting with a linear regression as previously specified in equation (8), we next derive the variance of both sides of the equation

$$var(AC_i^r) = var(\alpha_0 + \beta_o^r exp_i^r + \beta'^r X'^r_i) \quad (9)$$

which allows for transformation into the sum of co-variances between each regression component (here: exp_i^r and $k-1$ elements of X'^r_i) and the dependent variable AC_i^r:

$$var(AC^r) = cov(\beta_o^r exp_i^r, AC_i^r) + \sum_{k-1} cov(\beta_k^r X_k^r, AC_i^r) \quad (10)$$

We next compute the weights s_k of each regression component k (here: exp_i^r and $k-1$ elements of X'^r_i)

$$s_k(AC^r) = \frac{cov(\beta_k^r X_k^r, AC^r)}{var(AC^r)} \tag{11}$$

Each s_k represents the contribution in percent of each dependent variable k to the variance of carbon price incidence AC^r as estimated from the model in equation (8). We report all regression components that help to cumulatively explain at least 95% of the variation in AC^r in Table 2 and document all s_k for each country r in Table A24 to Table A39.

3.4. Logit regression

Results from OLS regression and inequality decomposition might help to provide insights into factors which are associated to *absolute* levels of carbon pricing incidence. Nevertheless, they are less helpful for identifying factors which are associated to *relative* levels of carbon pricing incidence, i.e., whether any household's consumption is especially carbon-intensive in comparison to other households. We call those households *hardship cases* – households which would face a carbon pricing incidence exceeding those of 80% of other households. While this definition does not necessarily include exceptionally high absolute levels of carbon pricing, those households expect a larger AC^r than 80% of the population. Accordingly, we define a binary variable HC_i^r expressing whether household i is part of the fifth quintile of carbon pricing incidence:

$$HC_i^r = \begin{cases} 1, & if\ AC_i^r \geq AC_{80}^r \\ 0, & if\ AC_i^r < AC_{80}^r \end{cases} \tag{12}$$

Next, we apply a logit regression framework and estimate

$$\log\left(\frac{p_{HC_i^r}}{1-p_{HC_i^r}}\right) = \alpha_0 + \beta_o^r exp_i^r + \beta'^r X'^r_i + \varepsilon_i^r \tag{13}$$

$p_{HC_i^r}$ expresses the probability of expecting larger costs AC_i^r than 80% of households in household i in region r. As above, we include log-transformed total household expenditures exp_i^r and several covariates X'^r_i pertaining to household i. Estimates from this regression express the correlation of each covariate with the log-odds transformed probability of $p_{HC_i^r} = 1$. We show results from this specification in Table 2 and detailed regression coefficients in Table A40 to Table A55. Our estimates provide a more precise intuition about which factors characterize households with especially carbon-intensive consumption patterns *in comparison* to households consuming less carbon-intensive goods and services. This could yield insights in country-specific tailored compensation mechanisms, which could help cushion detrimental impacts on those that are most substantially affected.

3.5. Analysis of cash transfers

We observe whether household i has access to any governmental monetary transfer gt_i^r (see Table A3) and subsequently derive a binary variable GT_i^r as follows:

$$GT_i^r = \begin{cases} 1, & if\ gt_i^r > 0 \\ 0, & if\ gt_i^r = 0 \end{cases} \tag{14}$$

GT_i^r expresses whether any household could potentially access reimbursing cash transfers by the government through *established* transfer programs, if governments were to redistribute revenues from carbon pricing. Implicitly, we do not account for the possibility of expanding the coverage of existing or the introduction of novel transfer programs. We show the share of households which have access to cash transfers in Figure 4 and Table A56.

We next test what characterizes households which would expect relatively high additional costs (i.e., $HC_i^r = 1$) and could not be compensated through existing cash transfers (i.e., $GT_i^r = 0$). We describe this group in absolute terms with the help of summary statistics (see Table A57) and in relative terms by estimating the introduced logit regression (equation (13)) on the log-odds transformed probability $p_{\theta_i^r}$ with

$$\theta_i^r = \begin{cases} 1, & if\ GT_i^r = 0 \cap HC_i^r = 1 \\ 0, & if\ GT_i^r = 1 \cup HC_i^r = 0 \end{cases} \tag{15}$$

Coefficients from this regression express the correlation of total household expenditures and several covariates with the log-odds transformed probability of facing higher additional costs from carbon pricing and having no access to governmental transfer programs. We show results from this specification in Table 3 and detailed regression coefficients in Table A58 to Table A73. Our estimates hint towards which parts of the population might require supplemental support by governments.

4. Results

Pricing carbon (and foregoing fossil fuel subsidies) leads to rising prices for consumption goods and services in the short term with detrimental effects for household welfare and eventually public acceptability of the policy. We inspect additional overnight costs to a carbon price of USD 40/tCO_2 in households of 16 countries from Latin America and the Caribbean. We assess various determinants of distributional effects of carbon pricing: i) differences between expenditure quintiles (vertical distributional effects), ii) differences within expenditure quintiles (horizontal distributional effects), iii) determinants of hardship cases, and iv) the possibility to receive reimbursements through existing governmental cash transfer programs in light of expected carbon pricing incidence.

4.1. Carbon Price Incidence in Latin America and the Caribbean

Figure 1 shows vertical and horizontal distributional effects of carbon pricing incidence in percentage points of total household expenditures. In eleven countries, results would be regressive, that is, the poorest 20% of households would be more affected at the median than the richest 20% of households. For Argentina, Bolivia, Brazil, Chile, Ecuador, El Salvador, and Uruguay we show strictly regressive results, that is, every poorer quintile faces higher additional costs at the median than the following richer one. In Barbados, Colombia, Costa Rica, and Peru impacts would be regressive at the median comparing the first and fifth expenditure quintile and strictly regressive on average in Colombia and Peru. Dominican Republic, Guatemala and Nicaragua show strictly progressive results at the median. Results for Mexico and Paraguay indicate progressive effects at the median, albeit with highest carbon price incidences among the second to fourth expenditure quintiles. Richer countries of our sample (such as Uruguay, Chile, Barbados, Argentina, Brazil) show regressive results, which is in line with findings from the literature (Ohlendorf et al. 2021). Strictly progressive outcomes correlate with a high share of traditional biomass use: In Guatemala, 70% of households report firewood as main cooking fuel (51% of households in Nicaragua, 29% in Paraguay, see Table A1). At lower levels of income households are more likely to use biomass for cooking. Since biomass would be difficult to tax, the incidence would fall on households who use LPG, natural gas or electricity for cooking and who are also relatively richer.

Horizontal distributional effects (i.e., differences within 90% of households in each expenditure quintile) exceed vertical distributional effects (i.e., differences in median or mean between quintiles) in every country and in every quintile. This implies that evaluating carbon pricing reforms exclusively with respect to vertical distributional effects (i.e., whether a policy would be pro-poor or pro-rich on average) is likely to disregard substantial heterogeneity among households with similar levels of income. For most countries we also document substantial variation of horizontal effects comparing poorer and richest quintiles (e.g., Barbados, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru and Uruguay). For example, the horizontal spread among 90% of households in the poorest expenditure quintile in Peru amounts to 6.6% compared to 2.2% among 90% of households in the richest expenditure quintile.

