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Household Welfare and CO2 Emission Impacts of Energy and Carbon Taxes in Mexico

Sebastian Renner, Jann Lay, and Hannes Greve

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WP Coordination and English-language Copyediting: Melissa Nelson
Editorial Assistance and Production: Silvia Bücke

GIGA German Institute of Global and Area Studies
Leibniz-Institut für Globale und Regionale Studien
Neuer Jungfernstieg 21
20354 Hamburg
Germany
<info@giga-hamburg.de>
<www.giga-hamburg.de>

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Abstract

We analyse the effects of environmental taxes on welfare and carbon emissions at the household level for the case of Mexico. The integrated welfare-environmental analysis, which is based on a censored energy consumer demand system, extends previous work in two ways. First, the estimation of a full matrix of substitution elasticities allows us to test the necessity of incorporating second-order effects into the welfare analysis. Second, the substitution elasticities derived from the demand system are used to estimate the short-run CO2 emission-reduction potential. We find that first-order approximations of welfare effects provide reasonable estimates, particularly for carbon taxes. Analog to evidence in other low- and middle-income countries, the taxation of all energy items is found to be regressive, with the exception of motor fuels. The inclusion of CH4 and N2O in a carbon tax regime comes with particularly regressive impacts because of its strong effects on food prices. The analysis of the emission implications of different tax scenarios indicates that short-run emission reductions at the household level can be substantial – though the effects depend on how revenue is recycled. This effectiveness combined with moderate and manageable adverse distributional impacts renders the carbon tax a preferred mitigation instrument. Considering the large effect of food price increases on poverty and the limited additional emission-saving potential, the inclusion of CH4 and N2O in a carbon tax regime is not advisable.

Keywords: climate policy, energy policy, Mexico, poverty, distributional effects

Dr. Sebastian Renner

is a postdoctoral researcher at the University of Göttingen and a research fellow at the GIGA German Institute of Global and Area Studies.
<sebastian.renner@giga-hamburg.de>
<www.giga-hamburg.de/en/team/renner>

Apl. Prof. Dr. Jann Lay

is an adjunct professor at the University of Göttingen, the head of GIGA Research Programme 3: Growth and Development, and acting director of the GIGA Institute of African Affairs.
<jann.lay@giga-hamburg.de>
<www.giga-hamburg.de/en/team/lay>

Hannes Greve

is a research fellow at the GIGA German Institute of Global and Area Studies and a doctoral student at the University of Göttingen.
<hannes.greve@giga-hamburg.de>

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Article Outline

1 Introduction

Mexico has become a major emitter of greenhouse gas emissions in recent decades, with both economic and population growth as driving forces. In response, the Mexican government committed to carbon dioxide emission reductions relative to a baseline scenario and passed a climate change law in 2012 with legally binding emission-reduction goals (Vance 2012). Additionally, substantial reform efforts have been made in the energy sector since 2013, which may affect energy prices. The oil and gas industry has been opened to competition in the up-, middle-, and downstream sectors, and Mexican households will be subjected to international gasoline prices by 2018. The Federal Electricity Commission (CFE) has been reformed with the objective of forming and regulating a competitive electricity market with incentives for private investment (IEA 2017). In the residential electricity market, large seasonal subsidies continue to exist in warmer regions of Mexico to cover higher demand for air conditioning (IEA Subsidies Report 2017; Davis et al. 2014; Komives et al. 2009).

While the effects of these reforms on energy consumer prices may be uncertain in some cases (oil sector) or modest in others (gasoline price subsidies), energy subsidy cuts and an ambitious climate policy are likely to increase energy prices in a country with a fossil-fuel reliant energy system. Higher energy prices are thus likely to lead in the short-run to welfare losses that may not be equally distributed. In developed countries, poorer households tend to be more vulnerable to energy price increases, as energy goods usually represent a larger proportion of their total expenditure, with some exceptions for transport fuels (Flues and Thomas 2015; Speck 1999). For developing countries, although there is less evidence on the distributional effects, Shah and Whalley (1991) as well as Shah and Larsen (1992) pointed out early on that the emerging distributional patterns are apparently different. Recent results in Sterner (2011) and Arze del Granado et al. (2012) show that high-income households capture significantly higher amounts of subsidies for fuels than low-income households. A similar result is found by Datta (2010), who investigates the distributional welfare effects of a fuel tax in India. Gillingham et al. (2006) show that the direct (consumption losses via higher prices) and indirect (income effects) welfare impacts of fuel price increases (both domestic and transport fuels) are either regressive or distributionally neutral in relative terms for a range of developing countries.

Most of this growing literature on the welfare effects of energy price changes or subsidy reforms focuses on single fuels, with a strong emphasis on gasoline. As households usually spend income on more than just one fuel, an understanding of substitution patterns between fuels and other goods is essential to understanding the welfare effects of energy price changes. Thus far, there is no such analysis for Mexico, where a clear understanding of household responses and welfare effects is particularly critical. In Mexico, nearly half of the population still lives below the official poverty line (Consejo Nacional de Evaluación de la Política de Desarrollo Social [CONEVAL 2014]). Potentially large welfare losses due to higher energy prices are particularly critical in a country with relatively high CO2 emissions; ambitious climate policy targets; and the need for further economic development, growth, and poverty reduction.

Against this background, the present study adds to the literature in two ways. First, we provide some evidence on the short-run poverty and distributional effects of energy price changes for Mexico. We calculate the welfare impacts of hypothetical price increases for electricity, motor fuels, gas, and public transportation. Since these price changes can be interpreted as environmental taxes, we can also assess how tax revenues can be redistributed – for example, by employing cash transfers to households. In addition to assessing price changes for energy items, we simulate the welfare impacts of scaling up the carbon tax that was initially introduced in 2014. By drawing on the demand estimates, we examine whether second-order effects need to be calculated for the welfare analysis in our context. By estimating a censored consumer-demand system, we incorporate the discrete choice to use certain energy types and the exact pattern of substitution between them and other goods. Second, we calculate the short-run CO_2-emission-savings potential of consumer responses due to energy and carbon taxes. CO_2 emissions are calculated from a demand-side perspective on the basis of household consumption, also known as carbon footprints.

The rest of the paper proceeds as follows. First, we present the database on which the analysis is based, with some descriptive statistics, in Section 2. In Section 3 we describe the theory and the closely connected empirical strategy for measuring welfare effects and household-induced CO_2 emissions. We present the results in Section 4, before concluding in Section 5 with some policy recommendations.

2 Household Energy Use

We use household expenditure data from Encuesta Nacional de Ingresos y Gastos de los Hogares (ENIGH) surveys conducted by the Instituto Nacional De Estadistica y Geografia (INEGI), the national institute for geography and statistics in Mexico. The data are representative at both the national level and for rural and urban areas. They contain itemised expenditure information for every household, as well as an extensive list of variables capturing household and sociodemographic characteristics. The expenditure categories used in the analysis are (1) electricity, (2) motor fuels (including low-/ and high-octane gasoline as well as diesel and gas), (3) gas (aggregate of natural gas and liquefied petroleum gas [LPG]), (4) public transportation, (5) food (excluding alcohol and tobacco), and (6) other goods. Figure 1 shows the distribution of energy expenditures over expenditure percentiles for 2014.[1] Expenditures for the four energy goods relative to total expenditures range between 6 and 13 percent of total household expenditures. A clear reverse U-shaped curve can be observed for total energy budget shares over the total expenditure distribution.

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[1] Nonparametric distributional curves are calculated with kernel-weighted local polynomial smoothing using an Epanechnikov kernel function with degree 0 and bandwidth 1.15.

