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Poverty and distributional effects of carbon pricing in low- and middle-income countries – A global comparative analysis

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ABSTRACT

Even though concerns about adverse distributional implications for the poor are one of the most important political challenges for carbon pricing, the existing literature reveals ambiguous results. For this reason, we assess the expected incidence of moderate carbon price increases for different income groups in 87 mostly low- and middle-income countries. Building on a consistent dataset and method, we find that for countries with per capita incomes of below USD 15,000 per year (at PPP-adjusted 2011 USD) carbon pricing has, on average, progressive distributional effects. We also develop a novel decomposition technique to show that distributional outcomes are primarily determined by differences among income groups in consumption patterns of energy, rather than of food, goods or services. We argue that an inverse U-shape relationship between energy expenditure shares and income explains why carbon pricing tends to be regressive in countries with relatively higher income. Since these countries are likely to have more financial resources and institutional capacities to deal with distributional issues, our findings suggest that mitigating climate change, raising domestic revenue and reducing economic inequality are not mutually exclusive, even in low- and middle-income countries.

1. Introduction

Mitigating climate change is indispensable for achieving the sustainable development goals under the Agenda 2030. Impacts of unabated climate change are expected to disrupt economic development and to disproportionally affect the poorest parts of the population, especially in lower-income countries (Dell, Jones, & Olken, 2012). In the Paris Agreement (UNFCCC, 2015), the international community, therefore, pledges to limit global warming below 2 °C.

Economists have frequently emphasized that carbon pricing is a prerequisite for efficient climate change mitigation (Nordhaus, 1993; Stern, 2008). The High-Level Commission on Carbon Prices (Stiglitz & Stern, 2017) concluded that carbon prices of USD 40–80/tCO_2 by 2020 and of USD 50–100/tCO_2 by 2030 would be necessary in all countries to achieve this target. Considerably higher global price levels might be justified when considering more ambitious temperature targets (IPCC, 2018) or possible catastrophic damages of climate change (Howard & Sterner, 2017; Nordhaus, 2018).

A common concern of introducing even moderate carbon prices – and thereby increasing fossil fuel prices – is their possible adverse impact on poverty and inequality. Such concerns of inclusive development can decisively hamper the political feasibility of respective reforms and provoke public resistance (Baranzini et al., 2017; Drews & van den Bergh, 2016; Gevrek & Uyduranoglu, 2015; Klenert et al., 2018; Lockwood, 2015). Recent contributions (reviewed in Section 2) have broadly confirmed that in industrialized countries carbon pricing tends to be regressive. In lower-income countries, however, the evidence is more ambiguous. Results seem to be driven by differences in the design of the study and methodological approach (c.f. Beck, Rivers, Wigle, & Yonezawa, 2015; da Silva Freitas, de Santana Ribeiro, de Souza, & Hewings, 2016; Rausch, Metcalf, & Reilly, 2011; Sterner, 2012b), which makes it difficult to derive robust insights regarding the distributional incidence of carbon pricing. Further, there has not been any attempt to identify the factors that explain differences in the

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magnitude and distribution of the effects on income across the countries.

To fill this gap, we analyze a consistent dataset of household expenditure data from 87 developing and emerging countries. Using multi-regional input–output tables (MRIO), we determine fossil energy-related carbon footprints (i.e. direct CO_2 emissions related to direct fossil fuel use as well as indirect CO_2 emissions generated to produce goods and services for final consumption) of households from different income groups in a consistent way across countries. We assess the effects of carbon pricing on income by means of a microsimulation to determine the costs of maintaining current consumption with a carbon price in place.

In our analysis, we first focus on effects on absolute income and poverty that an entry-level carbon price of USD 30/tCO_2 would entail for the poorest income group in each country. Second, we estimate whether a carbon price would be progressive or regressive in each country. By means of a novel within-country decomposition, we investigate how differences in consumption baskets between income groups drive domestic distributional outcomes.

We find that distributional outcomes within a country largely depend on energy expenditure patterns. Our results show that, as income levels rise, carbon prices are more likely to be regressive, i.e. the poorest households would be charged a greater proportion of their income than the national average. We show that this effect can be attributed to an inverse U-shape Engel curve relationship between income and the proportion of energy expenditure. These findings can help to inform national governments in designing domestic policies to reduce emissions, and for international negotiations on carbon pricing.

This paper proceeds as follows. In Section 2, we review the relevant literature on distributional impacts of carbon pricing. Section 3 describes the data and methods used for our analysis. We present the results of various analyses in Section 4, including the direct income effect of carbon taxes for the lowest income groups (4.1), the distributional effects within countries (4.2), within-country differences with varying consumption patterns (4.3) and an estimation of the energy Engel curve (4.4). A critical discussion including methodological issues follows in Section 5, and we conclude in Section 6.

2. Motivation and relation to previous literature

The aim of our study is to assess the distributional impacts of an economy-wide price on CO_2 emissions from using fossil fuels, for example implemented by means of a carbon tax. One major objection against carbon pricing in developing countries is related to the large share of emissions from land-use, agriculture and the use of traditional biomass as fuel. Because of the difficulty to monitor these emissions and due to related institutional and administrative barriers, it is frequently questioned whether carbon pricing is an adequate instrument for mitigating emissions from non-fossil energy sources (Grosjean et al., 2016). In contrast, fossil energy-related emissions potentially show much higher growth rates and are expected to dominate aggregate future emissions in most developing countries in business as usual pathways (Riahi et al., 2017). Hence, carbon pricing on fossil energy will become an important policy instrument to address carbon emissions in developing countries in the near- to mid-term future (Stiglitz & Stern, 2017), which is also reflected in many of the Nationally Determined Contributions (NDCs) submitted to the UNFCCC (World Bank, Ecofys, & Vivid Economics, 2017). Carbon pricing in our analysis, therefore, refers to carbon emissions from fossil energy.

Carbon pricing for fossil energy-related emissions can have important non-environmental benefits for developing countries. Coady, Parry, Sears, and Shang (2017) show that besides environmental benefits such as air quality and related health improvements (Deng, Liang, Liu, & Anadon, 2017), there are large fiscal and welfare gains from reforming fossil fuel subsidies (i.e. abolishing negative carbon prices). Upstream carbon taxes are generally easier to administer than other income or sales taxes (Fay et al., 2015). Furthermore, they can increase the efficiency of the tax system and broaden the tax base, especially in economies with a large informal sector (Bento, Jacobsen, & Liu, 2018; Liu, 2013; Markandya, González-Eguino, & Escapa, 2013). The revenues from carbon pricing can mobilize domestic funds for achieving sustainable development goals in line with the Addis Ababa Action Agenda (Franks, Lessmann, Jakob, Steckel, & Edenhofer, 2018; Jakob et al., 2016; OECD, 2017; UN, 2015), particularly in countries with low tax to GDP ratios (Besley & Persson, 2014). We, hence, conduct our analysis for carbon pricing of fossil energy- and process-based CO_2 emissions (occurring in, for example, power generation, industry, and transportation).