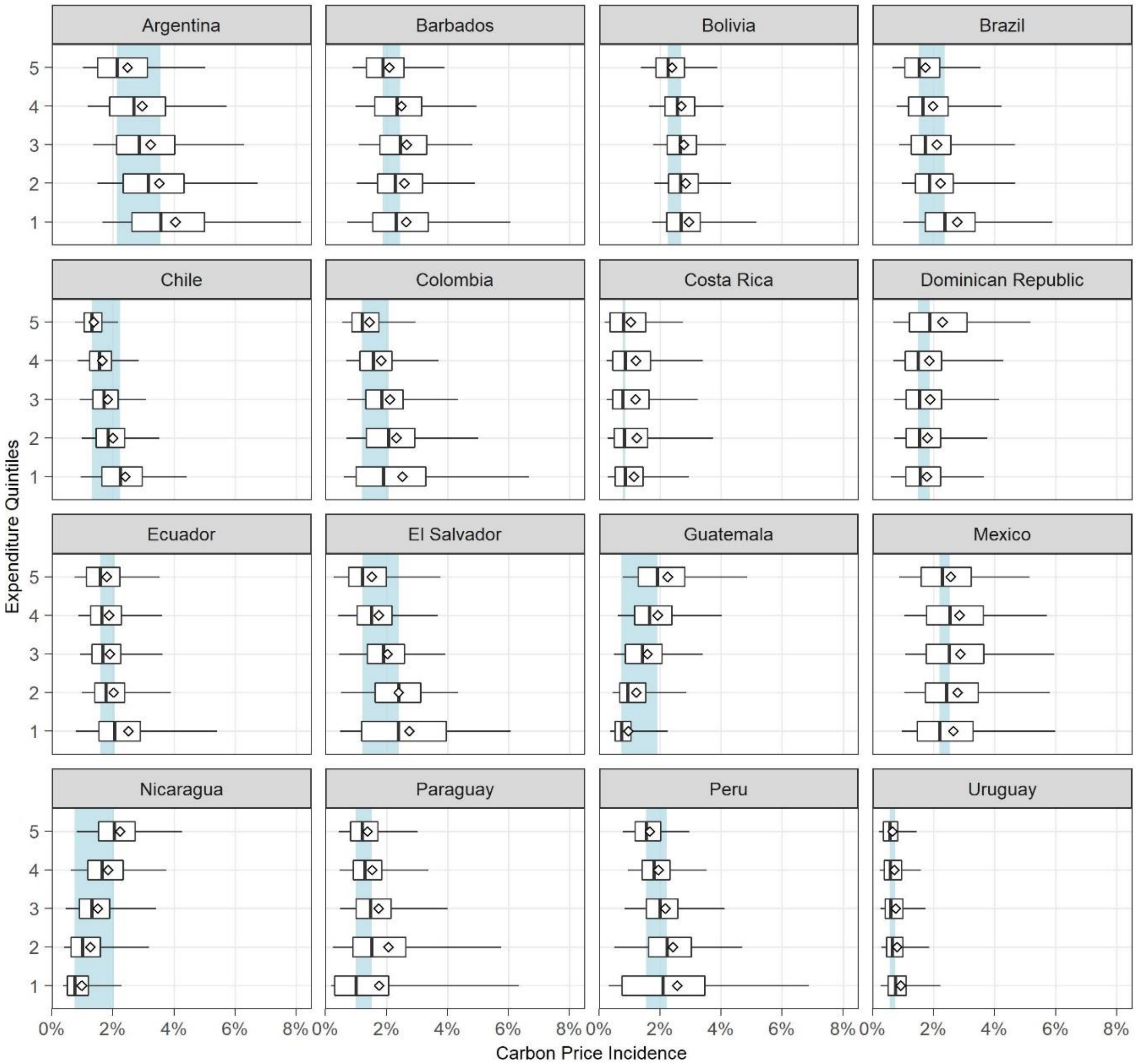

Figure 1: Carbon price incidence by expenditure quintiles: Additional costs on households induced by a carbon price of USD 40/tCO_2 in relation to total household expenditures (x-axis). The 1st quintile includes those 20% of households with least total expenditures per capita. The 5th quintile includes those 20% of households with highest total expenditures per capita. 1% additional cost indicates that a household would require an additional 1% of its actual expenditure budget in order to buy the same amount of goods they bought prior to the price increase. Rhombuses indicate the mean. The box indicates the 25th and 75th percentile; whiskers indicate the 5th and 95th percentile, respectively. The blue vertical bar expresses the vertical difference of carbon pricing incidence, i.e., the difference of median additional costs among the quintile with the highest and lowest median of additional costs, respectively.

The difference in horizontal inequality merits further investigation. For example, economists often propose lump-sum transfers as the preferred solution to circumvent regressive distributional effects of carbon pricing (Budolfson et al. 2021; Vogt-Schilb et al. 2019; Klenert and Mattauch 2016), because lump-sum transfers render distributional effects more progressive on average. Nevertheless, if horizontal inequality is more pronounced in lower expenditure quintiles, fundamentally progressive lump-sum transfers will fail to fully compensate parts of the poor, but highly affected population.

Figure 2 shows a systematic comparison of vertical and horizontal effects across countries. In Figure 2, we compare the spread between the 5th and the 95th percentile range within the first to the same spread within the fifth expenditure quintile ($\widehat{H}_r^1$, x-axis) to vertical differences at the median ($\widehat{AC}_r^1$, y-axis). We find horizontal differences exceeding vertical differences in 12 out of 16 countries, in two countries (Paraguay and Peru) even by factor 2. In 11 out of 16 countries results are both regressive and more heterogeneous in the first expenditure quintile. In such context, 'one size fits all'-solutions, such as equal per capita transfers, will fail to compensate all poor households for their additional costs. This underlines the necessity to design complementing, targeted compensation programs, if vulnerable households should be guarded against excessive costs of efficient climate policy.