Figure 1. Energy Expenditures

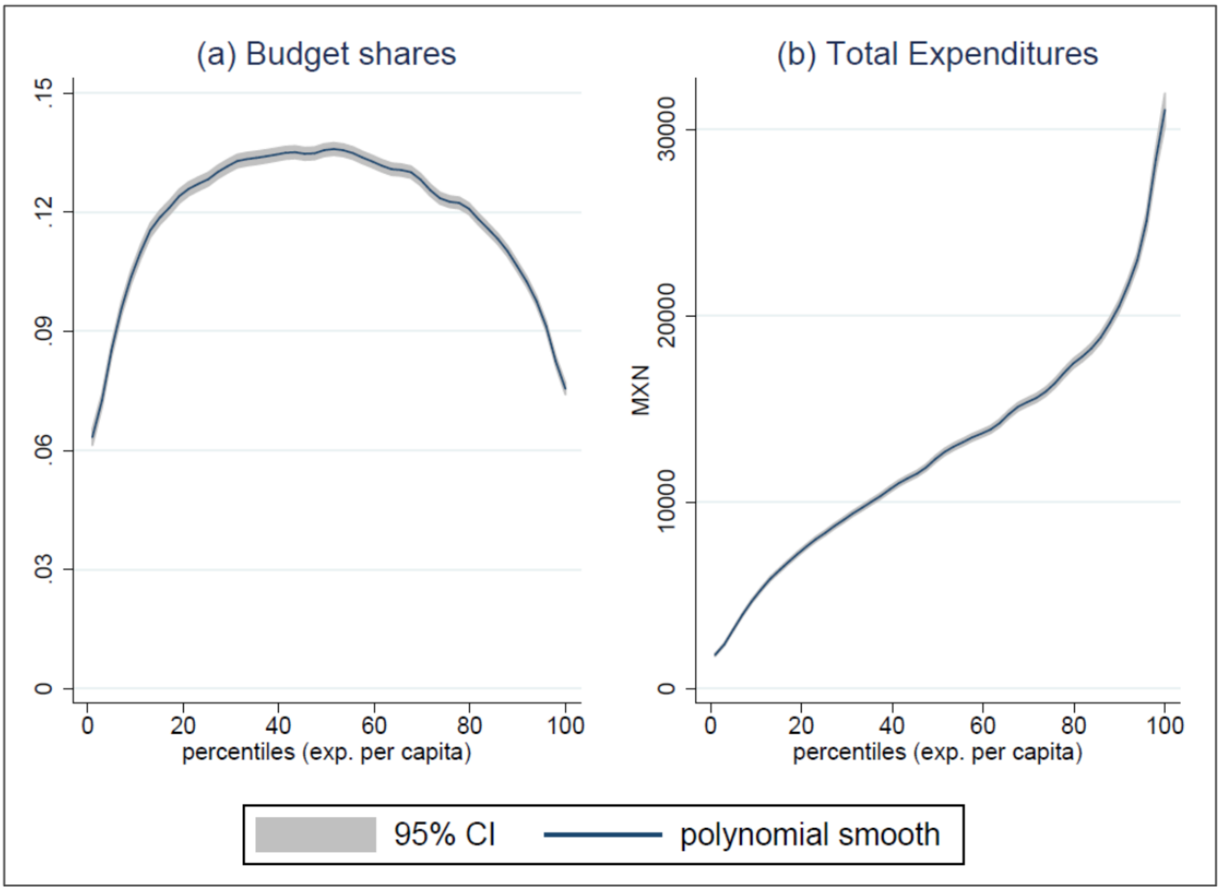
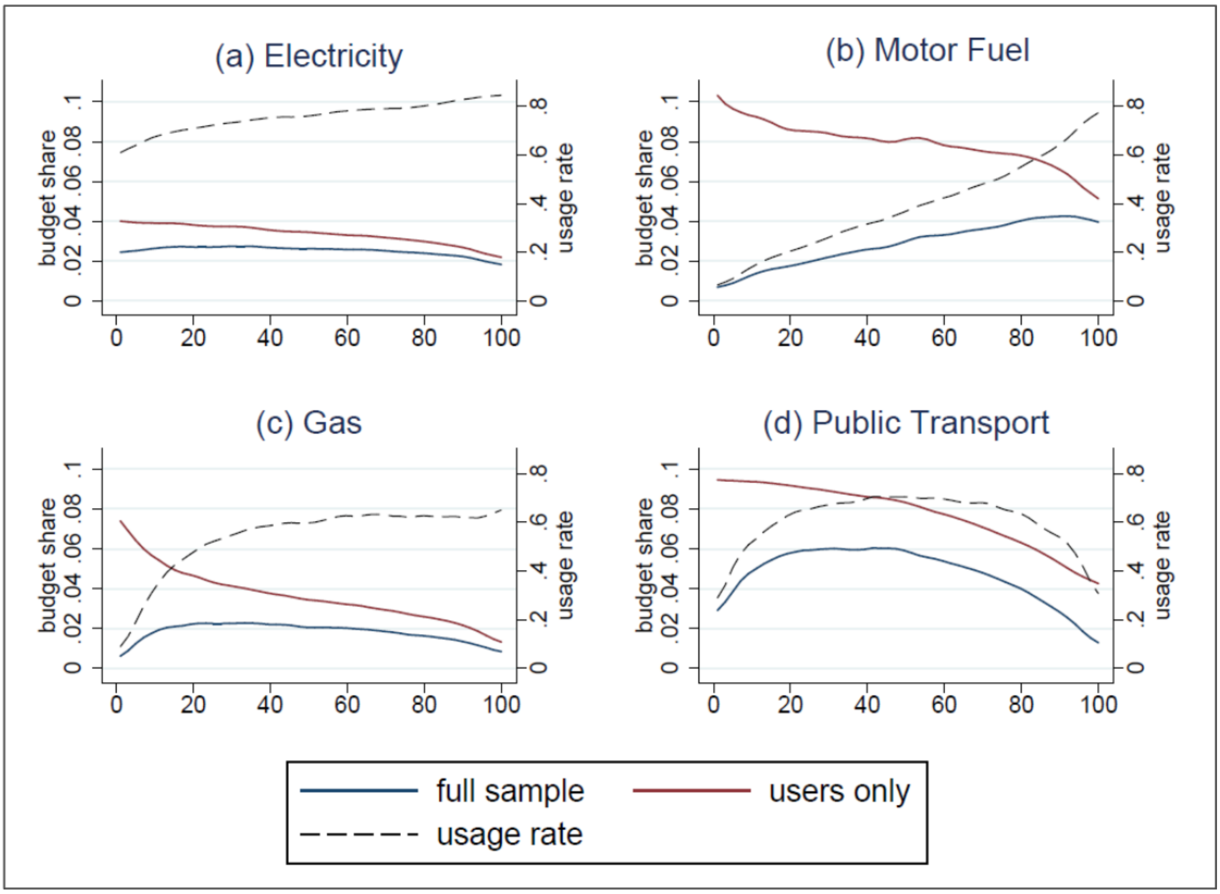


Figure 2 plots the distributional incidence for the energy goods separately and also distinguishes between users and non-users. This distinction matters for welfare analyses, as users of certain energy goods may not find it so easy to switch away from using them. Households may own vehicles and other energy-processing durables that they do not want to (or cannot) put out of use. When all observations are considered, the electricity consumption share decreases continuously over the expenditure distribution, but it exhibits little variation across percentiles and lies at approximately 2.4 percent for the poorest households. The slightly declining budget shares over the income distribution pattern are not found universally in other countries. For example, in Sri Lanka, Mali, and Indonesia, richer households exhibit larger electricity budget shares (Gillingham et al. 2006), partly as a result of the design of electricity tariffs. For motor fuels, the share increases over the expenditure distribution, ranging from approximately 1.6 percent to 4.3 percent. Both gas and public transport exhibit an inverse U-shaped curve over the expenditure distribution, with gas being the least important energy good.

Figure 2. Energy Budget Shares and Usage Rates



When only those households with positive expenditures for the respective energy goods are considered, budget shares decrease continuously with income for all energy types. The difference between users and non-users is most pronounced for motor fuel expenditures for the first decile, for which the mean share is just above 10 percent. Note that only around 16 percent of the households in the poorest decile own a vehicle, compared to 73 percent in the richest decile. Poor households that use gas also have a larger expenditure share than rich ones. Public transport expenditure shares for users reach nearly 10 percent for the first decile and decline over the expenditure distribution. Only minor differences in electricity expenditure shares are detected due to a high electrification rate. These findings indicate that the distributional incidence of relative expenditures depends heavily on the usage rate in the respective income groups. Poor households that depend on one of these energy goods might be disproportionately vulnerable when subjected to energy price increases. The data indicate that motor fuel usage in the poorest decile – that is, the percentage of households consuming some motor fuel – increased from 4.5 percent in 2002 to 16 percent in 2014. Poor households have thus become more vulnerable to motor-fuel price increases. We find that rural households spend slightly less of their current income on electricity than urban households. For the other energy goods, the data shows no significant difference in consumption patterns between rural and urban households.[2]

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[2] Results not reported.

3 Methodology

3.1 Demand System

We model the demand for electricity, motor fuels, gas, public transport, food, and other non-durables based on household survey data with a microeconomic, partial equilibrium demand framework. For our analysis we use the Quadratic Almost Ideal Demand System (QUAIDS) framework (Banks et al. 1997), since observed Engel curves appear to be well approximated by a quadratic relationship between budget shares and logarithmic transformed expenditures.[3] The estimation of a QUAIDS has been applied to the energy context by Brännlund and Nordström (2004) for Sweden, Labandeira et al. (2006) for Spain, Nikodinoska and Schröder (2016) for Germany, and Tiezzi and Verde (2016) for the United States, but according to our knowledge, no demand system specification of this type has been applied to the energy context in low- and middle-income countries to date.[4]

As a rank three quadratic logarithmic budget share system, the QUAIDS has an indirect utility function that takes the following form:

$$\ln V = \left\{ \left[\frac{\ln x - \ln a(p)}{b(p)} \right]^{-1} + \lambda(p) \right\}^{-1} \tag{1}$$

The price indexes $\ln a(p)$ and $b(p)$ are defined as:

$$\ln a(p) = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln p_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \ln p_i \ln p_j \tag{2}$$

$$b(p) = \prod_{i=1}^{n} p_i^{\beta_i} \tag{3}$$

The term $\lambda(p)$ in the indirect utility function is a differentiable, homogeneous function of degree zero of prices p and defined as:

$$\lambda(p) = \sum_{i=1}^{n} \lambda_i \ln p_i \tag{4}$$

With $\sum_{i=1}^{n} \lambda_i = 0$ the derived expenditure share system is:

$$w_i = \alpha_i + \sum_{j=1}^{n} \gamma_{ij} \ln p_j + \beta_i \ln \left[\frac{x}{a(p)} \right] + \frac{\lambda_i}{b(p)} \left\{ \ln \left[\frac{x}{a(p)} \right] \right\}^2 \tag{5}$$

where w_i is the share of commodity (group) i of total expenditures x. To be consistent with utility maximisation, the following restrictions need to hold:

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[3] For higher observed non-linearity, other systems such as the EASI from Lewbel and Pendakur (2009) would be more appropriate.

[4] The Almost Ideal Demand System (AIDS) has been used in related contexts in developed countries (Symons et al. 1994; West and Williams III 2004).