Existing studies on distributional effects examining both direct and indirect price changes (i.e. of energy use as well as consumption of goods and services that use energy as an input) largely observe regressive impacts for economy-wide CO_2 prices in higher-income countries, which can be explained by the more carbon-intensive consumption patterns (in terms of CO_2 emission per monetary unit) of poorer households (cf. Feng et al., 2010; Grainger & Kolstad, 2010; Kerkhof, Nonhebel, & Moll, 2009; Kerkhof, Moll, Drissen, & Wilting, 2008; Wier, Birr-Pedersen, Jacobsen, & Klok, 2005). Results for developing and middle-income economies are more diverse. Some studies find progressive impacts in South Africa (van Heerden et al., 2005), Pakistan (Shah & Larsen, 1992), China (Brenner, Riddle, & Boyce, 2007), India (Datta, 2010), Indonesia (Yusuf, 2008), Vietnam (Nurdianto & Resosudarmo, 2016) and Mexico (Renner, 2018). In contrast, regressive or mixed distributions are found in South Africa (Devarajan, Go, Robinson, & Thierfelder, 2011), Indonesia, Malaysia and the Philippines (Nurdianto & Resosudarmo, 2016), and Brazil (da Silva Freitas et al., 2016).

Those analyses not only differ in terms of regional coverage, but also deploy varying methods, data and research designs. This hampers a systematic comparison across countries as such differences decisively drive the results.[1] While studies for industrialized countries generally rely on microsimulations, most developing country studies are based on Computable General (or Partial) Equilibrium models. Very few previous studies have performed cross-country comparisons of the direct and indirect incidence of carbon pricing,[2] and none have, to our knowledge, provided insights as to why the absolute and distributional effects of carbon pricing vary across countries.

Our within-country decomposition accounts for the fact that consumption patterns systematically change with income. Engel (1895) was the first study to establish a negative relationship between income and the proportion spent on food, which has since been shown to be a robust empirical regularity across time and space (Engel's Law) (cf. Kaus, 2013). Following this line of research, relationships between income and consumption patterns are frequently called 'Engel curves'. Kaus (2013) confirms that systematic regularities in expenditure patterns across countries exist for some

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[1] Ohlendorf, Jakob, Minx, Schröder, and Steckel (2018) show that certain differences in study designs significantly determine the distributional findings, e.g. the types of energy carriers considered, or whether direct or indirect effects or behavioral adjustments are estimated.

[2] A recent review by Wang, Hubacek, Feng, Wei, and Liang (2016) provides a useful overview of the respective literature. However, it features mostly middle- and higher-income countries and also does not address the heterogeneity between existing studies. In contrast, del Granado et al. (2012) and Sterner (2012a) do provide country comparisons. However, they only consider direct effects from end-user fuel combustion.

aggregate consumption categories (e.g. transport). Recent works emphasize that in higher-income countries, direct energy consumption and (private) transport can be considered as necessities and exhibit decreasing expenditure shares with rising income (c.f. Flues & Thomas, 2015; Klenert, Schwerhoff, Edenhofer, & Mattauch, 2016; Levinson & O'Brien, 2015; Meier, Jamasb, & Orea, 2013). In many developing countries, however, there is often a lack of access to energy and transportation for the poorest income groups and direct energy expenditure shares increase with rising income. This is partially due to the use of traditional biomass (which is gathered rather than purchased) as primary fuel by the very poor (Bacon, Bhattacharya, & Kojima, 2010; del Granado, Javier, Coady, & Gillingham, 2012; Pachauri & Spreng, 2004; Sterner, 2012). Our paper contributes to this empirical literature as it is the first to estimate an energy Engel curve across countries to explain a systematic relationship between per capita incomes and the expected distributional impact of a carbon price.

3. Data and methods

In this section, we first provide an overview of the microsimulation method employed to estimate carbon footprints and to assess the absolute and distributional incidence. We then develop a novel decomposition approach to explain the distributional differences between countries. The decomposition breaks down the distribution across income groups within each country into four consumption categories, namely energy, food, goods and services. Finally, we develop the econometric model to estimate the energy Engel curve.

3.1. Data

In order to assess the distribution of income effects of carbon pricing (i.e. households' additional expenditures) across different income groups, we combine 2010 household expenditure data with fossil energy-related carbon intensity data from an environmentally-extended multiregional input-output (MRIO) model for the year 2011. The Global Consumption Database (GCD) (World Bank, 2017b) compiles and harmonizes data from representative household surveys in 92 countries between 2000 and 2010, covering roughly 75% of the world population in 2010 (World Bank, 2017c). For 87 of these countries, the data are of sufficient quality for this analysis (see supplemental appendices S1 for a list). The expenditure data are aggregated into 106 product and service categories and extrapolated for the year 2010 in order to ensure comparability. Households are categorized as rural or urban and divided into four consumption segments based on global average income distribution (cf. Table 1).[3] Since thresholds are fixed, the poorest income group, which we refer to, does not necessarily correspond to the poor as defined by national poverty lines. These ranged from below PPP-adjusted 2011 USD 1.9 in most low-income to an average of USD 3.2 per capita per day in lower-middle-income countries in 2010/2011 (Jolliffe & Prydz, 2016, 9ff. Online Appendices). Furthermore, the highest group is relatively smaller than other consumption groups in most countries. In a few least developed countries, data for this income group are completely non-existent.

The carbon intensities of products and services, i.e. the emissions per monetary unit, are based on an MRIO table that is derived from the Global Trade Analysis Project (GTAP 9; Narayanan, Aguiar, & McDougall, 2015). We use a procedure described by Peters, Andrew, and Lennox (2011), which traces the interdependencies of 57 sectors in 140 countries or world regions. The environmental extension of the GTAP database allows us to relate monetary flows to average indirect carbon emissions for each sector, taking account of all fossil energy commodities, their emission factors and energy conversion coefficients as well as other inputs used in production (Lee, 2008). Additionally, the direct emissions from household fossil fuel combustion are added for all sectors which produce final-demand fuel commodities. Dividing total emissions by their associated monetary values, we arrive at carbon intensities (see supplemental appendices S3 for further detail). As the GTAP data do not include other greenhouse gas emissions (e.g. methane or CO_2 emissions from land use change), the carbon price referred to in this paper only applies to fossil energy-related CO_2 emissions. Using conversion tables provided by GTAP, the 106 consumption categories of the household data are matched to the corresponding 33 GTAP sectors, which comprise end-consumer products, and assigned their sector's average carbon intensity for each country (see Fig. 1). The aggregate nature of the GCD consumption categories does not allow us to precisely single out expenditures or imputed values for solid biomass consumption because, for some countries, these expenditures are subsumed in the category 'Other Fuels' together with fossil solid and liquid fuel consumption. While this does not impact our estimate of the total fossil fuel-related emissions from respective consumption categories, it does influence how emissions are allocated among income groups. The GCD documentation does not provide information to identify the countries for which biomass use was considered. We discuss the implications of this aggregation in detail in Section 5.2.

While GTAP provides country-level data for most of the sample countries, 24 countries are subsumed in 10 of GTAP's aggregate world regions. In order to determine national emissions data for these countries, we disaggregate GTAP's regional sector emissions using CAIT Country GHG Emissions Data provided by the World Resources Institute (WRI, 2018). We split the regional emissions of goods and services sectors into national emissions based on the countries' shares in regional energy-born CO_2 emissions and, if available, we disaggregate the regional emissions from the energy sectors and electricity according the countries' shares in energy and electricity emissions (for further details and a list of aggregated countries, refer to Section S4).