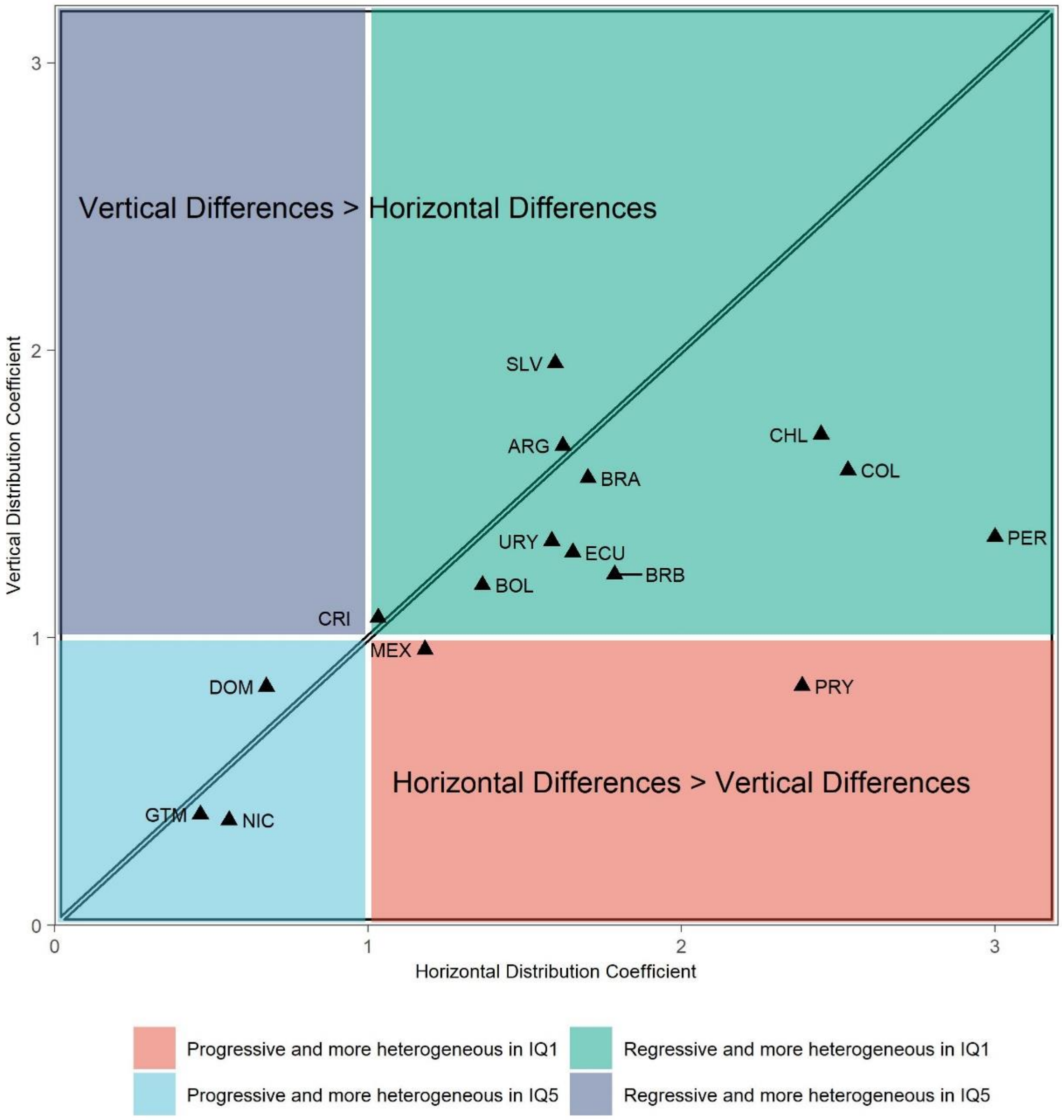

Figure 2: Systematic comparison of vertical and horizontal distributional effects: This figure displays normalized measures for vertical ($\widehat{AC}_r^1$) and horizontal ($\widehat{H}_r^1$) differences in carbon pricing incidence. We also denote represented values in Table A5.

4.2. Determinants of the Distributional Effects of Carbon Pricing

Distributional effects of carbon pricing across countries share similarities, but also exhibit differences. Aiming for explanations of differences across countries we analyze the correlation of expenditure shares of consumption items, such as energy, food, goods, and services (Figure 3A) and specific energy items (Figure 3B) across households within countries (see also Table A6, A7, and Figure A3). Confirming previous evidence (Dorband et al. 2019), we find that households' carbon pricing incidence correlates strongly and positively with expenditures on energy items in all countries. Correlation between carbon pricing incidence and expenditure shares on food, goods, or services is low or even negative. Energy expenditure shares correlate less strongly with carbon pricing incidence in Guatemala, Paraguay, Nicaragua, and Uruguay – which might express higher levels of non-taxed firewood consumption (Guatemala, Paraguay, Nicaragua) or lower levels of emissions intensity in the electricity sector (Uruguay, Paraguay). Since firewood and electricity consumption are large components of total energy expenditures in respective countries (for example, expenditures on firewood (electricity) comprise 41% (58%) on average of energy expenditures in Guatemala (Uruguay)), it is consistent with lower levels of correlation.

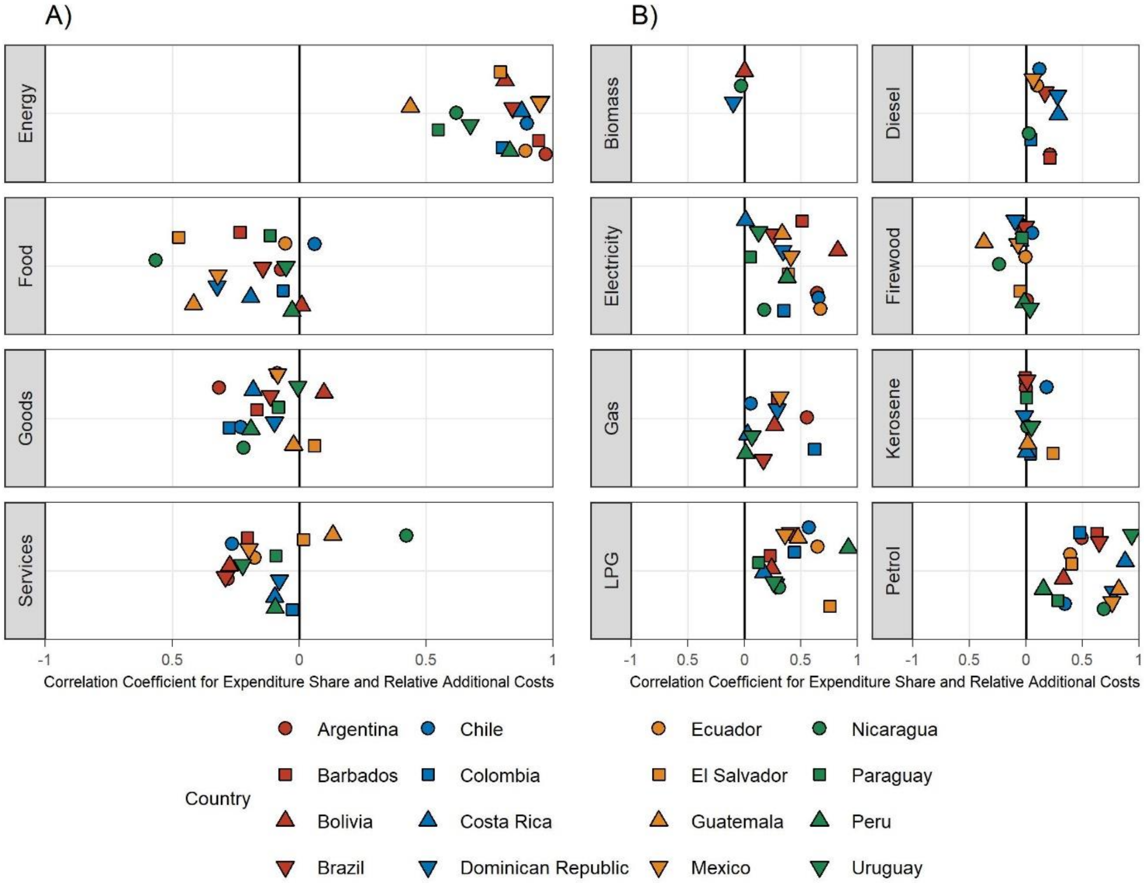

Figure 3: A) Correlation coefficient of carbon price incidence and consumption expenditure shares; B) correlation coefficients between carbon price incidence and energy item expenditure shares: This figure displays Pearson correlation coefficients for carbon price incidence and respective consumption shares on broad consumption categories (Panel A) and detailed energy items (Panel B). We also report correlation coefficients in Tables A6 and A7.

Figure 3B decomposes energy items even further. In general, expenditures on electricity, LPG and transport fuels are positively correlated with the carbon price incidence, which suggests that some fuels could be exempted from taxation to avoid high additional costs. Nevertheless, we also document differences between countries, e.g., for electricity. Countries that have a low carbon intensity in electricity generation, such as Costa Rica, Brazil, Paraguay, and Uruguay (Table A74), exhibit low levels of correlation between electricity consumption and the carbon pricing incidence. In other countries, such as Nicaragua and the Dominican Republic, electricity generation does not strongly correlate with the carbon pricing incidence despite a relatively high carbon intensity of electricity, which hints towards electricity expenditures not playing an important role in household expenditure shares (on average 2.4% in Dominican Republic and 2.5% in Nicaragua) or households consuming electricity in a similar proportion of total household expenditures. Expenditures on firewood correlate negatively with the carbon pricing incidence in Guatemala and Nicaragua. In some countries, namely Ecuador, Peru, and El Salvador, a high carbon pricing incidence correlates strongly with LPG, which is mostly used for cooking purposes (see also Figure A3).