Adding-up

$$\sum_{i=1}^{n} \alpha_i = 1; \quad \sum_{i=1}^{n} \gamma_{ij} = 0; \quad \sum_{i=1}^{n} \beta_i = 0; \quad \sum_{i=1}^{n} \lambda_i = 0 \tag{6}$$

Homogeneity

$$\sum_{j=1}^{n} \gamma_{ij} = 0 \tag{7}$$

Symmetry

$$\gamma_{ij} = \gamma_{ji} \tag{8}$$

Budget elasticities can be derived from the share equation:

$$e_i = \frac{\mu_i}{w_i} + 1 \tag{9}$$

With

$$\mu_i = \frac{\partial w_i}{\partial \ln x} = \beta_i + \frac{2\lambda_i}{b(p)} \left\{ \ln\left[\frac{x}{a(p)}\right] \right\} \tag{10}$$

The uncompensated price elasticity is given by:

$$e_{ij}^{u} = \frac{\mu_{ij}}{w_i} - \delta_{ij} \tag{11}$$

With

$$\mu_{ij} = \frac{\partial w_i}{\partial \ln p_i} = \gamma_{ij} - \mu_i \left(\alpha_j + \sum_{k}^{n} \gamma_{jk} \ln p_k \right) - \frac{\lambda_i \beta_j}{b(p)} \left\{ \ln\left[\frac{x}{a(p)}\right] \right\}^2 \tag{12}$$

and δ_{ij} is the Kronecker delta. Compensated-price elasticities are derived using the Slutsky equation

$$e_{ij}^{c} = e_{ij}^{u} + e_i w_j \tag{13}$$

Demographic demand shifters including sex, age, and education of the household head, household size, and a rural area dummy influence preferences through αi in equation 5. To account for zero expenditures, we follow Shonkwiler and Yen (1999) and obtain elasticity estimates in a censored system setting. In a first step, a household-specific probit model is estimated with the outcome of 1 if the household consumes good i and 0 otherwise. For each household in the sample, the standard normal probability density function (pdf) $\varphi(z_{ih}, w_i)$ and the cumulative distribution function (cdf) $\Phi(z_{ih}, w_i)$ are calculated by regressing w_i on a set of independent variables z_{ih}. In a second step, the pdf and the cdf are integrated into the system of equations:

$$w_i^{*} = \Phi w_i + \varphi_i \phi \tag{14}$$

In opposition to Heckman (1979), this approach is based on the full sample in both steps of the estimation process. The elasticities change as:

Expenditure elasticity

$$e_i^* = \frac{\Phi(\mu_i)}{w_i} + 1 \tag{15}$$

Price elasticity

$$e_{ij}^* = \frac{\Phi(\mu_i)}{w_i} + \phi\tau_{ij}(1 - \frac{\varphi_i}{w_i}) - \delta_{ij} \tag{16}$$

Since we use prices as dependent variables in the first stage estimation, τ_{ij} is the coefficient of price j from equation i of the probit model. The respective expenditure and price elasticities, e_i and e_{ij}, are derived under the modified system (14). Explanatory variables used in the probit estimation are listed in Table 2. This two-step methodology has been extensively applied in agricultural demand contexts (see for example Ecker and Qaim [2011]; Shonkwiler and Yen [1999]; Yen et al. [2002]) but not yet for energy demand. The censored system is estimated for the full system and therefore loses the adding-up restriction, which is why we calculate approximate second-order welfare effects based on equation (20). We use a two-step feasible generalised non-linear least squares (FGNLS) estimator for the estimation of equation (17). The identification of price elasticities is enabled through cross-sectional (spatial) and time variation. We select eight years for the demand system estimation: 2002, 2004, 2005, 2006, 2008, 2010, 2012, and 2014. In addition to this considerable variation in time, spatial variation comes from CPI data at the city level. The price data consist of indices that are available from INEGI for 46 cities throughout Mexico, and every state is represented by at least one city. Households not residing in one of the 46 cities are assigned to the city that is located in their state. When more than one city lies in the respective state, an unweighted average of the price indices is calculated. The price indices are disaggregated for the categories food, gasoline, electricity, gas (aggregated index for both LPG and natural gas), and public transport (inter alia). For other goods, we use the general price index. For motor fuels, we use the aggregated index of low- and high-octane gasoline. To correct for city-specific effects, we incorporate city-fixed effects in the αi term in equation 5.

3.2 *Simulation and Welfare Effects*

We simulate price changes for different scenarios, where the price change per good i is simply:

$$\frac{\Delta p_i}{p_i^0} = \frac{p_i^1 - p_i^0}{p_i^0} \tag{17}$$

and the new price level after the tax change is:

$$p_i^1 = \left(1 + \frac{\Delta p_i}{p_i^0}\right) p_i^0 \tag{18}$$

$\ln a(p)$ and $b(p)$ (equation 14) are adjusted accordingly with new price levels, and we obtain simulated budget shares for good i and each household according to:

$$w_i^1 = \Phi\left(\widehat{\alpha_i} + \sum_{j=1}^{n} \widehat{\gamma_{ij}} \ln p_j^1 + \widehat{\beta_i} \ln\left[\frac{x^0}{a(p^1)}\right] + \frac{\widehat{\lambda_i}}{b(p^1)}\left\{\ln\left[\frac{x^0}{a(p^1)}\right]\right\}^2\right) + \varphi_i \phi + \widehat{\epsilon_i}^0 \tag{19}$$

The "hats" are estimated coefficients from equation 14, and the superscripts denote the periods of reference. Household characteristics in the α term remain unchanged in all scenarios. Since the demand system does not predict household expenditures perfectly, the residual term ϵ_i containing household-specific unexplained effects is included.[5]

The literature on the welfare impacts of energy price increases and subsidy reforms focuses to a large extent on first-order effects as in Sterner (2011). These first-order effects, based on the work of Feldstein (1972) and Stern (1987), only require the observed demand and no additional information on substitution behaviour due to price changes. First-order welfare losses relative to income (total expenditures are used as a proxy) are calculated as:

$$FO = \sum_{i=1}^{n} w_i \left(\frac{\Delta p_i}{p_i^0}\right) \tag{20}$$

With estimated coefficients at hand, we calculate a second-order approximation to the Compensating Variation (CV), which is the amount of money the household needs to be compensated with to attain the utility level u_0 prior to the price changes, again relative to total household expenditures:[6]

$$CV = \sum_{i=1}^{n} w_i \left(\frac{\Delta p_i}{p_i^0}\right) + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} w_i e_{ij} \left(\frac{\Delta p_i}{p_i^0}\right)\left(\frac{\Delta p_j}{p_j^0}\right) \tag{21}$$

The CV is compared to the first-order effect to clarify the necessity of estimating a demand system in our context. The price change in equation (17) can also be interpreted as an ad valorem tax rate t_i. Tax payments per household are then calculated as:

$$T = \sum_{i=1}^{n} \frac{\Delta p_i}{p_i^0}(p_i^0 * q_i^1) = \sum_{i=1}^{n} t_i \frac{exp_i^1}{1 + \frac{\Delta p_i}{p_i^0}} \tag{22}$$

which are multiplied with household weights and summed over all households to obtain the total tax revenue. With household substitution already incorporated, simulated expenditures based on equation (19) are used for the tax calculation and deflated to the base period. When tax revenues are redistributed to households in the form of direct cash transfers, we assume the additional income is completely spent on non-durable consumption and the new budget shares are:

$$w_i^{1,tr} = \Phi\left(\widehat{\alpha_i} + \sum_{j=1}^{n} \widehat{\gamma_{ij}} \ln p_j^1 + \widehat{\beta_i} \ln\left[\frac{x^1}{a(p^1)}\right] + \frac{\widehat{\lambda_i}}{b(p^1)}\left\{\ln\left[\frac{x^1}{a(p^1)}\right]\right\}^2\right) + \varphi_i \phi + \widehat{\epsilon_i}^0 \tag{23}$$

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[5] Additionally, with the missing adding-up restriction, budget shares do not add up perfectly to 1. We find this error to be very small in our simulations, in the range of a 0.03–0.3 percentage point deviation.

[6] The approximation is based on a second-order Taylor series expansion of the expenditure function (Banks et al. 1996; Deaton and Muellbauer 1980b; Friedman and Levinsohn 2002).

3.3 CO2 Emissions

In our analytical framework, CO2 emissions (C) are calculated from a demand-side perspective. The carbon content of the goods in our analysis may come from three different sources. First, fuels have a direct CO2 content per physical unit (C_{dir}).[7] Second, goods are produced using energy, which leads to the emission of CO2, the direct production emissions. Third, other goods used in the production process are responsible for the indirect production emissions. We categorise production emissions from direct and indirect energy use as indirect emissions C_{ind}. Total emissions C are simply the sum of direct and indirect emissions:

$$C = C_{dir} + C_{ind} \tag{24}$$

Where applicable, as in the case of fuels, $\mathrm{C_{dir}}$ can be calculated based on the expenditure data. The indirect emissions $\mathrm{C_{ind}}$ are calculated with an environmentally extended input-output model based on data from the World Input-Output Database (Timmer et al. 2015) as:

$$C_{ind} = CI'x = CI'(I - A)^{-1}y \tag{25}$$

where CI is the direct carbon intensity of production, $(\mathrm{I} - \mathrm{A})^{-1}$the Leontief inverse, and $\mathrm{CI}'(\mathrm{I} - \mathrm{A})^{-1}$ the indirect carbon intensities containing all direct and indirect production emissions.[8] These CO2 emissions embedded in household consumption – also termed carbon footprints – are derived by multiplying expenditures per good with the respective carbon intensity CI (tCO2/MXN):

$$CO_2^0 = \sum_{i=1}^{n}(exp_i^0 * CI_i) \tag{26}$$

In each scenario, new expenditure levels $\mathrm{exp_i^1}$ per good i and each household are derived from new budget shares $\mathrm{w_i^1}$. New carbon emissions are then calculated as:

$$CO_2^1 = \sum_{i=1}^{n}\left(\frac{exp_i^1}{1 + \frac{\Delta p_i}{p_i^0}} * CI_i\right) \tag{27}$$

For the calculation of tax revenue, the simulated expenditures are real expenditures at base prices. They isolate the unobserved quantity effect from the nominal expenditure change. Aggregating over households by using household weights, we obtain total carbon emissions resulting from domestic household demand. The difference from the baseline value is then exclusively explained by consumer substitution. Substitution effects are also taken into ac-

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[7] For motor fuels we assume the CO2 content of gasoline: 2.31 kg CO2/l. Gas/LPG: 1.5 kg CO2/kg. These physical units are transformed to CO2 intensities per monetary unit by assuming prices of MXN 13 per litre of motor fuel and MXN 13 per kg of gas. Although this procedure is not precise due to different prices for households over space and fuel choice, it corrects for the otherwise missing direct carbon content of consumption in the absence of quantity information.