3.2. Microsimulation

We assess the financial costs of maintaining a given household's current consumption after the introduction of a carbon price. We assume that this price applies to domestic as well as imported goods and services. This scenario corresponds to either a globally uniform carbon price, or a domestic price in combination with border-tax adjustment for emissions that were generated to produce imports (Jakob, Steckel, & Edenhofer, 2014). The underlying household data used in our analysis are empirical observations under the existing subsidy and tax regimes. For this reason, the scenarios we analyse correspond to situations in which a carbon price is applied, with the existing pricing regimes still in place. Alternatively, one could also think of a setting in which fossil fuel subsidies are replaced by a carbon price that is differentiated across fuel types and economic sectors. This would reflect the political economy aspects which explain existing differentiated subsidies by political and economic power relations. It seems reasonable to assume that these relations will also result in differentiated carbon prices.[4] Upstream taxes levied on all fossil

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[3] Following the literature, we use consumption expenditure data as proxy for lifetime income to divide households into income groups. For a discussion, refer to Sterner (2012a), or Poterba (1991), Metcalf (1999), Hassett et al. (2009).

[4] It might be worthwhile studying the distributional impacts of fossil fuel subsidy reform in isolation, or of a tax that imposes a uniform carbon price throughout the entire economy. The required information, however, cannot easily be retrieved from available data across the sample countries.

Table 1
Definition of consumption segments and associated percentiles of the global income distribution as used in World Bank (2017b).

Income groups	Lowest	Low	Middle	Higher
Total daily per capita consumption (PPP-adjusted USD)	<2.97	2.97–8.44	8.44–23.03	>23.03
Global income distribution (percentile)	<50th	51st–75th	76th–90th	>91st

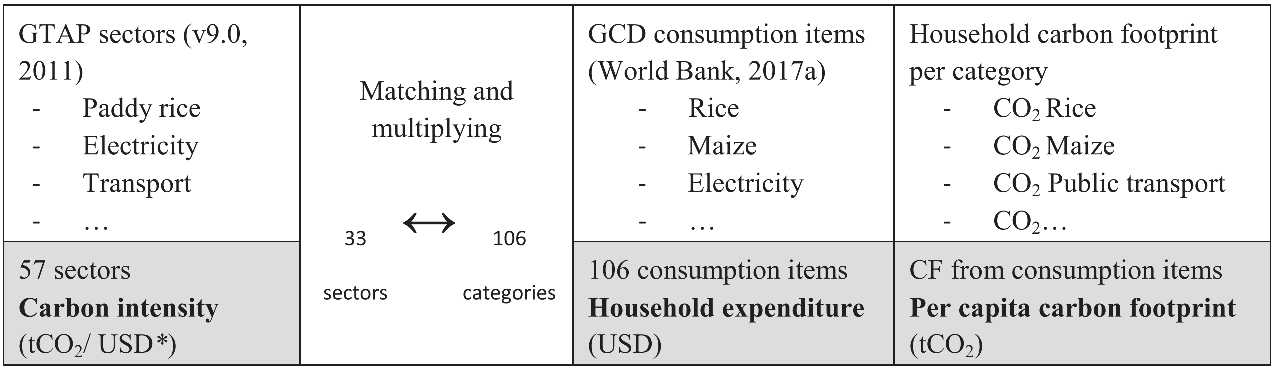

Fig. 1. Matching of MRIO sectors with disaggregated household consumption items; *USD from GCD, refer to Section S3 in the supplemental appendices for further detail.

fuels according to their carbon intensity at the source or point of import would be straightforward to implement and could increase the overall efficiency of the tax system, especially in countries with low institutional and administrative capacities and a large informal sector (Liu, 2013; Markandya, González-Eguino, & Escapa, 2013).

For the assessment of income effects, we focus on the short-term welfare changes in terms of compensating variation. We conduct a microsimulation in which we apply an arithmetic approach that assumes fixed consumption patterns, i.e. that households do not adjust their behavior in response to the carbon price (Bourguignon & Spadaro, 2006): Total annual additional expenditures e arising from the carbon price of income group *i* in country *c* are a multiplicative function of (a) carbon intensities (tCO_2/USD) κ of consumption items from each sector *j*, (b) total expenditures α, and of (c) the tax rate t (USD/tCO_2),

$$e_{ic} = \sum_{j} \kappa_{jc} * \alpha_{ijc} * t \tag{1}$$

For the global level, we calculate expenditures e_{iw} and carbon intensities κ_{jw} based on expenditure-weighted sums over all countries in our sample. Consistent with the literature, all price increases resulting from an economy-wide carbon tax are expected to be fully passed through from producers to final consumers (cf. Kerkhof, Nonhebel, & Moll, 2009).

Adapted from the basic MRIO structure (cf. Leontief, 1986; Minx et al., 2009) emission intensities κ_{jc} are derived as:

$$\kappa_{jc} = c(I - A)^{-1} * Y \tag{2}$$

where *c* is a vector assigning a carbon coefficient to each sector. The $(I - A)^{-1}$ matrix, or Leontief inverse (cf. Leontief, 1986), accounts for all upstream inputs that are required to produce one unit of final demand for each sector. A is a matrix of technical coefficients based on inter-sectoral commodity flows, I is the identity matrix and *Y* is the vector of final residential demand.

3.3. Decomposition analysis of within-country distribution

In order to explain differences in the exposure to carbon pricing of different income groups in a country, we decompose the price burden relative to the national average into the effects from four different consumption categories. These are energy, food, goods and services. The deviation of income group *i*'s expenditure share on sector *j* from the national average is $\Delta\alpha_{ijc} = \alpha_{ijc}\text{-}\alpha_{jc}^{avg}$, and the deviation of sector *j*'s carbon intensity from the national carbon intensity is $\Delta\kappa_{jc} = \kappa_{jc}\text{-}\kappa_{c}^{avg}$. This allows us to express the relative distributional impact, i.e. which share of the disposable income group *i* in country *c* would pay relative to the national average. This measure, which we call σ_{ic}, can be expressed as:

$$\sigma_{ic} = \frac{\sum_j \kappa_{jc}\alpha_{ijc}}{\sum_j \kappa_{jc}\alpha_{jc}^{avg}} = \frac{\sum_j (\kappa_c^{avg} + \Delta\kappa_{jc})(\alpha_{jc}^{avg} + \Delta\alpha_{ijc})}{\sum_j \kappa_{jc}\alpha_{jc}^{avg}}$$
$$= 1 + \frac{\sum_j (\kappa_c^{avg} + \Delta\kappa_{jc})\Delta\alpha_{ijc}}{\sum_j \kappa_{jc}\alpha_{jc}^{avg}} \tag{3}$$

As $\sum_j \kappa_c^{avg}\Delta\alpha_{ijc} = \kappa_c^{avg}\sum_j \Delta\alpha_{ijc} = 0$, this becomes:

$$\sigma_{ic} = 1 + \frac{\sum_j \Delta\kappa_{jc}\Delta\alpha_{ijc}}{\sum_j \kappa_{jc}\alpha_{jc}^{avg}}. \tag{4}$$

That is, if households in income group *i* consume a greater share of goods that are more carbon intensive than the country average household, they will be more heavily affected and the expression will exceed unity.