To further understand the heterogeneity in carbon pricing incidences, Table 2 summarizes findings from three statistical analyses. Column a) shows which household characteristics explain large parts of the variation in carbon pricing incidence, comprising results from an inequality decomposition (see equations (8) to (11)): cumulatively, factors marked with a disk (either half or full), explain at least 95% of variation in carbon pricing incidence among households within a country. Factors marked with a full disk explain by itself at least 10% of the variance (see also Table A24 to A39). Column b) indicates the (positive or negative) correlation between household characteristics and carbon pricing incidence (see equation (8)). Column c) indicates the (positive or negative) correlation between the log-odds transformed probability for households with each characteristics to face higher additional costs than 80% of all households (see equation (13)). We show detailed regression tables in Tables A8 to A55.

Table 2: Overview of variables correlating with high carbon pricing incidence. Column **a** indicates which variables explain cumulatively at least 95% of variation in carbon pricing incidence (◑ or ●). Variables that explain by themselves at least 10% of total variance in carbon pricing incidence are marked with a full disk (●). All variables with an empty disk (○), together, contribute less than 5% of the variation in carbon pricing incidence. See Tables A24 to A39 for detailed results. Column **b** indicates the correlation of variables with carbon pricing incidence. Symbol **+** represents positive and statistically significant ($p<0.05$) coefficients from OLS regression on carbon pricing incidence. Symbol **-** represents negative and statistically significant ($p<0.05$) coefficients from OLS regression on carbon pricing incidence. See Tables A8 to A23 for detailed results. Column **c** indicates the correlation of variables with the log-odds transformed probability of higher carbon pricing incidence than 80% of all households. Here, symbol **+** (**-**) represents positive (negative) and statistically significant ($p<0.05$) coefficients from logit regression on carbon pricing incidence. See Tables A40 to A55 for detailed results. In Dominican Republic and Guatemala, *LPG* serves as the reference for the factor variable of most frequently used cooking fuel. Grey cells indicate that variables are missing in the data.

	Total expenditures (log)			Household Size			Car ownership			Cooking Fuel (Ref: Electricity)							Education			Urban			Ethnicity			Electricity access		
										Cooking Fuel	LPG		Natural Gas		Firewood													
	a	b	c	a	b	c	a	b	c	a	b	c	b	c	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Argentina	●	-	-	◑	+	+	●	+	+	○	+		+		-	-	◑	-	-							○	+	+
Barbados	●	-	-	○	+		●	+	+	◑	+	+	+	+		-	○		-				○			○	+	+
Bolivia	●	-	-	○	+	+	◑	+	+	●	-	-			-	-	○			○	+	+	○	-	-	◑	+	+

Brazil	●	- -	○	+ +	●	+ +	○			- -	○		◑	- -	○	- -	○	- -
Chile	●	- -	○	+ +							◑							
Colombia	●	- -	○	+ +	◑	+ +	●	+ +	+ +	- -	◑	- -	○	- -	○	- -	○	+ +
Costa Rica	○	- -	○	+ +	●	+ +	●	+ +		-	○	-	○	- -	○		○	+ +
Dominican Republic	○	- -	○	- -	●	+ +	◑	Ref.		- -	○	-	○	- -			○	+ +
Ecuador	●	- -	○	+ +	●	+ +	○	+		- -	○		○	-	○	- -	○	+ +
El Salvador	●	- -	●	+ +	●	+ +	●			- -	○	+ +	○				○	
Guatemala	○	-	○	- -	●	+ +	●	Ref.		- -	◑		○	+ +	◑	- -	◑	+ +
Mexico	○	- -	○	+ +	●	+ +	●	+ +	+ +		○	-	○	-	○	- -	○	+ +
Nicaragua	●	+ +	○		●	+ +	●	+			○		○	- -	○	+	○	
Paraguay	◑	- -	○		○	+ +	●	+ +			◑	- -	○				○	+
Peru	●	- -	○	+ +	○	+ +	●	+ +	-	- -	○	-	○	+	○	+	○	+ +
Uruguay	●	- -	○	+	●	+ +	○	+ +	+ +		○	-	●	- -	○		○	- -

Higher total household expenditures correlate with lower levels of carbon pricing incidence in every country, except in Nicaragua. In 12 countries, variance in total household expenditures is also a meaningful predictor for variance in carbon pricing incidence, which indicates that transfer programs targeting households with lower incomes could prove useful.

In addition, inequality decomposition analyses corroborate the relevance of car ownership (in 13 countries) and cooking fuel use (in eleven countries) for disentangling variance in carbon pricing incidence. Car ownership correlates positively with carbon pricing incidence in all countries, which alludes to the possibility of using revenues for transport sector policies to circumvent unintended distributional effects (see also Table 4).

In contrast to households that cook with electricity, cooking with LPG (with Bolivia as exception) or natural gas (with Peru as exception) is associated with a higher carbon pricing incidence. Our results further stress the relevance of considering firewood consumption when designing efficient and equitable carbon pricing reforms; households using firewood are less likely to face exceptionally high additional costs from carbon pricing in ten countries. To prevent households from switching to firewood, exempting some cooking fuels from carbon pricing or leveraging other measures addressing energy use for cooking purposes might be suitable complementing policies.

Variance in other socio-demographic variables (such as urban citizenship, education, electricity access or ethnicity) is less likely to correspond to variance in carbon pricing incidence. Nevertheless, households are less prone to high carbon pricing incidences if they i) live in urban areas (in six countries), ii) are better educated (in eight countries), iii) identify themselves as part of indigenous communities or ethnic minorities (in six countries) or iv) do not have access to the electricity grid (in eleven countries). This might hint towards viable pathways for targeted revenue recycling, albeit requiring careful consideration of country-specific circumstances.

4.2. Accessibility of Governmental Cash Transfer Programs

Governments can use parts of expected revenues from carbon pricing for compensation. Recycling revenues provides an opportunity to correct regressive impacts or to cushion adverse effects on excessively affected hardship case households, whose consumption is especially carbon-intensive. Using *existing* transfer programs to channel revenues to households could be an institutionally feasible channel with comparatively little administrative costs. Figure 4 analyzes the share of the population which currently has access to governments' transfer programs (*Access to transfers)*, with respect to available income (*Poorest 20%*) and expected carbon price incidence (20% *most affected*).

Our analysis suggests that using existing transfer programs could help compensate substantial parts of the population that would face a high carbon price incidence. For example, governments of Argentina, Brazil, Colombia, Nicaragua or Uruguay could target approximately 50% of households, which would be among the 20% most affected by carbon pricing (see also Table A56). In contrast, the data indicates that governments of Paraguay, El Salvador, or Guatemala could not reach many of most affected households. Since many households with high carbon pricing incidence are also likely to be relatively poor (see section 4.1), using existing transfer programs to compensate households is prone to excluding most vulnerable households. For example, in countries such as Barbados, Chile, El Salvador, Paraguay, or Peru, 18% to 37% of the most affected 20% of households find themselves among the poorest quintile in the population *and* do not have access to governmental transfer programs (see also Table A56). This group amounts to 4% to 7% of the entire population (Figure 4). Therefore, our findings highlight the need to expand coverage of existing transfer programs or to design novel compensation mechanisms, if governments envisage compensating households for additional losses.