[8] For details on the calculation of carbon intensities and matching with household expenditures for Mexico, see Renner and Bold (2017). The way in which we matched the 34-sector production classification to our 6-good demand classification is described in Table A1.

count in redistribution scenarios when total expenditures increase through cash transfers. New expenditure levels $exp_i^{1,tr}$ based on equation (23) are expected to be higher with normal goods and reduce the emission-saving potential determined by the size of β and λthrough the budget elasticity.

4 Poverty, Welfare, and CO$_2$ Emissions

In order to understand the implications of energy price changes for household welfare and carbon footprints, we simulate separate stylised scenarios with price changes for each fuel, as well as one scenario with price changes for all energy types simultaneously. In a second step, we take a closer look at potential future policy interventions in the form of different carbon tax rates. In the process, we assess the importance of calculating second-order effects for welfare analysis in this context. For the effects on poverty, we calculate absolute welfare effects and subtract them from household income, since domestic poverty lines are constructed with household income per capita (CONEVAL 2014). We calculate Foster-Greer-Thorbecke (FGT) poverty indices on the basis of the poverty lines for Mexico provided by the National Council for the Evaluation of Social Development Policy CONEVAL (Consejo Nacional de Evaluacion de la Politica de Desarrollo Social). CONEVAL indicates two different poverty lines. One refers to extreme poverty, as illustrated by the minimum standard of individual well-being, which corresponds to the value of the food basket per person per month (Bienestar minimo – Canasta alimentaria). Those living below this poverty line cannot acquire enough food to ensure adequate nutrition. The second poverty line is equivalent to the total value of the food plus non-food basket per person per month and hence refers to a general standard of well-being (Bienestar - Canasta alimentaria y no alimentaria). We provide results for both poverty lines in order to distinguish between effects on extreme and moderate poverty.

4.1 Energy Price Changes

Since the direct interpretation of the coefficients is difficult, we report elasticities in Table 1. Following Banks et al. (1997), we calculate elasticities for each household individually and construct a weighted average, with the weights generated as the household's share of total sample expenditure for the relevant good. The estimated budget elasticities suggest that, on average, households perceive motor fuels as a luxury good and electricity, gas, and public transport as necessities. For the latter three energy items, income elasticities are fairly close to 1, which indicates quickly rising energy demand with income growth. Income plays a more nuanced role for the discrete energy use decision. Due to Mexico's very high electrification rate, income is not an important determinant of electricity use. In the case of motor fuel, income plays a major role in determining private transport vehicle ownership. The probability of public transport use, on the other hand, is only slightly affected by rising incomes, and more so by the necessity and convenience of this transportation mode, as reflected in the large effect of the rural dummy. Uncompensated own-price elasticities all show the expected negative signs and reflect inelastic household responses to price changes with the exception of electricity and motor fuels. Cross-price elasticities between energy items show the expected pattern – for example, the domestically used electricity and gas and transport expenditures for motor fuel and public transport are substitutes, though fairly inelastic in nature. Compensated-price elasticities for energy items, used in the calculation of welfare effects, do not differ significantly since expenditure elasticities are all close to 1. For food and other goods, the elasticities become indistinguishable from 0. Based on the observance of energy price elasticities, we would not expect large differences between the first- and second-order welfare effects except in the case of electricity-price changes.

Table 1. Demand Elasticities

Uncompensated Price Elasticities

		Price					
		Electricity	Motor Fuel	Gas	Publ Trans	Food	Other
demand	Electricity	-1.49	-0.16	0.14	0.03	0.03	0.28
		(0.002)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)
	Car fuels	-0.09	-1.03	0.02	0.10	0.26	-0.45
		(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.002)
	Gas	0.18	0.04	-0.69	-0.16	-0.29	0.11
		(0.001)	(0.000)	(0.001)	(0.001)	(0.002)	(0.000)
	Publ Trans	0.01	0.10	-0.06	-0.65	-0.74	0.63
		(0.000)	(0.001)	(0.001)	(0.002)	(0.004)	(0.004)
	Food	0.01	0.06	**-0.02**	-0.15	-0.10	-0.50
		(0.000)	(0.000)	(0.000)	(0.000)	(0.003)	(0.001)
	Other	0.01	-0.03	0.00	0.05	-0.43	-0.73
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Compensated Price Elasticities

		Price					
		Electricity	Motor Fuel	Gas	Publ Trans	Food	Other
demand	Electricity	-1.43	-0.12	0.16	0.06	0.30	0.82
		(0.002)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)
	Car fuels	-0.06	-0.92	0.03	0.12	0.56	0.28
		(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)
	Gas	0.20	0.07	-0.66	-0.13	-0.04	0.58
		(0.001)	(0.000)	(0.001)	(0.001)	(0.002)	(0.001)
	Publ Trans	0.03	0.11	-0.05	-0.53	-0.44	1.00
		(0.000)	(0.001)	(0.001)	(0.002)	(0.004)	(0.003)
	Food	0.02	0.08	-0.01	-0.12	0.16	-0.24
		(0.000)	(0.000)	(0.000)	(0.000)	(0.003)	(0.003)
	Other	0.04	0.01	0.02	0.09	-0.12	0.04
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Expenditure Elasticities

		0.96	1.22	0.84	0.85	0.60	1.20
		(0.001)	(0.001)	(0.001)	(0.003)	(0.002)	(0.000)

Table 2. Probit Energy Demand (Marginal Effects)

Variables	(1) Electricity	(2) Motor Fuel	(3) Gas	(4) Public Transport
lnp1	-0.00634***	-0.134***	0.241***	0.160***
	(0.00127)	(0.00596)	(0.00664)	(0.00684)
lnp2	0.0485***	-0.369***	0.0204	0.415***
	(0.00614)	(0.0237)	(0.0269)	(0.0275)
lnp3	-0.0108***	0.150***	0.0558***	-0.106***
	(0.00226)	(0.0117)	(0.0133)	(0.0135)
lnp4	0.00653*	-0.322***	0.242***	0.332***
	(0.00347)	(0.0171)	(0.0193)	(0.0197)
lnp5	-0.0281***	0.794***	0.117**	-1.051***
	(0.0103)	(0.0508)	(0.0570)	(0.0582)
lnp6	-0.00596	-0.335***	-0.998***	0.418***
	(0.0151)	(0.0739)	(0.0825)	(0.0846)
lnm	0.00627***	0.317***	0.177***	0.0305***
	(0.000456)	(0.00178)	(0.00216)	(0.00224)
male	-0.00233***	0.156***	-0.000476	-0.0829***
	(0.000647)	(0.00286)	(0.00327)	(0.00336)
age	0.000299***	0.000955***	0.00189***	-0.00212***
	(1.94e-05)	(8.32e-05)	(9.24e-05)	(9.37e-05)
education	0.00103**	0.0758***	-0.0159***	-0.0707***
	(0.000482)	(0.00211)	(0.00246)	(0.00247)
household size	0.000599***	-0.00687***	0.00843***	0.0289***
	(0.000142)	(0.000654)	(0.000754)	(0.000770)
rural	-0.00331***	0.0754***	-0.136***	-0.143***
	(0.000553)	(0.00307)	(0.00336)	(0.00343)
Observations	117,656	117,656	117,656	117,656

Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

The descriptive analysis of budget shares has already revealed the potential distributional patterns of price changes for the respective energy types. Reflecting these expenditure patterns, the magnitude of a stylised price change of 20 percent per energy good is displayed in Figure 3. We find almost no difference between first- and second-order welfare losses. Overall, the calculated own-price elasticities imply, on average, a smaller second-order effect relative to the first-order effect. However, the use of 95 percent confidence intervals in the calculation of average welfare effects per percentile reveals no statistically significant difference with the exception of electricity. Electricity price changes have a slightly regressive effect as opposed to motor-fuel price changes, which are clearly progressive. Welfare losses for gas and public-transport price increases rise with expenditures until the 20th percentile and start falling from the 50th percentile. As expected from the descriptive analysis in Section 2, price changes for public transport have the potential to create the largest welfare losses for low- and middle-income households. Absolute welfare losses are strictly rising with expenditures for all energy goods. Simultaneous price increases for all energy-related expenditures lead to an inverse U-shaped distributional impacts curve (Figure 4). The magnitude of welfare losses is more distribution neutral and smaller in magnitude than welfare losses from food price increases, which are strongly regressive. With multiple price changes, the necessity of calculating second-order welfare effects is visible between the 20th and 90th percentiles. First-order effects overestimate the welfare loss by up to 10 percent for middle-income households.