3.4. Engel curve for energy expenditure shares

To describe the systematic relationship between income and energy expenditures which is crucial for distributional outcomes, we estimate a stylized energy Engel curve. Following the literature, we use a simple model, which describes energy expenditure shares of income group *i* in country *c* as a function of per capita income $pcExp_{ic}$ (cf. Levinson & O'Brien, 2015; Isaksen & Narbel, 2017; Meier, Jamasb, & Orea, 2013). As energy expenditures comprise fossil fuels, electricity as well as public transport, the estimated relationship with income subsumes the individual underlying consumption patterns. Due to the aggregate nature of the data and the merely descriptive purpose of the estimate, we think of our results as stylized facts and refrain from including additional covariates in the econometric specification. This seems reasonable as income and expenditure levels have been identified as the strongest predictors of household energy needs (Hasan & Mozumder, 2017; Lenzen et al., 2006; Meier, Jamasb, & Orea, 2013). In order to account for idiosyncratic differences in energy consumption patterns between countries, we include country-fixed effects. We compare three models with energy expenditure share as a linear, square, and cubic function of income.

4. Results

In this section, we first focus on the absolute income effects that would arise in the poorest households from a USD 30 per ton CO_2 price increase and how they differ across countries. Second, we map the distributional effects of a carbon price within countries and decompose them into four consumption terms. Finally, we estimate an Engel Curve for energy expenditures.

4.1. Tax burden for the poorest income group

The absolute reduction of the disposable incomes of households in the lowest group, which would result from a carbon price increase of USD 30 per ton CO_2 (cf. Section 5.3 for a discussion of the price level), are mapped in Fig. 2. In the majority of sample countries, the lowest group would lose less than 2.5% of their income at current consumption levels. The effects vary widely, ranging from less than 0.2% (Ethiopia) to up to 5.5% (Belarus). While the results are rather heterogeneous, the poorest in middle-income economies suffer larger impacts than those in lower-income countries. Apart from Belarus, Kazakhstan (5.4%), Mongolia (5.4%), South Africa (4.1%) and Azerbaijan (3.8%) also show pronounced income effects.

The total impact not only depends on the magnitude of the income loss to the poorest, but also on the size of the poorest group – in relative and absolute terms. Fig. 3 (left) shows that for the assumed carbon price of USD 30/tCO_2, in 17 countries, the poorest income group would lose more than 2.5% of their disposable income. However, in only five of these countries, the share of the population that belongs to the lowest income group amounts to more than 50%, namely in India, Egypt, Indonesia, Benin and Nicaragua. Hence, implementing a carbon price in these countries might be in conflict with poverty eradication targets and, therefore, require particular attention from policy makers. From a global perspective, the majority of strongly affected poor live in a limited number of countries, mainly in Indonesia and India, followed by other populous emerging economies, particularly China (cf. Fig. 3, right).

4.2. Progressive and regressive distributional impacts within countries

To analyze distributional implications within countries, we compare the income effects on the lowest income group e_{1c} to the national average (cf. Fig. 4). We prefer this measure over inequality measures such as the Gini or the Theil index for two reasons. First, our household expenditure data are structured as four discrete income groups, which would permit only a coarse approximation of the respective indices. Second, the distributional implication for the poor and nearly poor segments of society is arguably the most important element for climate policies aligned with poverty reduction targets. In any case, the results we obtain with this measure of tax distribution are significantly correlated with distributional estimates based on the more standard Gini coefficient of inequality (see Appendix 1).

We find that richer countries are more likely to show regressive effects (i.e. values greater than unity). In Bosnia and Herzegovina, a carbon price would be most regressive. The poorest group would, relative to their income, pay more than three times as much as the country average. In Belarus, Serbia, Montenegro and South Africa the lowest income group would pay a share about 1.5 times as large as the national average. In contrast, most Sub-Saharan African countries, and lower-income countries in South East Asia and Latin America show (at least slightly) progressive outcomes.[5]

Fig. 5 reveals a positive correlation between distributional impacts and average per capita incomes. That is, on average, carbon pricing can be expected to display progressive effects on the income distribution in poorer countries, while having regressive effects in richer countries (with per capita incomes of above roughly USD 15,000).

4.3. Consumption patterns determining the within-country distribution

In order to understand what drives differences in within-country distributional outcomes, we decompose the income effect on the lowest income group relative to the national average (σ_{ic} in Eq. (4)) into effects from four major consumption categories, namely direct energy (which includes private and public transport), food, services and other goods. The magnitude and direction of each consumption term is driven by the sector's carbon intensity relative to the national average $\Delta\kappa_{jc}$, as well as the lowest income group's expenditure share for that sector relative to the national average $\Delta\alpha_{ijc}$. Fig. 6 plots both components against each other for each country. It reveals that energy products are more carbon intensive than the national average in all countries while food and services are less carbon intensive. The relative carbon intensity of the goods category varies across countries. In terms of consumption, the lowest income group most often consumes relatively less energy, services and goods than the national average, but spends relatively more than average on food. The color coding of progressive (green) and regressive (red) outcomes indicates that all countries in which carbon pricing would be progressive exhibit lower than average energy expenditure shares among the poorest households. We apply a simple linear probability regression of the signs of the consumption terms using a dummy which denotes whether σ_{ic} is smaller or larger than unity. It shows that a positive energy term increases the probability of a carbon price being regressive by 95% (at a significance level of 1%, see Appendix 2). As $\Delta\kappa_{jc}$ is positive in all countries, i.e. the carbon intensity of energy is always greater than the average carbon intensity, the sign of the energy term depends exclusively on the energy expenditure share ($\Delta\alpha_{ijc}$). Thus, across our sample of 87 countries the decomposition analysis shows that the domestic distribution of carbon prices largely depends on relative direct energy consumption patterns of the poor.

4.4. Engel curve estimation for energy expenditure shares

Differences in carbon footprints within a country are primarily determined by differences in energy expenditure shares between income groups (cf. Fig. 6). Understanding the relationship between per capita incomes and energy consumption patterns can help to explain why we find carbon pricing to be progressive for poorer countries and regressive for richer ones (cf. Fig. 5). For this reason, we estimate Engel curves that explain energy expenditure shares as a function of income.

Table 2 reports the results for country-fixed effects model specifications of the energy Engel curve for a linear, quadratic, and a cubic functional form.[6] Each of the four income groups in each sample country constitutes one observation. Both the significance levels

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[5] Note that we refrain from comparing our results with those of previous country studies due to the reasons outlined in Section 2 and endnote 1.

[6] We obtain very similar results in terms of magnitude and significance of the coefficients using a simple OLS model without fixed effects, and one including a measure of income inequality (refer to Section S5 in the supplemental appendices for results tables).