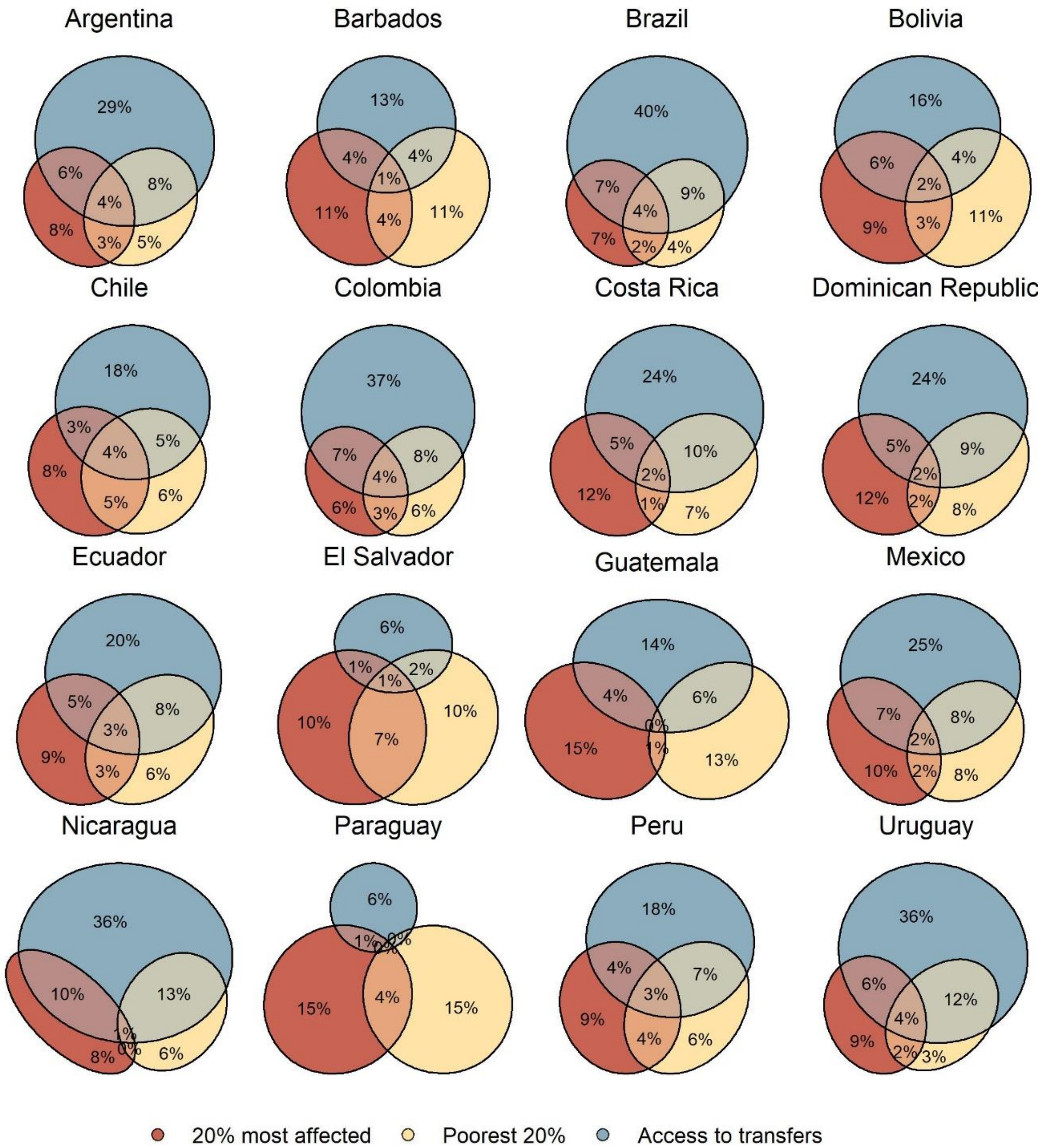

*Figure 4: Expecting high additional costs and having access to transfers S*hare of population in 16 different countries that can be characterized by at least one of the following criteria: a) facing higher additional costs to carbon pricing than 80% of each country's population (*20% most affected* , $HC_i^T = 1$), ii) being poorer than 80% of each country's population (*Poorest 20%*, i.e., expenditure quintile $j = 1$) and/or iii) currently having access to governmental transfers, such as pensions, cash transfers, or stipends (*Access to transfers,* $GT_i^T = 1$). Numbers express the share of total population in each sub-group.

Existing transfer programs exclude some parts of the population of which some are prone to excessive additional costs by carbon pricing. In our sample, this group corresponds to approximately 21 million households. Table 3 (detailed regression results in Table A58 to Table A73, see also Table A57) gives an overview of household characteristics of highly affected households that do not have access to existing transfer programs in comparison to the rest of population. Confirming evidence from section 4.2, we document that households which are most heavily affected by carbon pricing and do not have access to transfer programs are more likely to be poorer in all countries (except Nicaragua). They are also more likely to own a car compared to the rest of the population. Expecting relatively high additional costs from carbon pricing without having access to transfer programs correlates positively with using LPG for cooking (in seven countries) and negatively with using firewood (in ten countries), compared to households using electricity. Highly affected households without access to transfers are more likely to live in urban areas in Bolivia, Guatemala or Peru, but more likely to live in rural areas in Brazil, Costa Rica, Dominican Republic, Mexico, Nicaragua or Uruguay. We document an increased probability of relatively high carbon pricing incidence without access to transfers for households from indigenous communities in Nicaragua (see also Table A70) and Peru (see also Table A72), but for households identifying with ethnic majorities in Bolivia, Colombia, Ecuador, Guatemala, or Mexico. This underpins the relevance of socio-demographic factors (such as ethnicity) as an influential factor in the context of designing energy and climate policy (Aklin et al. 2021; Sunter et al. 2019).

Table 3: Variables associated to especially high carbon pricing incidence and not having access to existing transfer programs (in comparison to the whole population). This table provides a comparison of variables which correlate significantly ($p<0.05$) with the logs-odds transformed probability of higher carbon pricing incidence than 80% of the total population ($HC_i^r = 1$) and not having access to governmental transfer programs ($GT_i^r = 0$). We present detailed regression results in Table A58 to A73. Symbols **+** (**-**) represent positive (negative) correlations. In Dominican Republic and Guatemala, *LPG* serves as the reference for the factor variable of most frequently used cooking fuel. Grey cells indicate that variables are missing in the data.

	Total expenditures (log)	Household Size	Car ownership	Cooking fuel (Ref. Electricity)			Education	Urban	Ethnicity	Electricity access
				LPG	Natural Gas	Firewood				
Argentina	-	+	+			-	+			+
Barbados	-		+	+		-	-			+
Bolivia	-	+	+					+	-	+
Brazil	-		+			-		-		
Chile	-									
Colombia	-		+	+	+	-	-		-	
Costa Rica	-	-	+	+		-		-		+
Dominican Republic	-	-	+	Ref.			+	-		
Ecuador	-		+			-			-	+
El Salvador	-	+	+			-				
Guatemala	-	-	+	Ref.		-		+	-	+
Mexico	-	+	+	+	+	-	+	-	-	
Nicaragua	+	-	+	+				-	+	
Paraguay	-		+	+						
Peru	-		+	+		-		+	+	+
Uruguay	-	-	+					-		

5. Discussion

Our results show that existing cash transfer programs can only partially help reimburse households in Latin America and the Caribbean for high costs of carbon pricing. We first discuss methodological limitations and their potential impacts on our results. Then we review options to improve the effectiveness of transfer schemes in shielding vulnerable parts of the population which could potentially increase public acceptance of carbon pricing reforms.

Our core simulation of carbon pricing incidence depends on multi-regional input-output data which allows for comparison of results across countries, but does not capture general equilibrium effects, such as changes in wages or effects on demand for goods such as biomass. Despite our analysis focusing on differences in cost burden, carbon pricing incidences do not reflect the ability of households to substitute to cleaner goods or to deploy different technologies. In general microsimulations based on input-output data are hence an upper-bound estimate of carbon pricing incidence (Ohlendorf et al. 2021) and its general effectiveness. Nevertheless, the welfare effects of carbon pricing might be underestimated, e.g., when levying a carbon price provides stronger incentives for households to use biomass (Greve and Lay 2022). In our sample, this might potentially apply to

Guatemala, Nicaragua, and Paraguay, where biomass consumption is widespread and where a carbon price would be progressive.