Figure 3. First- and Second-Order Welfare Effects (CV), Energy Items

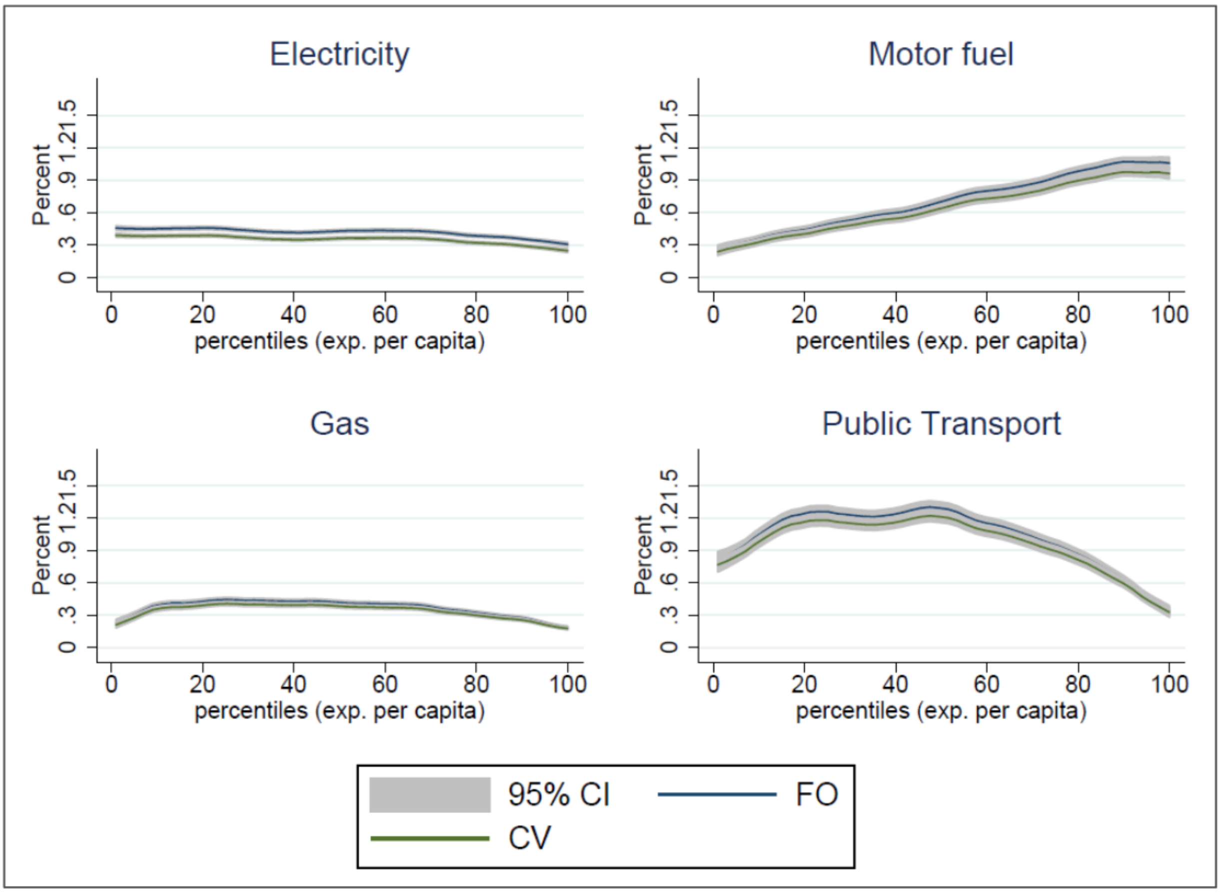
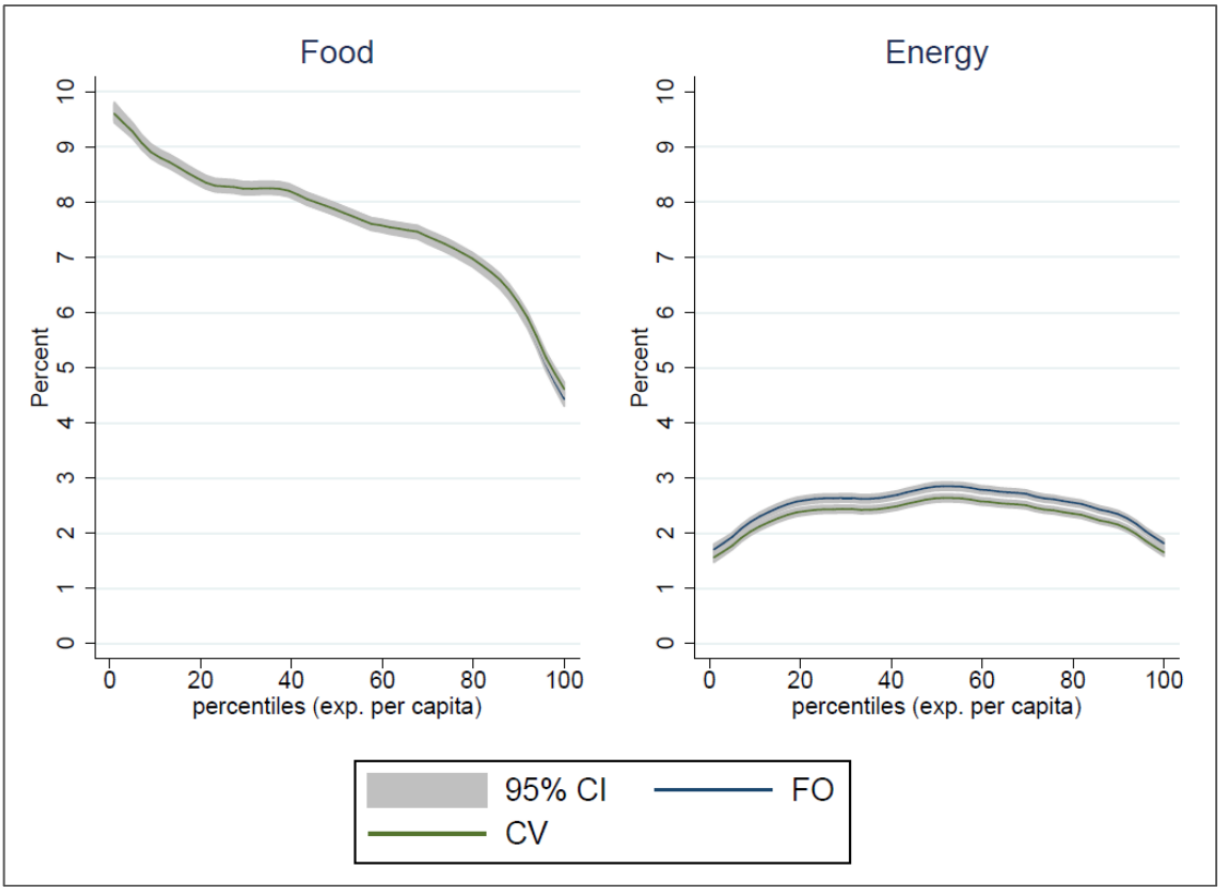


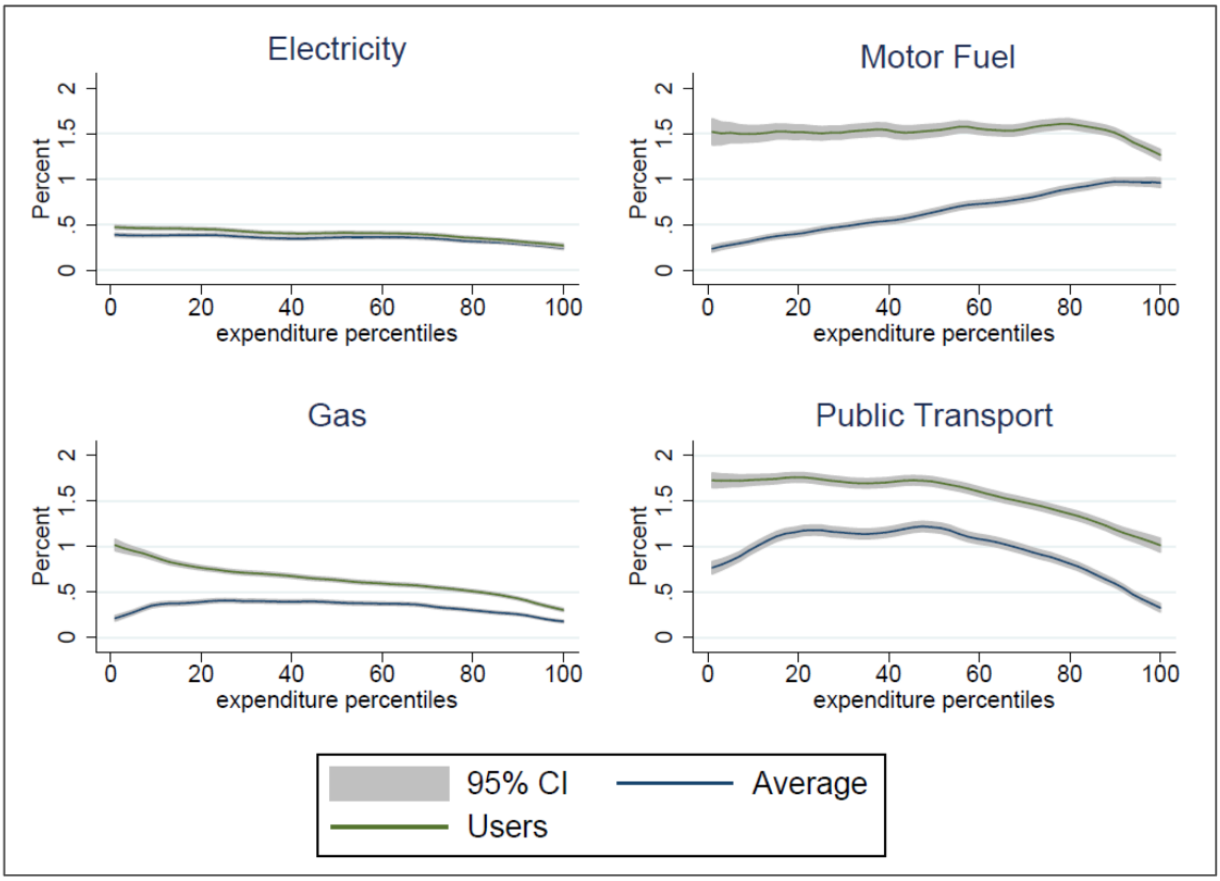
Figure 4. First- and Second-Order Welfare Effects (CV), Energy and Food