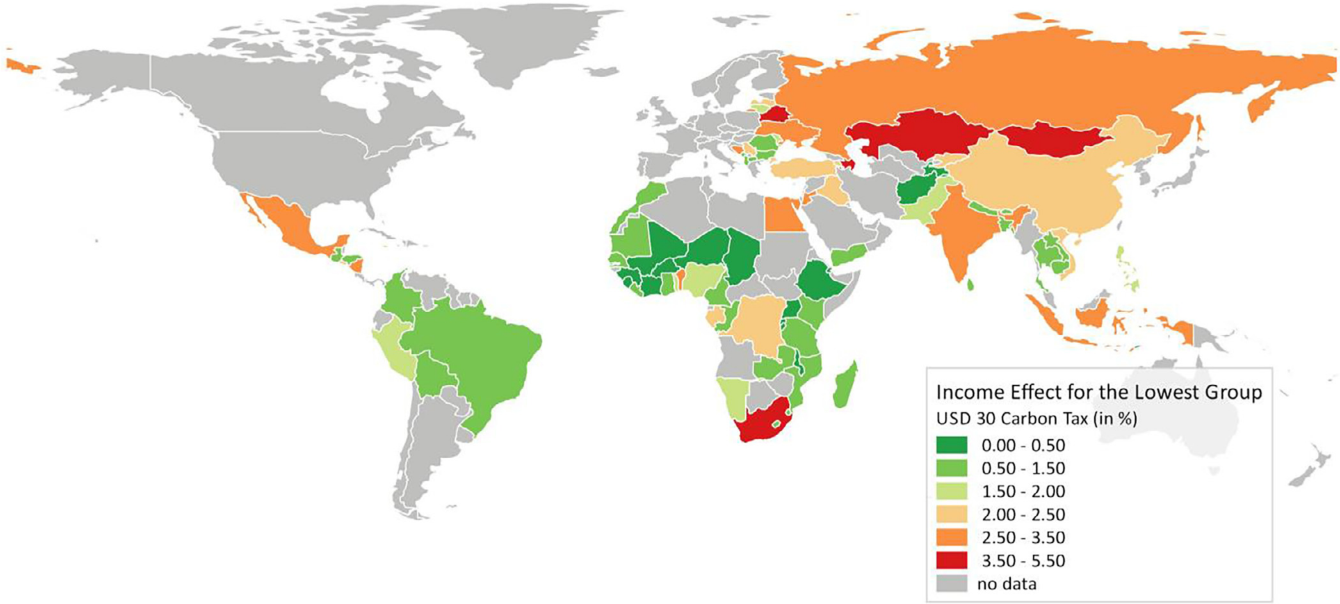

Fig. 2. Income losses (as percent of disposable income) for the lowest income group when applying a price of USD 30 per ton CO_2.

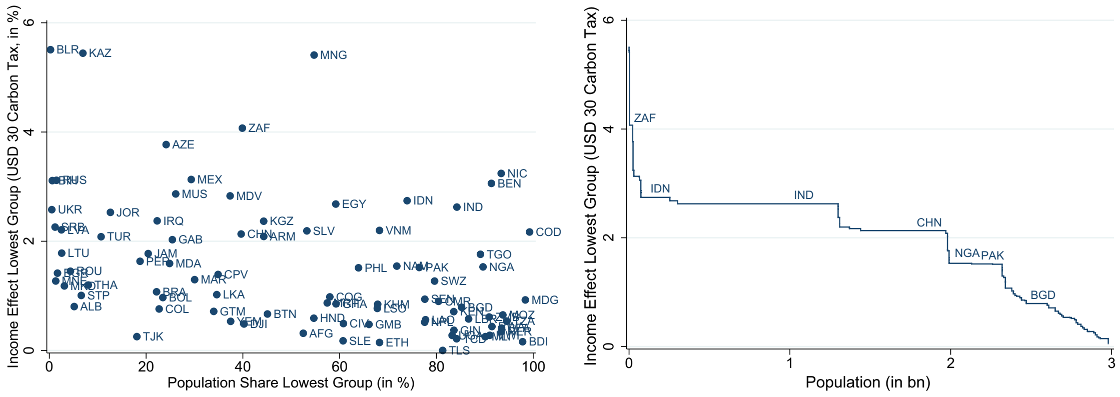

Fig. 3. Effects on the lowest income group (<2.97 USD/day) compared to its share of the total population (left), and the absolute number of people (in bn) in the lowest income group (<2.97 USD/day) in the respective country (right).

of the coefficients and the Bayesian information criterion (BIC) suggest a quadratic relationship. The quadratic and the cubic regression show a similar non-linear behavior. While the linear term is positive, the squared term is negative (both significant at the 1% level), indicating an inverse U-shape relationship between income and energy expenditure shares. The turning points for the quadratic and cubic regression are comparable, calculated at USD 7720 and 9740 annual per capita income, respectively (for a graphic representation, see Appendix 3). The cubic model further implies a second inflection point at USD 30,450, which is, however, well beyond the maximum observed income of USD 26,000 (c.f. descriptive statistics in Appendix Table A2).

The inverse U-shape relationship between income and the energy expenditure share can explain the heterogeneity of within-country distributional outcomes of carbon pricing. At an average income level below the threshold, the country is on the upward-sloping part of the curve and the poorest households exhibit a lower energy expenditure share than the average household. The distributional impact of carbon prices will thus be progressive. Once countries become rich enough that even the poorest households earn above the threshold, the distributional impact of carbon prices will become regressive. This finding explains the turning point for distributional effects at a national average income of around USD 15,000 per capita which we observe in the cross-sectional regression (Fig. 5). The turning points in both approaches differ as they refer to different outcome variables (i.e. income in Table 2 and distributional effects in Fig. 5, which depends on the income effect and the prevailing income distribution). In summary, this stylized energy Engel curve can explain why carbon pricing tends to be regressive in richer economies, but progressive in very poor countries – and that there are less clear distributional effects in countries in which households cluster around the turning point.

5. Discussion

In this section, we discuss the above presented results in light of four methodological and content-related aspects, namely general equilibrium effects, the use of traditional biomass, carbon price levels, and the relevance of distributional effects for political feasibility. Further sensitivity analyses provide insights to the robustness of our findings against certain assumptions.