In addition, data on received transfers might be incomplete, thereby possibly affecting results depicted in Figure 4. Some datasets do not necessarily reflect economic situations of households as of today (but instead, e.g., for the year 2011 in Paraguay). Any changes in households' consumption behavior, the setup of new transfer programs, or alterations of the respective national energy mixes could not be captured with our simulation. While such limitations are common in the literature, future country-level analyses could benefit from more recent, granular data on both, the household- and industry-level to provide more nuanced estimates of carbon pricing incidences.

In spite of the limitations, our findings underpin the necessity to evaluate climate policy instruments (such as carbon pricing) as part of more comprehensive policy packages. Since carbon pricing generates fiscal revenues, governments can use parts of additional funds to compensate households for excessive additional costs. Using existing transfer programs might be beneficial as they do not require (potentially costly) institutional reforms and are well-established among both, governments and citizens of countries in Latin America and the Caribbean. As we demonstrate, existing cash transfer programs would however provide an imperfect basis to shield households from high costs of carbon pricing. Moreover, characteristics of those households, who would bear high costs, but could not be compensated through existing transfer schemes, are country-specific, which stresses the absence of a single best solution for governments to address all households with reimbursements.

Several alternative options to compensate households exist (see also Table 4). First, governments could reform existing transfer programs to include more households or introduce novel programs, potentially targeted at certain parts of the population. Second, governments could establish in-kind transfers. For example, if expenditures on transport fuels are a major determinant of cost burden, governments could find it worthwhile to reduce households' dependence on fossil-fueled cars, e.g., by promoting electric vehicles or increasing investments in public transport infrastructure. Other examples of in-kind transfers comprise financing public goods, such as education, health facilities, or water infrastructure (Franks et al. 2018) or promoting the adoption of electric cooking stoves. Providing some basic amount of LPG at low cost (Schaffitzel et al. 2019) can help circumvent detrimental impacts on LPG users, which are otherwise prone to eventually switching from LPG use to burning (untaxed) firewood or biomass. This matters in the context of development, as residential biomass consumption is associated with dangerous indoor air pollution (Cameron et al. 2016), negative impacts on gender equality (Dinkelman 2011), and unsustainable deforestation (Bailis et al. 2015).

A third conceivable option would be reducing existing taxes (Goulder 1995). For example, lowering excise taxes on food and subsistence goods is likely to render any reform more progressive, since poorer households spend a larger budget share on those goods. In the context of low- and middle-income countries, where informality is widespread, lowering taxes on income or labor would in contrast benefit mostly richer households (Jensen 2022; Besley and Persson 2009). Nevertheless, levying a carbon price while lowering income taxes can help decrease informality, since upstream carbon prices are difficult to evade for the informal sector (Bento et al. 2018).

Countries in which especially affected households differ from others with respect to cooking fuel use or car ownership might also consider exempting cooking or transport fuels from carbon pricing, albeit with detrimental implications for aggregate efficiency, effectiveness and vertical inequality.

Table 4: Stylized channels to compensate households with high carbon pricing incidence: This table shows a selection of stylized instruments that governments could use to compensate households who face exceptionally high additional costs from carbon pricing and differ from the total population by various characteristics. This table hinges on the assumption that governments are primarily concerned about additional costs to households. It neglects other opportunities such as green fiscal spending or reimbursing industries.

Compensating those households for excessive costs which	Example of country	Example of instrument to be considered
are relatively poor?	• Argentina • Bolivia • Brazil • Colombia • Chile • Ecuador	• Lump-sum transfers • Expansion of coverage of existing transfer programs • Subsidies on subsistence consumption goods, such as food, water or housing • In-kind transfers (food, water, health goods and services)
are relatively rich?	• Nicaragua	• Reduction of labor or income taxes • Reduction of contributions to health insurance or contributions to pensions
own (and) use a car?	• Barbados • Brazil • Costa Rica • Dominican Republic • Ecuador • Guatemala • Mexico • Uruguay	• Vouchers for transport fuels • Investments in public transport infrastructure • Subsidies on electric vehicles • Exemption of transport fuels from carbon price • Targeted compensation for car owners (and users), e.g., through vehicle tax
use LPG?	• Mexico • Paraguay • Peru	• Vouchers for LPG • Exemption of LPG from carbon price • Subsidies on electric cook stoves
live in rural/urban areas?	• Brazil • Uruguay	• Provision of local public goods (health, education, water) • Setup of targeted transfer programs
use electricity?	• Bolivia • Guatemala	• Subsidies on electricity prices for consumers • Introduction of block tariffs • Incentives for energy efficiency improvements
identify as ethnic minority?	• Nicaragua • Peru	• Setup of targeted transfer programs
do not have access to established transfer programs?	• El Salvador • Guatemala • Paraguay	• Expansion coverage of existing programs • Setup of targeted transfer programs

6. Conclusion

Our study assesses the role of existing cash transfer schemes in alleviating the impacts of carbon pricing policies on households in 16 countries of Latin America and the Caribbean. First, by providing a comprehensive assessment of cross-country similarities and differences of carbon pricing reforms, we find that differences in consumption patterns *within* expenditure quintiles may matter more than differences in consumption patterns *across* expenditure quintiles. Country-specific factors characterize hardship cases, i.e., especially affected households. Second, the incidence of carbon pricing correlates only poorly with coverage of existing transfer programs. In some cases existing transfer programs are insufficient instruments for facilitating socially balanced carbon pricing policies. Climate policy which is supposed to be efficient, equitable and socially acceptable thus requires additional compensation mechanisms. Future research can help identify such complementary instruments and inspect their implications for public acceptance and hence political feasibility.

7. References

Aguiar, Angel; Chepeliev, Maksym; Corong, Erwin L.; McDougall, Robert; van der Mensbrugghe, Dominique (2019): The GTAP Data Base: Version 10. In *Journal of Global Economic Analysis* 4 (1), pp. 1–27. DOI: 10.21642/JGEA.040101AF.

Aklin, Michaël; Cheng, Chao-Yo; Urpelainen, Johannes (2021): Inequality in policy implementation: caste and electrification in rural India. In *J. Pub. Pol.* 41 (2), pp. 331–359. DOI: 10.1017/S0143814X20000045.

Andersson, Julius J. (2019): Carbon Taxes and CO2 Emissions: Sweden as a Case Study. In *American Economic Journal: Economic Policy* 11 (4), pp. 1–30. DOI: 10.1257/pol.20170144.

Bah, Adama; Bazzi, Samuel; Sumarto, Sudarno; Tobias, Julia (2019): Finding the Poor vs. Measuring Their Poverty: Exploring the Drivers of Targeting Effectiveness in Indonesia. In *The World Bank Economic Review* 33 (3), pp. 573–597. DOI: 10.1093/wber/lhx020.

Bailis, Robert; Drigo, Rudi; Ghilardi, Adrian; Masera, Omar (2015): The carbon footprint of traditional woodfuels. In *Nat. Clim. Chang.* 5 (3), pp. 266–272. DOI: 10.1038/nclimate2491.

Baranzini, Andrea; van den Bergh, Jeroen C. J. M.; Carattini, Stefano; Howarth, Richard B.; Padilla, Emilio; Roca, Jordi (2017): Carbon pricing in climate policy: seven reasons, complementary instruments, and political economy considerations. In *WIREs Clim Change* 8 (4). DOI: 10.1002/wcc.462.