As expected from the descriptive analysis of users versus non-users of energy types, the distributional results differ significantly for the average user with strictly positive demand for the respective energy good (Figure 5). While we see almost no difference for electricity, price increases for all other energy items are clearly regressive for the user part of the population. Taking motor fuel as an example, the population average progressive effects can be explained by the low car ownership rates of the lower part of the expenditure distribution. For public transport, a major share of rural low-income households appears to be less dependent on public transport. We therefore find smaller welfare losses than for the rest of the population. Although these differences between users and non-users shed light on heterogeneity in welfare effects within the same income group, the share of the population affected around the poverty lines is more relevant for poverty incidence. Price increases for each energy type separately have quite modest impacts on the well-being poverty rate, with differences for each energy good (Figure 6). We calculate welfare losses for first- and second-order effects to assess the importance of taking into account substitution behaviour for poverty incidence. Price increases of up to 50 percent for the single energy items produce nearly identical poverty rate outcomes for first- and second-order effects. Only beyond this range do the differences become significant. For joint price increases for all energy goods, the difference between first- and second-order effects starts earlier and is more pronounced. The domestically used electricity and gas both show little sensitivity to price increases with respect to the poverty rate.

An electricity price rise of 50 percent would increase the well-being poverty rate by 0.5 percentage points maximum. Domestic energy prices for consumers in Mexico are relatively low in international comparison.

Figure 5. First- and Second-Order Welfare Effects (CV), Users vs. Average



Energy price increases in general have less impact on poverty than food price increases, as reflected in a steeper gradient in Figure 6. Nevertheless, at the well-being poverty line, a 20 percent price increase for energy has substantial effects on poverty, with an increase in the poverty rate of 1.4 percentage points (Table 4). The higher budget shares and associated welfare effects for middle-income households, on average, also lead to greater increases in the well-being poverty rate for all energy goods and for food relative to the minimum well-being poverty rate (Table 3). In addition to experiencing changes in poverty, middle-income households close to the poverty line will be disproportionally affected by higher energy prices although they will not technically be defined as poor after the price change.

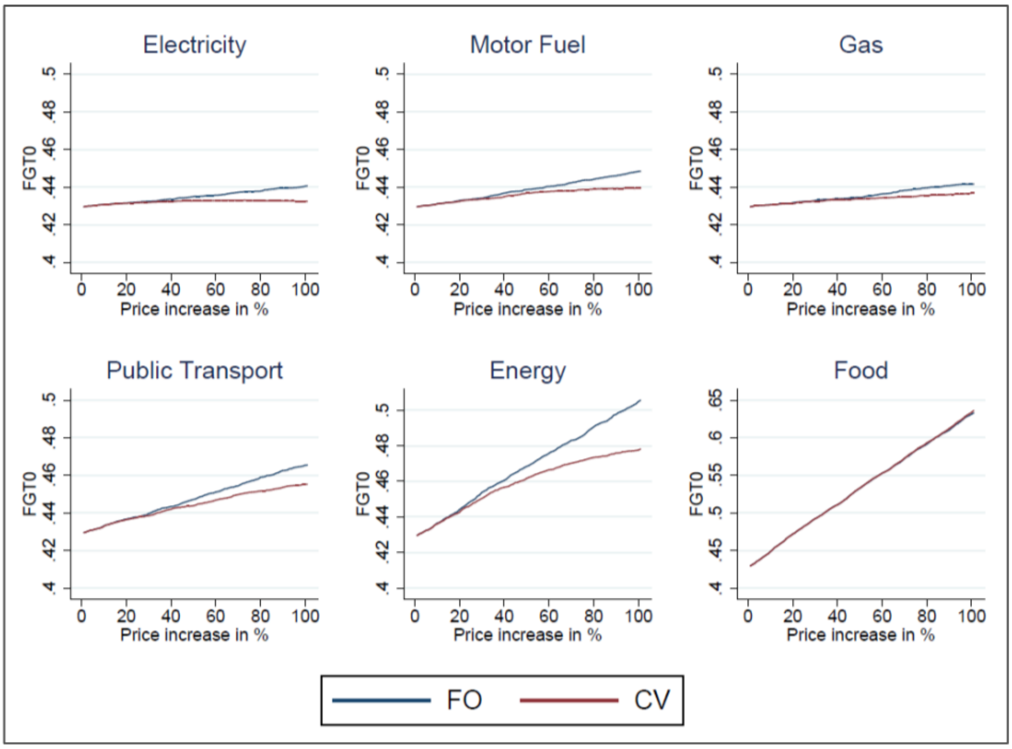
Table 3. FGT Poverty Indices (in %), Changes from Baseline, Minimum Well-Being Poverty Line

	FGT	Electricity	Motor Fuel	Gas	Public Transport	Energy	Food
price change	0	0.143	0.099	0.169	0.373	0.785	3.077
	1	0.041	0.043	0.043	0.124	0.259	1.299
	2	0.019	0.022	0.019	0.057	0.122	0.692
lum-sum	0	-0.091	-0.481	-0.081	-0.215	-0.775	-1.307
	1	-0.030	-0.159	-0.046	-0.096	-0.323	-0.540
	2	-0.018	-0.084	-0.027	-0.058	-0.180	-0.293
Prospera	0	-0.213	-0.821	-0.308	-0.601	-1.820	-2.581
	1	-0.115	-0.377	-0.151	-0.330	-0.745	-0.622
	2	-0.067	-0.200	-0.088	-0.183	-0.357	-0.193

Table 4. FGT Poverty Indices (in %), Changes from Baseline, Well-Being Poverty Line

	FGT	Electricity	Motor Fuel	Gas	Public Transport	Energy	Food
price change	0	0.192	0.316	0.184	0.710	1.440	4.414
	1	0.097	0.127	0.123	0.356	0.720	2.687
	2	0.061	0.074	0.075	0.216	0.438	1.808
lum-sum	0	-0.015	-0.311	0.003	-0.043	-0.598	-0.925
	1	-0.043	-0.285	-0.056	-0.088	-0.475	-0.934
	2	-0.035	-0.205	-0.047	-0.086	-0.371	-0.688
Prospera	0	-0.046	-0.440	-0.117	-0.046	-0.647	-1.647
	1	-0.135	-0.531	-0.170	-0.352	-1.043	-1.571
	2	-0.118	-0.423	-0.151	-0.318	-0.816	-0.972

Figure 6. Poverty Rate (FGT0, Well-Being Poverty Line) and Price Increases



For each price increase, we calculate the resulting changes in the household carbon footprint (energy-related CO_2 emissions and CO_2-equivalent emissions including CH_4 and N_2O), as displayed in Table 5. Although motor fuel does not have the highest carbon intensity, a motor-fuel price increase/tax would create the largest emission reductions, driven by relatively large budget shares. Emission reductions through electricity price changes would also be large, determined by high price elasticities despite relatively small budget shares. Remarkably, taxing gas alone has no observable effect on CO_2 emissions. This seemingly counterintuitive result can be explained by positive cross-price elasticities with electricity. As a clear substitute and with higher carbon intensity, increased electricity demand turns the emission saving from reduced gas use into a small net emission increase. A similar finding can be observed for a tax on public transport, which results in zero emission savings due to substitution with motorised private transport. These findings demonstrate the importance of obtaining a full range of own- and cross-price effects to simulate integrated welfare-environmental models. Multiple price changes for all energy-related goods may lead to very strong emission reductions through decreased household demand. Food price increases have, as discussed above, significant effects on poverty, as well as a significant impact on energy-related CO_2 emissions. As households are estimated to have close to zero own-price elasticities for food, the complementary character of gas, public transport, and other goods accounts for the energy-related emission reduction.