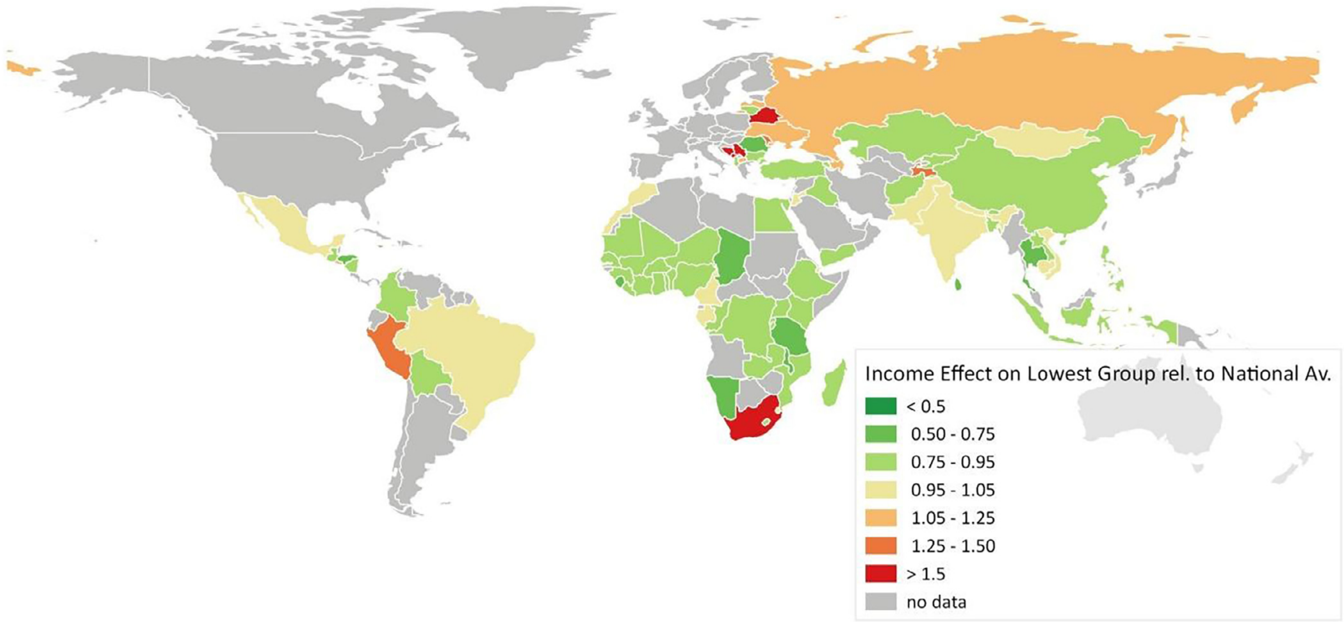

Fig. 4. Income effect of a carbon tax on the lowest income group relative to the national average (σ_{ic} in Eq. (4)). Values smaller (greater) than unity indicate progressive (regressive) distributional outcomes.

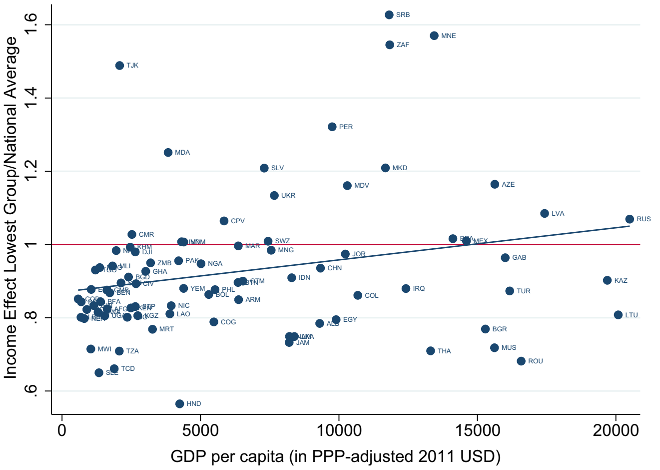

Fig. 5. Income effect of a carbon tax on the lowest income group relative to the national average (e_{1c}/e_c) over GDP per capita (from World Bank, 2017c). The positive correlation indicates that, on average, carbon pricing is more likely to have regressive impacts in richer countries. The correlation coefficient $\beta = 1.2e{-}05$ is statistically significant at the 5% confidence level. The blue line is the estimated relationship from a simple linear regression model, $R^2 = 0.05$; two outliers excluded (BLR, BIH). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

5.1. General equilibrium effects

Our results are based on an arithmetic microsimulation based on MRIOs. As MRIOs are price shifting models, they disregard several equilibrium effects, such as responses in household or firm behavior (del Granado et al., 2012). However, as consumption and production patterns arguably require time to adjust, our results can be interpreted as short-term estimates. Static first-order effects tend to dominate political decision-making, as immediate short-term impacts on the poor and nearly poor comprised in the lowest income group have proven to be crucial for public or political opposition to carbon prices (Lockwood, 2015; Ravallion, 2010; van Donge, Henley, & Lewis, 2012). Moreover, our static approach provides a straightforward interpretation as a first-order approximation of the welfare changes in terms of compensating variation. Nevertheless, we discuss in the following the implications equilibrium effects through (i) demand-side and (ii) supply-side adjustments.

On the demand side, considering homogenous own-price elasticities for consumption goods, as in Coady et al. (2017), would lower the income loss of all income groups in a proportional way. To provide an intuition of how distributional outcomes might change when allowing for demand adjustments, we compare global emission shares with global average (uncompensated) Cournot own-price elasticities of demand. We use elasticities estimated by Muhammad, Seale, Meade, and Regmi (2011, p. 37), which are differentiated by income level and consumption category (Table 3). As comprehensive estimates of income-specific demand elasticities within lower-income countries are missing, we consider the heterogeneity of demand elasticities for low-, middle- and high-income country averages as indication for the heterogeneity of demand elasticities among different income groups within countries. Low-income households are more price-responsive in the five categories “Food, beverages and tobacco”, “Medical and health”, “Transport and communication”, “Recreation” as well as “Other”. Therefore, poorer households can be expected to reduce their consumption more than rich households due to tax-induced price increases in these categories while the reduction in other consumption categories is homogeneous. Considering responses in demand, the real income loss would, therefore, be lower for poorer households, which would make distributional effects more progressive. As CO_2 emissions from these categories account for 44 percent of global CO_2 emissions, it remains open whether the progressive effect of the demand-side adjustment can overcompensate the potentially regressive first-order income effect that is more prevalent in middle- and high-income countries. In any case, considering changes in demand leads to smaller income losses on average as well as to smaller income losses of the poorest group compared to the national average than simulated by our analysis.

With respect to supply-side adjustments, longer time horizons need to be considered as changing production technologies require large-scale investments into the energy system. Switching from

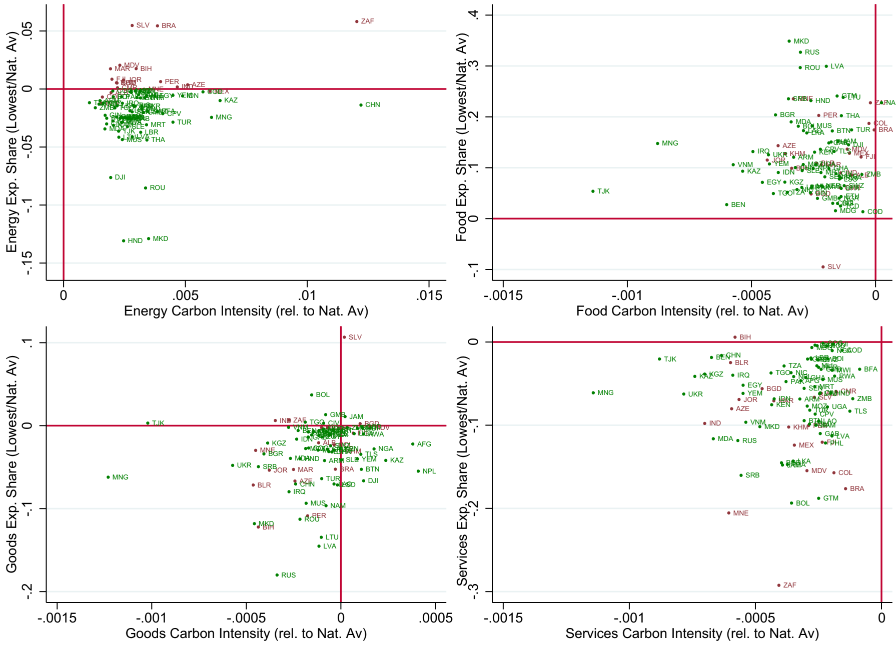

Fig. 6. Carbon intensities relative to national average carbon intensity, $\Delta\kappa_{jc}$, against expenditure shares of the lowest income groups relative to national average, $\Delta\alpha_{ijc}$, for each consumption category. Each data point represents one country; countries in green exhibit progressive distributional outcomes, those in red regressive ones. Note: different scales in energy plot. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2

Engel curve for energy expenditure shares as a function of per capita expenditure (pcExp) in PPP-adjusted 2011 USD. Country fixed effects linear regression results using the within-estimator; t statistics in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; Note: the constants report the mean of the fixed effects across all countries as we are mainly interested in the curvature (not the levels); when using a regression with country dummies, the R^2 adj. increases to 0.180 (linear) and 0.288 (square, cubic) while coefficients remain unchanged (refer to Section S5 for results tables).