Bastagli, Francesca; Hagen-Zanker, Jessica; Harman, Luke; Barca, Valentina; Sturge, Georgina; Schmidt, Tanja (2019): The Impact of Cash Transfers: A Review of the Evidence from Low- and Middle-income Countries. In *J. Soc. Pol.* 48 (03), pp. 569–594. DOI: 10.1017/S0047279418000715.

Bento, Antonio M.; Jacobsen, Mark R.; Liu, Antung A. (2018): Environmental policy in the presence of an informal sector. In *Journal of Environmental Economics and Management* 90, pp. 61–77. DOI: 10.1016/j.jeem.2018.03.011.

Besley, Timothy; Persson, Torsten (2009): The Origins of State Capacity: Property Rights, Taxation, and Politics. In *American Economic Review* 99 (4), pp. 1218–1244. DOI: 10.1257/aer.99.4.1218.

Best, Rohan; Burke, Paul J.; Jotzo, Frank (2020): Carbon Pricing Efficacy: Cross-Country Evidence. In *Environ Resource Econ* 77 (1), pp. 69–94. DOI: 10.1007/s10640-020-00436-x.

Budolfson, Mark; Dennig, Francis; Errickson, Frank; Feindt, Simon; Ferranna, Maddalena; Fleurbaey, Marc et al. (2021): Protecting the poor with a carbon tax and equal per capita dividend. In *Nat. Clim. Chang.* 11 (12), pp. 1025–1026. DOI: 10.1038/s41558-021-01228-x.

Cain, J. Salcedo; Hasan, Rana; Magsombol, Rhoda; Tandon, Ajay (2010): Accounting for Inequality in India: Evidence from Household Expenditures. In *World Development* 38 (3), pp. 282–297. DOI: 10.1016/j.worlddev.2009.11.014.

Calel, Raphael (2020): Adopt or Innovate: Understanding Technological Responses to Cap-and-Trade. In *American Economic Journal: Economic Policy* 12 (3), pp. 170–201. DOI: 10.1257/pol.20180135.

Cameron, Colin; Pachauri, Shonali; Rao, Narasimha D.; McCollum, David; Rogelj, Joeri; Riahi, Keywan (2016): Policy trade-offs between climate mitigation and clean cook-stove access in South Asia. In *Nat Energy* 1 (1). DOI: 10.1038/nenergy.2015.10.

Cowell, Frank A.; Fiorio, Carlo V. (2011): Inequality decompositions—a reconciliation. In *J Econ Inequal* 9 (4), pp. 509–528. DOI: 10.1007/s10888-011-9176-1.

Cronin, Julie Anne; Fullerton, Don; Sexton, Steven (2019): Vertical and Horizontal Redistributions from a Carbon Tax and Rebate. In *Journal of the Association of Environmental and Resource Economists* 6 (S1), S169-S208. DOI: 10.1086/701191.

Dinkelman, Taryn (2011): The Effects of Rural Electrification on Employment: New Evidence from South Africa. In *American Economic Review* 101 (7), pp. 3078–3108. DOI: 10.1257/aer.101.7.3078.

Dorband, Ira Irina; Jakob, Michael; Kalkuhl, Matthias; Steckel, Jan Christoph (2019): Poverty and distributional effects of carbon pricing in low- and middle-income countries – A global comparative analysis. In *World Development* 115, pp. 246–257. DOI: 10.1016/j.worlddev.2018.11.015.

Douenne, Thomas; Fabre, Adrien (2022): Yellow Vests, Pessimistic Beliefs, and Carbon Tax Aversion. In *American Economic Journal: Economic Policy* 14 (1), pp. 81–110. DOI: 10.1257/pol.20200092.

Duro, Juan Antonio; Teixidó-Figueras, Jordi; Padilla, Emilio (2017): The Causal Factors of International Inequality in CO2 Emissions Per Capita: A Regression-Based Inequality Decomposition Analysis. In *Environ Resource Econ* 67 (4), pp. 683–700. DOI: 10.1007/s10640-015-9994-x.

Farrell, Niall (2017): What Factors Drive Inequalities in Carbon Tax Incidence? Decomposing Socioeconomic Inequalities in Carbon Tax Incidence in Ireland. In *Ecological Economics* 142, pp. 31–45. DOI: 10.1016/j.ecolecon.2017.04.004.

Fay, Marianne; Hallegatte, Stephane; Vogt-Schilb, Adrien; Rozenberg, Julie; Narloch, Ulf; Kerr, Tom (2015): Decarbonizing Development: Three Steps to a Zero-Carbon Future: The World Bank.

Fazekas, Andreas; Bataille, C.; Vogt-Schilb, Adrien (2022): Achieving Net-Zero Prosperity: How Governments Can Unlock 15 Essential Transformations. Inter-American Development Bank.

Feindt, Simon; Kornek, Ulrike; Labeaga, José M.; Sterner, Thomas; Ward, Hauke (2021): Understanding regressivity: Challenges and opportunities of European carbon pricing. In *Energy Economics* 103, p. 105550. DOI: 10.1016/j.eneco.2021.105550.

Feng, Kuishuang; Hubacek, Klaus; Liu, Yu; Marchán, Estefanía; Vogt-Schilb, Adrien (2018): Managing the distributional effects of energy taxes and subsidy removal in Latin America and the Caribbean. In *Applied Energy* 225, pp. 424–436. DOI: 10.1016/j.apenergy.2018.04.116.

Fields, Gary S. (2003): Accounting for Income Inequality and its Change: A New Method, With Application to the Distribution of Earnings in the United States. In *Research in Labor Economics* (22), pp. 1–38. Available online at 0147-9121/doi:10.1016/S0147-9121(03)22001-X.

Fischer, Carolyn; Pizer, William A. (2019): Horizontal Equity Effects in Energy Regulation. In *Journal of the Association of Environmental and Resource Economists* 6 (S1), S209-S237. DOI: 10.1086/701192.

Franks, Max; Lessmann, Kai; Jakob, Michael; Steckel, Jan Christoph; Edenhofer, Ottmar (2018): Mobilizing domestic resources for the Agenda 2030 via carbon pricing. In *Nat Sustain* 1 (7), pp. 350–357. DOI: 10.1038/s41893-018-0083-3.

Garaffa, Rafael; Cunha, Bruno S.L.; Cruz, Talita; Bezerra, Paula; Lucena, André F.P.; Gurgel, Angelo C. (2021): Distributional effects of carbon pricing in Brazil under the Paris Agreement. In *Energy Economics* 101, p. 105396. DOI: 10.1016/j.eneco.2021.105396.

Goulder, Lawrence (1995): Environmental taxation and the double dividend: A reader's guide. In *International Tax and Public Finance* 2 (2), pp. 157–183. Available online at https://econpapers.repec.org/article/kapitaxpf/v_3a2_3ay_3a1995_3ai_3a2_3ap_3a157-183.htm.

Greve, Hannes; Lay, Jann (2022): "Stepping down the ladder": The impacts of fossil fuel subsidy removal in a developing country. In *Journal of the Association of Environmental and Resource Economists*, Article 721375. DOI: 10.1086/721375.

IMF (2020): World Economic Outlook Database, October 2020. In *IMF*. Available online at https://www.imf.org/en/Publications/WEO/weo-database/2020/October, checked on 2/11/2021.

Jenkins, Jesse D. (2014): Political economy constraints on carbon pricing policies: What are the implications for economic efficiency, environmental efficacy, and climate policy design? In *Energy Policy* 69, pp. 467–477. DOI: 10.1016/j.enpol.2014.02.003.

Jensen, Anders (2022): Employment Structure and the Rise of the Modern Tax System. In *American Economic Review* 112 (1), pp. 213–234. DOI: 10.1257/aer.20191528.