Table 5. CO_2(e) Emission Impacts, Energy Price Changes (20%)

		Electricity	Motor Fuel	Gas	Public Transport	Energy	Food
Carbon Tax	CO2	-4.7%	-5.9%	0.0%	0.0%	-10.8%	-2.1%
	CO2e	-2.8%	-3.1%	-0.1%	-1.2%	-7.3%	-3.1%
+ Lump-sum	CO2	-4.5%	-5.3%	0.3%	0.7%	-9.1%	3.5%
	CO2e	-2.6%	-2.5%	0.2%	-0.5%	-5.5%	2.4%
+ Prospera	CO2	-4.5%	-5.4%	0.3%	0.6%	-9.3%	2.5%
	CO2e	-2.6%	-2.5%	0.2%	-0.5%	-5.6%	2.0%

The redistribution of tax revenues leads to moderate progressive welfare effects when lump-sum transfers are used (Figure 7). For the most part, net taxes are paid by the rich households, with the exception of public transport, where the middle class pays the bill. If all tax revenues are redistributed solely to PROSPERA recipients, a governmental social assistance programme, progressivity becomes very strong, with large welfare gains of approximately 11 percent of expenditures for the poorest households in the case of motor fuel or public transport taxes.[9] Compared to the pure lump-sum scheme, households are less well compensated starting at the 50th percentile, which is also above the moderate poverty line. As a result, the poverty rate decreases by 0.65 percentage points at the well-being poverty line in the case of a simultaneous tax of 20 percent on all four energy goods and redistribution via

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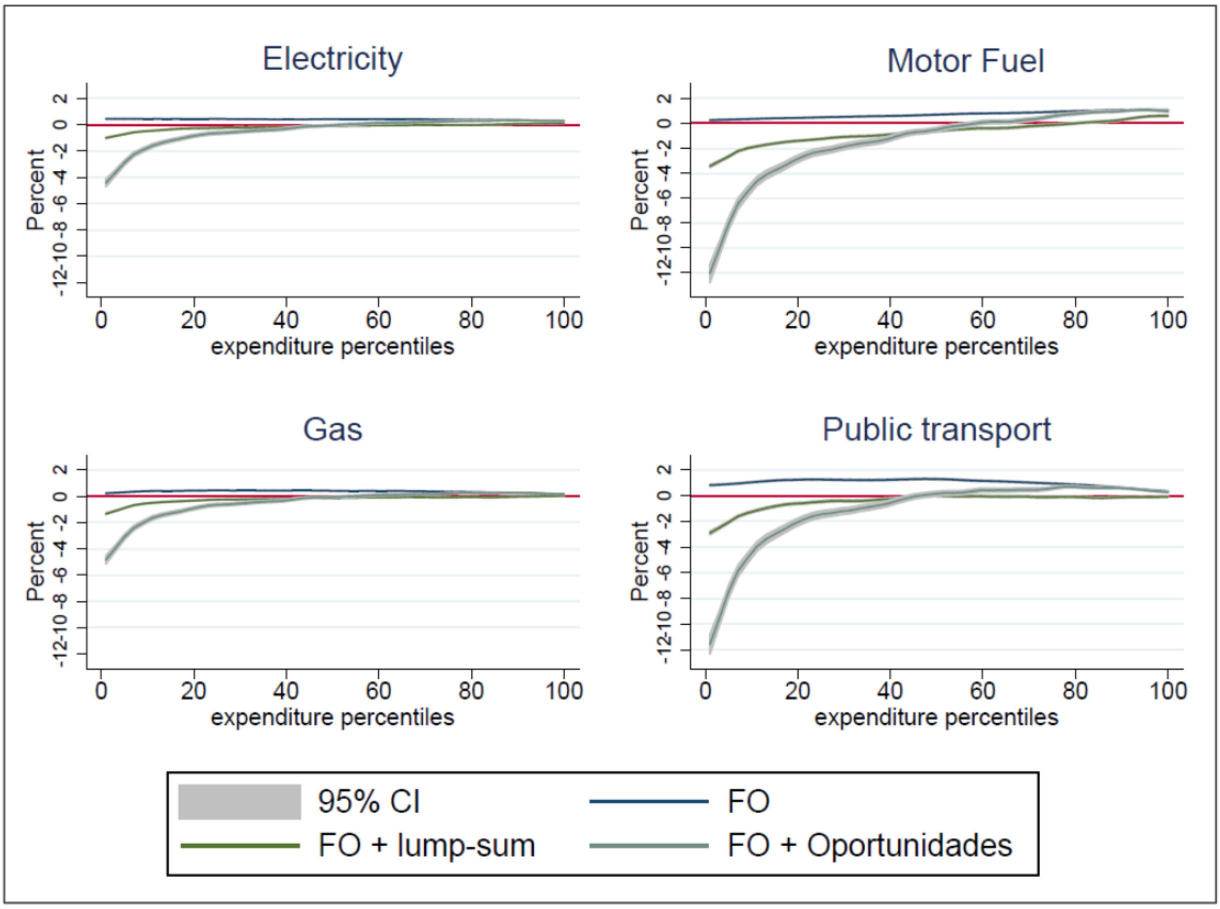
[9] PROSPERA was formerly known as Oportunidades, which was rebranded in 2014.

PROSPERA. On the other hand, poverty measured at the minimum well-being poverty line reacts more sensitively to redistribution through the relatively large compensation amounts. In this case and in the case of redistribution via PROSPERA, we find a reduction in the poverty rate of 1.8 percent. CO_2 reductions are slightly larger when redistribution takes place via PROSPERA rather than via universal lump-sum transfers, but the differences are small. When all energy-related goods are taxed at a rate of 20 percent and tax revenue is fully redistributed via PROSPERA, household CO_2 emissions are calculated to be 9.5 percent less than in the baseline and 1.5 percent less than without redistribution. On the other hand, a tax on food accompanied by the simultaneous redistribution of tax revenues has positive effects on household CO_2 emissions. Driven by increased demand for direct energy and other goods, the positive income effect from the relatively large redistribution amount has a strong effect on direct energy demand despite the negative cross-price effects on energy goods such as electricity.

Figure 7. Welfare Effects, Redistribution Scenarios



4.2 *Carbon Tax*

The first-order welfare and poverty effects of a carbon tax in Mexico have been analysed in Renner (2017). We take their sector-specific price changes and apply them to our product categorisation to assess the validity of using first-order effects and to calculate the short-run CO_2

emissions-reduction potential when price increases are shifted completely to consumers.[10] The approximate price increases for a USD 25/tCO_2 tax and for two different tax bases are displayed in Table 6. Considering that the tax rate in 2014 was at USD 3.5/tCO_2, we focus on the USD 25/tCO_2 scenario as an upper bound of potential tax increases in the short term. Price changes for households are most severe for electricity, followed by motor fuel and gas. Public transport and food items are less affected by taxes on energy-related CO_2 emissions. Food prices are clearly more sensitive to taxation of N_2O and CH_4, while direct energy items are hardly affected. Generally, carbon-tax-induced price changes are less than those discussed in the previous section on energy- and food-price changes, although the simulated tax rate can be considered non-marginal.

Table 6. CO_2 Intensities and Price Changes, Carbon Tax

		CI (kg/MXN)		Price Change (t = 25 USD)	
	item	CO2	CO2e	CO2	CO2e
1	Electricity	0.290	0.297	9.0%	9.2%
2	Motor Fuel	0.217	0.222	6.7%	6.9%
3	Gas	0.140	0.140	4.3%	4.3%
4	Public Transport	0.029	0.031	0.9%	1.0%
5	Food	0.020	0.070	0.6%	2.2%
6	Other	0.013	0.022	0.4%	0.7%

The first- and second-order effects are plotted in Figure 8, and we observe that their 95 percent confidence intervals in the calculation of average welfare effects per percentile clearly overlap. This result holds despite the fact that electricity prices are a major channel of carbon-tax-induced welfare losses and the finding of a large estimated own-price elasticity. The magnitude of electricity-price changes in the range of 9 percent does not necessarily require the estimation of demand elasticities. In Scenario I, where only energy-related CO_2 emissions are taxed, welfare effects are slightly progressive: in the range of 0.9 and 1.1 percent for lower- and higher-income households, respectively.

When CH_4 and N_2O are incorporated in the tax scheme, the welfare effects are regressive overall and particularly severe for low-income households at 2 percent of total expenditures. The much greater welfare effects are mostly caused by food price increases. Considering the inability of households to substitute away from food expenditures, this scenario has greater welfare and poverty effects. These generally increase with the tax base, with a 1.1 percentage point increase in the well-being poverty rate (Table 7). As in the case of energy price increases, the moderate well-being poverty rate is more affected than the minimum well-being poverty rate. Redistribution via lump-sum transfers or PROSPERA can case the welfare effects to become clearly progressive. The poverty indicators even improve over all dimensions.