		Energy expenditure share (linear)	Energy expenditure share (square)	Energy expenditure share (cubic)
pcExp		1.53e−06	1.29e−05***	1.59e−05***
		(1.66)	(4.83)	(5.49)
pcExp squared			−6.60e−10***	−1.03e−09***
			(−5.17)	(−4.35)
pcExp cubic				1.13e−14
				(1.60)
Cons/mean fixed effect		0.110***	0.103***	0.083***
		(22.57)	(19.16)	(11.28)
N		341	341	341
R^2	within	0.024	0.155	0.158
	within adj.	0.021	0.150	0.151
BIC		−1054.3	−1097.8	−1099.1
Turning point(s)		/	9,738	7,720 30,451

Table 3

Cournot own-price elasticities of demand and CO_2 emission shares: average elasticities for low-, middle-, and high-income countries for nine consumption categories, based on Muhammad et al. (2011, p. 37), and shares of total CO_2 emissions embedded in household consumption, own calculation based on Narayanan, Aguiar, and McDougall (2015); Note: refer to Table S6 in the supplemental appendices for matching table.

Average Cournot own-price elasticities of demand	Low income	Middle income	High income	Total CO_2 emissions (%) (Full country sample)
Food, beverages & tobacco	−0.737	−0.588	−0.431	17.00%
Clothing & footwear	−0.726	−0.723	−0.722	4.40%
Housing	−0.822	−0.821	−0.821	34.20%
House furnishings	−0.786	−0.783	−0.783	4.20%
Medical & health	−1.344	−0.962	−0.917	4.60%
Transport & communications	−0.903	−0.871	−0.863	18.20%
Recreation	−2.086	−1.025	−0.952	3.90%
Education	−0.692	−0.684	−0.679	4.00%
Other	−1.389	−0.966	−0.923	9.50%

coal-based power plants to renewable energy, for example, makes electricity prices less responsive to further carbon price increases, but decarbonization of the energy system implies usually higher energy prices (Kalkuhl, Edenhofer, & Lessmann, 2013). As we have shown in Section 4.3, the distributional impact of carbon pricing comes largely from the distributional impact of energy price increases and consumption patterns. We thus expect similar, but less pronounced, impacts on households.

Further general equilibrium effects are related to changes in wages and interest rates. While modelling such changes could yield more comprehensive estimates, the required computable general (or partial) equilibrium models are much more data intensive and sensitive to (in many instances rather arbitrary) model assumptions. These models require detailed specifications of economic structures, especially for distributional analyses to be comparable across countries. They also require price elasticities for all economic sectors, differentiated by rural and urban households, across income levels, and over time and space (Boccanfuso, Estache, & Savard, 2011; Grubler & Pachauri, 2009). The necessary information is generally lacking, unreliable or of poor quality, especially in developing countries (Beegle, Christiaensen, Dabalen, & Gaddis, 2016). Hence, the results of such highly sophisticated models are not as transparently tractable as the parsimonious method applied in this paper, and are associated with significantly larger uncertainties.

Some studies for high-income countries suggest a more progressive incidence if changes in factor prices are taken into account (Beck et al., 2015; Dissou & Siddiqui, 2014). If capital-intensive sectors are also carbon intensive, a carbon price lowers the return to capital, which mostly affects richer households. Hence, including these effects would not overturn our finding that carbon pricing would be progressive in most countries. Rather, carbon pricing would become less regressive, or could even turn progressive, for those countries for which we have found regressive impacts. However, one cannot ascertain whether the finding that carbon pricing is more likely to be regressive in richer countries would still hold when including factor returns in the analysis as this might not only shift the relationship between income and distributional effect (Fig. 5), but also affect its slope.

5.2. Traditional biomass

Our analysis focuses on fossil energy-related carbon prices which can be levied upstream at the source or point of import. The GCD includes expenditures or imputed use-values for traditional biomass in the cases in which this information is elicited in the primary national survey data. Such biomass expenditures are aggregated in the category 'Other Fuels' together with fossil liquid and solid fuels. Using GTAP emissions data, we can still correctly estimate fossil energy-related emissions from the entire 'Other Fuels' consumption in each country as GTAP disregards emissions from biomass. We can, however, with our approach not correctly infer about the allocation of fossil and biomass fuels across different income groups. Our estimate of the fossil emission footprint of 'Other Fuels' across income groups is, therefore, only correct if the share of biomass use versus fossil fuel use is constant across income groups within countries. When absolute biomass use varies little with income, our results would further imply that a carbon tax on fossil energy would be less regressive than simulated in those countries in which biomass use is accounted for in 'Other Fuels'. The empirical literature does not find a systematic relation between income and biomass use as structural and behavioral factors tend to be decisive (Malakar, Greig, & van de Fliert, 2018; Muller & Yan, 2018; Schuenemann, Msangi, & Zeller, 2018). We, therefore, cannot asses a-priori whether we underestimate or overestimate the regressive impact of carbon pricing. A sensitivity analysis which compares the distributional income effects, including and excluding 'Other Fuels' consumption as a whole, indicates that the distributional incidence is not strongly affected when omitting this entire category. As expected, excluding 'Other Fuels' tends to result in slightly more progressive effects of carbon pricing across countries (for a graphic representation, refer to Fig. S1). Hence, we conclude that this imprecision is of minor relevance.

5.3. Carbon price level

Our analysis has an explicit focus on the immediate and short-term incidence that dominates political economy dynamics in most countries. Arguably, USD 30/tCO$_2$ is a relatively low price level compared to the ones needed to achieve internationally agreed climate targets in the long-run (Boyce, 2018; Pindyck, 2013). However, it provides a useful benchmark for an entry point into carbon pricing, given the various political barriers to introducing carbon pricing (Klenert et al., 2018). Moreover, countries with successful fossil fuel subsidy reform used a gradual approach in reducing subsidies (Rentschler & Bazilian, 2017; Pahle et al., 2018). Against this lesson, the introduction of very low levels of carbon prices that increase over time seems to be a more feasible approach than starting with very high prices. Higher carbon prices will further have stronger implications for behavioral changes and investments in the energy system, demanding a more sophisticated modeling approach that includes general-equilibrium effects. Nevertheless, our results are linearly scalable in the carbon price level, implying a proportional impact on disposable income under higher or lower carbon prices and no impact on the distributional incidence.

5.4. Distributional implications and the political feasibility of reforms

Our analysis suggests that, from an income distribution point of view, carbon pricing might be socially and politically more acceptable in poorer countries. This is of particular relevance as price-related reforms in the energy sector, mainly related to abolishing fossil fuels, have often been sidelined by public protest, which in many cases had the power to block reforms (Rentschler & Bazilian, 2017). While protests against increasing energy prices have not typically been found to be led by the very poor, Lockwood (2015) and Ravallion (2010) acknowledge that in many lower-income countries a rapidly growing group, often referred to as emerging middle class, has gained political importance. As this group often clusters just above the national poverty lines and is partly located in the lowest income group (<2.97 USD/day) in our dataset, its members remain vulnerable to respective price shocks. Additionally, Baranzini et al. (2017) conclude from the literature that also the general public has a strong preference for carbon pricing policies whose design is such that they protect low-income households.