Klenert, David; Mattauch, Linus (2016): How to make a carbon tax reform progressive: The role of subsistence consumption. In *Economics Letters* 138, pp. 100–103. DOI: 10.1016/j.econlet.2015.11.019.

Klenert, David; Mattauch, Linus; Combet, Emmanuel; Edenhofer, Ottmar; Hepburn, Cameron; Rafaty, Ryan; Stern, Nicholas (2018): Making carbon pricing work for citizens. In *Nature Clim Change* 8 (8), pp. 669–677. DOI: 10.1038/s41558-018-0201-2.

Lambert, Sylvie; Ravallion, Martin; van de Walle, Dominique (2014): Intergenerational mobility and interpersonal inequality in an African economy. In *Journal of Development Economics* 110, pp. 327–344. DOI: 10.1016/j.jdeveco.2014.05.007.

Leroutier, Marion (2022): Carbon pricing and power sector decarbonization: Evidence from the UK. In *Journal of Environmental Economics and Management* 111, p. 102580. DOI: 10.1016/j.jeem.2021.102580.

Maestre-Andrés, Sara; Drews, Stefan; van den Bergh, Jeroen (2019): Perceived fairness and public acceptability of carbon pricing: a review of the literature. In *Climate Policy* 19 (9), pp. 1186–1204. DOI: 10.1080/14693062.2019.1639490.

Malerba, Daniele; Gaentzsch, Anja; Ward, Hauke (2021): Mitigating poverty: The patterns of multiple carbon tax and recycling regimes for Peru. In *Energy Policy* 149, p. 111961. DOI: 10.1016/j.enpol.2020.111961.

Montenegro, Cristhian; Ramirez-Alvarez, Jose (2022): Fuel subsidies in Ecuador: A Computable General Equilibrium model for targeting evaluation. Available online at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4044106.

Morduch, Jonathan; Sicular, Terry (2002): Rethinking Inequality Decomposition, with Evidence from Rural China. In *Econ J* 112 (476), pp. 93–106. DOI: 10.1111/1468-0297.0j674.

Ohlendorf, Nils; Jakob, Michael; Minx, Jan Christoph; Schröder, Carsten; Steckel, Jan Christoph (2021): Distributional Impacts of Carbon Pricing: A Meta-Analysis. In *Environ Resource Econ* 78 (1), pp. 1–42. DOI: 10.1007/s10640-020-00521-1.

Olson, Mancur (1965): The logic of collective action. Public goods and the theory of groups. Cambridge, Massachusetts, London, England: Harvard University Press (Harvard economic studies, Volume 124).

Parry, Ian W. H.; Black, Simon; Vernon, Nate (2021): Still not getting energy prices right. A global and country update of fossil fuel subsidies. Washington, D.C. (IMF working paper, WP/21, 236). Available online at https://www.elibrary.imf.org/downloadpdf/journals/001/2021/236/001.2021.issue-236-en.xml.

Pearce, David (1991): The Role of Carbon Taxes in Adjusting to Global Warming. In *Econ J* 101 (407), p. 938. DOI: 10.2307/2233865.

Peters, Glen P.; Andrew, Robbie; Lennox, James (2011): Constructing an Environmentally-Extended Multi-Regional Input-Output Table Using the GTAP Database. In *Economic Systems Research* 23 (2), pp. 131–152. DOI: 10.1080/09535314.2011.563234.

Pigou, Artur C. (1920): The Economics of Welfare. Edited by Macmillan.

Poterba, James M. (2016): Is the Gasoline Tax Regressive? In Don Fullerton (Ed.): Distributional effects of environmental and energy policy: Routledge (International library of environmental economics and policy), pp. 31–50. Available online at https://www.taylorfrancis.com/chapters/edit/10.4324/9781315257570-2/gasoline-tax-regressive-james-poterba.

Rafaty, Ryan; Dolphin, Geoffroy; Pretis, Felix (2020): Carbon Pricing and the Elasticity of CO2 Emissions (EPRG Working Paper, 2035). Available online at https://www.jstor.org/stable/pdf/resrep30490.pdf.

Rausch, Sebastian; Metcalf, Gilbert E.; Reilly, John M. (2011): Distributional impacts of carbon pricing: A general equilibrium approach with micro-data for households. In *Energy Economics* 33, S20-S33. DOI: 10.1016/j.eneco.2011.07.023.

Renner, Sebastian (2018): Poverty and distributional effects of a carbon tax in Mexico. In *Energy Policy* 112, pp. 98–110. DOI: 10.1016/j.enpol.2017.10.011.

Rentschler, Jun; Bazilian, Morgan (2017): Policy Monitor—Principles for Designing Effective Fossil Fuel Subsidy Reforms. In *Review of Environmental Economics and Policy* 11 (1), pp. 138–155. DOI: 10.1093/reep/rew016.

Robles, Marcos; Rubio, Marcela G.; Stampini, Marco (2019): Have cash transfers succeeded in reaching the poor in Latin America and the Caribbean? In *Dev Policy Rev* 37 (S2). DOI: 10.1111/dpr.12365.

Sager, Lutz (2019): Income inequality and carbon consumption: Evidence from Environmental Engel curves. In *Energy Economics* 84, p. 104507. DOI: 10.1016/j.eneco.2019.104507.

Schaffitzel, Filip; Jakob, Michael; Soria, Rafael; Vogt-Schilb, Adrien; Ward, Hauke (2019): Can government transfers make energy subsidy reform socially acceptable? A case study on Ecuador. In *Energy Policy*, p. 111120. DOI: 10.1016/j.enpol.2019.111120.

Shorrocks, A. F. (1982): Inequality Decomposition by Factor Components. In *Econometrica* 50 (1), p. 193. DOI: 10.2307/1912537.

Steckel, Jan C.; Dorband, Ira I.; Montrone, Lorenzo; Ward, Hauke; Missbach, Leonard; Hafner, Fabian et al. (2021): Distributional impacts of carbon pricing in developing Asia. In *Nat Sustain* 4 (11), pp. 1005–1014. DOI: 10.1038/s41893-021-00758-8.

Stiglitz, Joseph E.; Stern, Nicholas; Duan, Maosheng; Edenhofer, Ottmar; Giraud, Gaël; Heal, Geoffrey M. et al. (2017): Report of the High-Level Commission on Carbon Prices.

Sunter, Deborah A.; Castellanos, Sergio; Kammen, Daniel M. (2019): Disparities in rooftop photovoltaics deployment in the United States by race and ethnicity. In *Nat Sustain* 2 (1), pp. 71–76. DOI: 10.1038/s41893-018-0204-z.

Symons, Elizabeth; Proops, John; Gay, Philip (1994): Carbon Taxes, Consumer Demand and Carbon Dioxide Emissions: A Simulation Analysis for the UK. In *Fiscal Studies* 15 (2), pp. 19–43. DOI: 10.1111/j.1475-5890.1994.tb00195.x.

Vogt-Schilb, Adrien; Hallegatte, Stephane (2017): Climate policies and nationally determined contributions: reconciling the needed ambition with the political economy. In *WIREs Energy Environ* 6 (6), e256. DOI: 10.1002/wene.256.

Vogt-Schilb, Adrien; Walsh, Brian; Feng, Kuishuang; Di Capua, Laura; Liu, Yu; Zuluaga, Daniela et al. (2019): Cash transfers for pro-poor carbon taxes in Latin America and the Caribbean. In *Nat Sustain* 2 (10), pp. 941–948. DOI: 10.1038/s41893-019-0385-0.

World Bank (2020): World Development Indicators DataBank. Available online at https://databank.worldbank.org/source/world-development-indicators, checked on 2/11/2021.

World Bank (2021): State and Trends of Carbon Pricing 2021. Washington, DC: World Bank. Available online at https://openknowledge.worldbank.org/handle/10986/35620.