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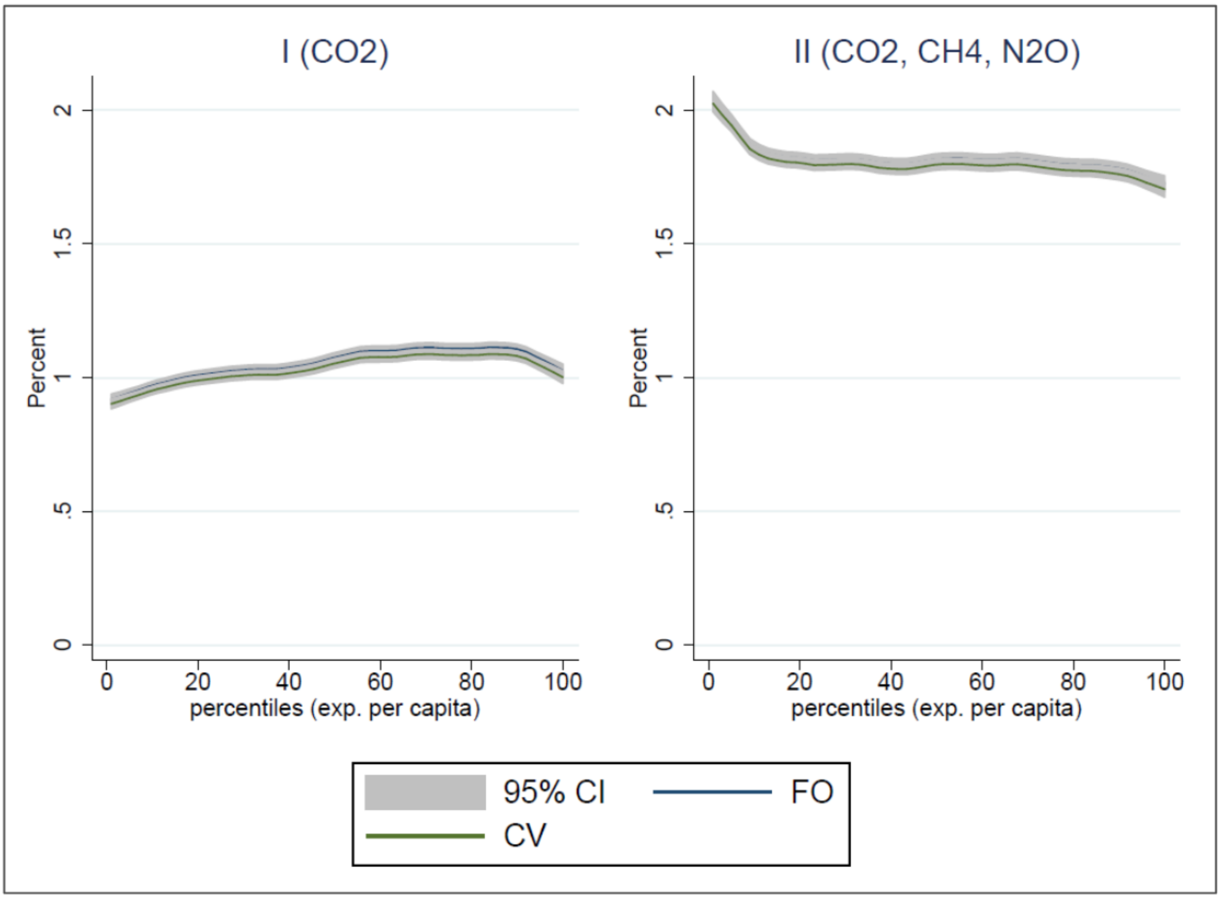
[10] Aggregation scheme available upon request.

The short-run emission-reduction potential of consumer substitution is 5.6/3.5 (CO_2/CO_2e) percent of total household-induced CO_2/CO_2e emissions and rises to 6/4 (CO_2/CO_2e) percent in Scenario II. The taxation of CH_4 and N_2O not only leads to adverse poverty effects, but the additional short-run CO_2e-emission-saving potential is also very limited.

Figure 8. Welfare Effects of Carbon Taxes



It is important to note, however, that these simulated emission reductions are relative to a baseline with zero income growth and tax revenues that are completely reinvested without further carbon emissions. In addition to the expected income growth, the redistribution of tax revenues to households in the form of cash transfers, tax rebates, or the increased use of public goods inevitably leads to the use of goods produced with fossil fuels if the energy system remains untransformed. In the case of direct cash transfers to households, the CO_2-emission-saving potential can shrink to 83 percent of the reductions achieved in scenarios without redistribution. If CH_4 and N_2O are taken into account, the wider tax base generates large tax revenues and lump-sum transfers, which in turn lead to large income effects and smaller CO_2 and CO_2e savings, which are reduced to 75 and 62 percent, respectively. Redistribution via PROSPERA leads to slightly larger CO_2 emission reductions, as already observed in the case of energy price changes. Considering the problematic link between taxing CH_4 and N_2O and food prices, taxing CO_2 alone provides an option for an ambitious short-run climate policy with moderate welfare effects that could be turned into welfare gains with proper redistribution schemes.

Table 7. FGT Changes, Carbon Tax

		Minimum wellbeing		**wellbeing**	
		Tax Scenario			
	FGT	I (CO2)	II(CO2, CH4, N2O)	I (CO2)	II(CO2, CH4, N2O)
Carbon Tax	0	0.399	0.755	0.723	1.186
	1	0.140	0.264	0.392	0.651
	2	0.066	0.130	0.233	0.406
+ Lump-sum	0	-0.407	-0.607	-0.061	-0.301
	1	-0.147	-0.228	-0.189	-0.347
	2	-0.083	-0.126	-0.161	-0.272
+ Prospera	0	-0.407	-1.505	-0.292	-0.493
	1	-0.147	-0.633	-0.518	-0.854
	2	-0.083	-0.311	-0.446	-0.686

Table 8. CO_2(e) Emission Impacts (USD 25/t CO_2(e))

		Tax Scenario	
		I (CO2)	II (CO2, CH4, N20)
Carbon Tax	CO2	-5.6%	-6.0%
	CO2e	-3.5%	-4.0%
+ Lump-sum	CO2	-4.7%	-4.5%
	CO2e	-2.6%	-2.5%
+ Prospera	CO2	-4.9%	-4.7%
	CO2e	-2.6%	-2.4%

5 Conclusion

In this paper, we have simulated the short-run poverty and distributional effects of energy price changes and carbon taxes in a partial equilibrium framework. We have estimated a full matrix of substitution elasticities, testing first- versus second-order welfare effects and finding that the latter are only slightly different from the former – as in the case of electricity – but differ with multiple price changes. Despite this finding, two practical reasons speak against the abandonment of demand estimation in our context. First of all, assessing the validity of using first-order effects is preferable to assuming it. Second, without estimated substitution elasticities we are unable to calculate the CO_2-emission-saving potential that comes from household consumption. The latter has usually been lacking in the existing literature.

By simulating stylised price-increase scenarios, we find that only motor fuels have progressive effects. Taxing electricity, gas and public transport is regressive, although in the latter case the middle class is most affected. Also important to consider is the heterogeneity within income percentiles. For actual users with positive demand for energy items, price increases are regressive. To put energy price changes into perspective, we find that food price increases have significantly larger welfare effects. Households spend a larger percentage on food products than on energy and show limited sensitivity to prices, as reflected in a close to zero own-price elasticity. Middle-income households close to the well-being poverty line are more affected by higher energy prices than low-income households. Although the smaller effects on extreme poverty are welcome from a development perspective, the political economy behind this pattern could be problematic. The progressive distribution pattern of welfare effects resulting from a carbon tax is largely driven by private motorised transport. Though the absolute monetary losses are small for households, the public opinion on environmental policy reforms appears to be quite sensitive to gasoline-price changes.

We also simulate a carbon tax at USD 25 per t CO_2 and find slightly progressive welfare effects and substantial emissions reductions. The additional taxation of CH_4 and N_2O has the potential to create large price changes in the agricultural sector, which makes their incorporation into a carbon tax regime an unsuitable option for creating poverty and environmental synergies in short-run climate policies. Considering the problematic link between CH_4 and N_2O taxation and food prices, taxing CO_2 alone provides an option for an ambitious short-run climate policy with moderate welfare effects that could be turned into welfare gains with proper redistribution schemes. The calculated emission reductions through energy and carbon taxes must be understood as household-consumption-induced emission reductions relative to a baseline with no income growth. Emission reductions through substitution by households can be quite substantial even in the case of small price changes. Income and related consumption growth, on the other hand, reduce the emission-saving potential. Taking into account the latter through redistribution via cash transfers, the initially large numbers become significantly smaller but remain substantial. Unsurprisingly, the redistribution of simulated tax revenue can make any regressive outcome progressive and reduce poverty. Targeted transfer through a social welfare programme (PROSPERA) proves to be preferable in terms of poverty and emission outcomes. Since compensation amounts are relatively large for lower-income households, poverty reduction through redistribution is clearly more visible at the lower, minimum poverty line and also creates fewer additional consumption effects and associated emission increases.

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Appendix

Table A1. ENIGH-WIOD Reduced Matching and Carbon Intensities

Item	WIOD code	WIOD description	CI (kg/MXN)	
			CO2	CO2e
Electricity	17	Electricity, Gas and Water Supply	0.290	0.297
Motor Fuels	8	Coke, Refined Petroleum	0.217	0.222
Gas	8	Electricity, Gas and Water Supply	0.140	0.140
Public Transport	23	Inland Transport	0.029	0.031
Food	1	Agriculture	0.032	0.173
	3	Food processing	0.016	0.044
Other	4	Textiles	0.017	0.024
	5	Leather, Footwear	0.013	0.019
	6	Wood and Wood Products	0.018	0.047
	7	Pulp, Paper	0.019	0.020
	8	Chemicals and Products	0.014	0.022
	9	Rubber and Plastics	0.013	0.015
	10	Other Non-Metallic Mineral	0.056	0.100
	11	Basic Metals and Fabricated Metal	0.021	0.028
	12	Machinery	0.005	0.006
	13	Electrical and Optical Equipment	0.008	0.009
	14	Transport Equipment	0.008	0.010
	15	Manufacturing; Recycling	0.022	0.027
	16	Construction	0.018	0.023
	17	Sale Motor Vehicles and Fuel	0.017	0.019
	18	Wholesale and Commission Trade	0.008	0.010
	19	Retail Trade	0.012	0.014
	20	Hotels and Restaurants	0.025	0.026
	21	Water Transport	0.147	0.152
	22	Air Transport	0.013	0.075
	23	Other Transport	0.018	0.019
	24	Post and Telecommunications	0.008	0.009
	25	Financial Intermediation	0.004	0.005
	26	Real Estate Activities	0.004	0.004
	27	Renting of M&Eq and Other	0.009	0.010
	28	Public Admin and Defence	0.015	0.016
	29	Education	0.012	0.012
	30	Health and Social Work	0.011	0.013
	31	Other Services	0.013	0.101

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GIGA German Institute of Global and Area Studies / Leibniz-Institut für Globale und Regionale Studien
Neuer Jungfernstieg 21 • 20354 Hamburg • Germany
E-mail: <info@giga-hamburg.de> • Website: <www.giga-hamburg.de>