Yet, even in countries in which carbon pricing is not particularly regressive, additional policies will be necessary to prevent adverse impacts on the poor as they are also affected negatively in absolute terms. Such measures include preventing an increased use of traditional biomass due to higher prices of fossil energy, which would likely aggravate health problems and accelerate deforestation (Toman & Bluffstone, 2017). Providing affordable access to clean and reliable energy carriers for the poor could be one option to address both issues.

In contrast, for newly industrializing countries that have largely carbonized their energy systems in recent years (Steckel, Edenhofer, & Jakob, 2015) and in which the distributional effects of carbon pricing have already turned regressive, climate policy might face greater political resistance. However, higher levels of income often coincide with improved institutions to implement effective transfer and compensation schemes (World Bank, 2017a). Schemes that include lump-sum dividends, government provision of public services, or targeted financial transfers to households, such as those adopted in British Columbia or Switzerland, have been found to enjoy greater political support (Ali, Fjeldstad, & Sjursen, 2014; Boyce, 2018; Carattini et al., 2017; Klenert et al., 2018). Using part of the tax revenues raised to invest in infrastructure and public goods will have varied distributional impacts, probably conferring higher benefits on poorer households (cf. Dorband, Jakob, & Steckel, 2017). By making the associated benefits more tangible to the population, such a recycling scheme for carbon pricing revenues could enhance the political feasibility of carbon pricing.

6. Conclusion

The distributional aspects of carbon pricing are relevant from the political economy perspective as well as from a normative perspective. Building on a consistent dataset and method, this study is the first to identify which factors determine the distributional incidence of introducing a modest carbon price across a large set of low- and middle-income countries. We find strong evidence that, in most lower-income countries, the first-order income effect of carbon pricing would be progressive. Neglecting medium- to long-term adjustment processes, the disposable income of the poorest group is reduced by 0.2–5.5%. We also observe that in richer countries carbon pricing tends to be more regressive. In countries with an average annual per capita income below a turning point of around USD 15,000 (PPP-adjusted), carbon pricing is likely to be progressive (and regressive above this threshold). This turning point can be explained by an inverse U-shape of the energy expenditure to income relationship: Energy expenditure shares increase up to a household per capita income around USD 8,000–10,000 (PPP-adjusted) and decrease thereafter. Actual income effects of carbon pricing can be expected to be lower and more progressive if demand adjustment takes place and the use of traditional biomass is consistently exempted from carbon pricing.

Declarations of interest

None.

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Appendix

1. Comparison of inequality measures

We choose to measure the distributional impact of carbon pricing as income effect on the lowest income group compared to the country average (σ_{ic} in Eq. (4)). This measure puts an emphasis on the income loss of the most vulnerable income group, which is especially relevant in the developing country context, not least because the prevalence of absolute poverty is already high among its members. In order to compare this measure to a more standard measure of inequality, we estimate the pre- and post-tax Gini coefficients for each country. We conduct a stepwise calculation based on the four income group observations, assuming a USD 30 carbon price is imposed. The difference between pre- and post-tax Gini reveals the distributional impact. Negative (positive) values indicate progressive (regressive) carbon prices as inequality decreases (increases). The results we obtain with our distributional measure, i.e. σ_{ic} being smaller or greater than unity, are positively related to the Gini estimates at a high significance level (Fig A1).

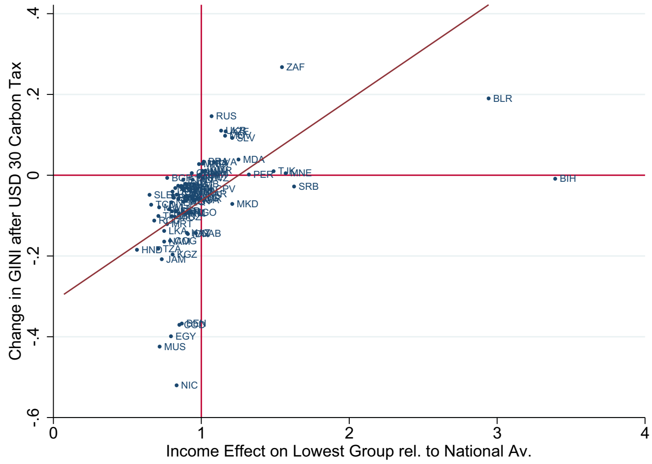

Fig. A1. Significant positive correlation between both measures of inequality; Spearman's Rho = 0.74, p-value = 0.00.

Table A1
Linear Probability Model (OLS), explaining the of distributional outcome (σ_{ic}>/<1) with the signs of the four consumption terms; t statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Sigma Dummy (0/1 for </>1)
Energy Dummy (0/1 if −/+)	0.945*** (0.03)
Food Dummy (0/1 if −/+)	−0.062* (0.03)
Goods Dummy (0/1 if −/+)	0.078** (0.03)
Services Dummy (0/1 if −/+)	0.0349* (0.02)
Constant	−0.023 (0.02)
N	87

2. Econometric analysis of within-country decomposition results

The results of a simple linear probability regression of the signs of the consumption terms on a dummy which denotes whether σ_{ic} is smaller or larger than unity are listed in Table A1. A positive energy term, that is, energy expenditure shares of the poorest being larger than national average, increases the probability of a carbon price being regressive by 95%.

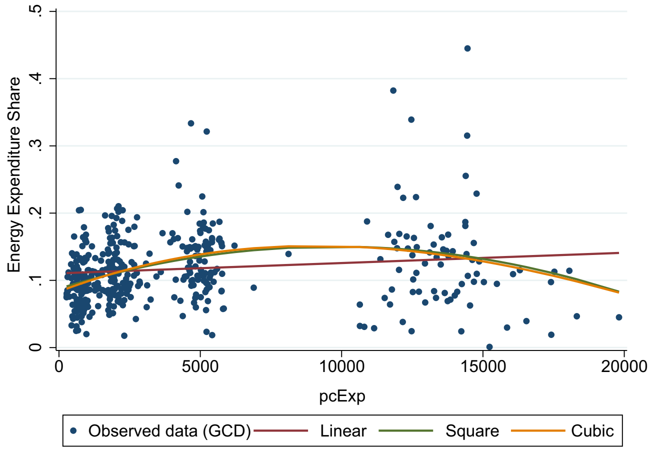

Fig. A2. Observed and fitted values of expected energy expenditure shares over annual per capita expenditures from linear, square and cubic Engel curve model specifications.

Table A2
Summary statistics of annual per capita expenditures (as proxy for income (pcExp)) in PPP-adjusted 2011 USD.

Income groups	Obs	Mean	Std. Deviation	Min	Max
Lowest	87	740	207	267	1167
Low	87	2053	282	1554	2852
Middle	87	5028	439	4016	6210
Higher	80	14,572	5848	10,498	26,351

3. Econometric estimation of the Engel curve for energy expenditures

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.worlddev.2018.11.015.

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