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Poverty and Distributional Effects of a Carbon Tax in Mexico

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Poverty and Distributional Effects of a Carbon Tax in Mexico

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Abstract

Mexico recently declared ambitious goals in reducing domestic CO_2 emissions and introduced a carbon tax in 2014. Although negative effects on household welfare and related poverty measures are widely discussed as possible consequences, empirical evidence is missing. We try to fill this gap by simulating an input-output model coupled with household survey data to examine the welfare effects of different carbon tax rates over the income distribution. The currently effective tax rate is small and has negligible effects on household welfare. Higher simulated tax rates, maintaining the current tax base, show a slight progressivity but welfare losses remain moderate. Welfare losses, regressivity and poverty rise more with widening the tax base towards natural gas and other greenhouse gases (CH_4, N_2O) mainly through food price increases. For a complete analysis of the policy, we simulate a redistribution of calculated tax revenues and find that the resulting effects become highly progressive, also for high rates, wider tax bases and even in the absence of perfect targeting of social welfare programs.

JEL Classification: C67, Q28, Q48, Q52, H23, I38

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1 Introduction

Among the group of middle income countries, Mexico has become one of the most significant emitters of CO_2 in absolute and per capita terms in recent years. In 2014, it was ranked the 15th biggest economy and the 12th biggest carbon emitter in the world with more economic growth and fossil fuel intensive energy use to be expected in the future (Olivier et al., 2015; World Bank, 2016). Since the beginning of the 1970s, emissions have increased by over 350 percent, reflecting both per capita economic and large population growth (figure 1). On average, income per capita has increased by over 80 and carbon emissions per capita by over 100 percent. This unequal growth rates can be linked to the rising carbon intensity (CO_2/GDP) of the economy until the 1990s; since then we observe a decline accompanied by more efficient energy use. Although the economy became less carbon intensive, energy efficiency improvements since 2000 have been small.

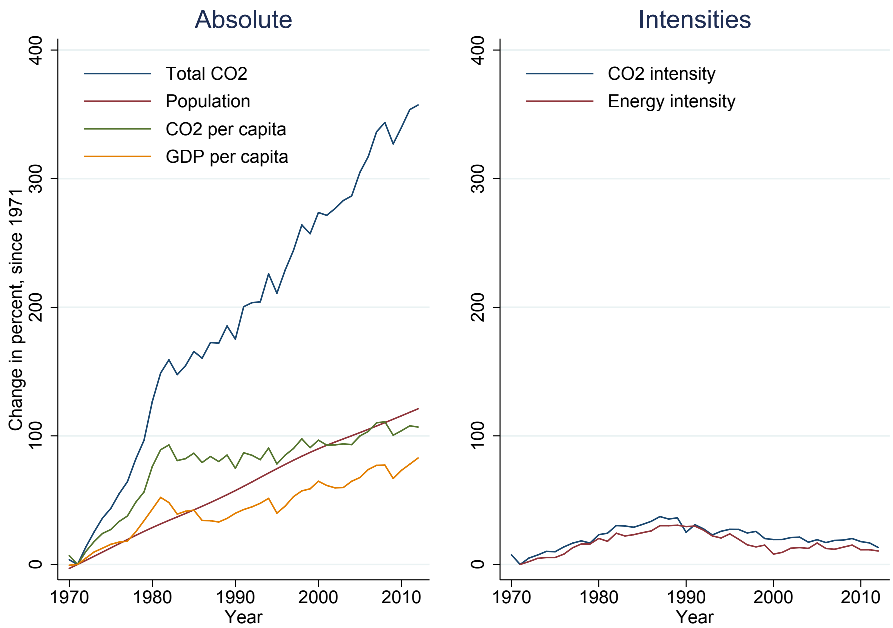

Figure 1: CO_2 emissions, GDP and CO_2 intensities Mexico

Among Mexican policymakers, a rising awareness of this development can be observed over recent years. Mexico started to voluntarily commit itself to greenhouse gas emission reduction targets in 2010 at the Cancun Climate Change Conference. In 2013, the government launched additional and further reaching reforms to the Mexican energy markets and thus prepared the ground for a green fiscal reform (Metcalf, 2015). In October 2013, the Mexican Congress approved the

Government's proposal of a tax on the sale and import of fossil fuels which came into effect on January 1, 2014, making Mexico the first non-developed country to adopt such a policy. The price of the proposed carbon tax was calculated by weighting the carbon price of various international markets and the carbon content of each fossil fuel sold in Mexico using emission factors of the combustion process. However, the tax is not levied on all emissions but only on those generated by fossil fuels other than natural gas and jet fuel. The currently rather low tax rate with major exceptions in the tax base is unlikely to create large disincentives for the use of fossil fuels. In 2015, Mexico submitted its Nationally Determined Contribution (NDC) to the UNFCCC in 2015 as the first middle income country. Although the instruments to realize the planned emission savings are not mentioned in detail, an increase in the carbon price appears as one highly suitable candidate. If Mexico wants to change its growth path towards a low carbon pathway as discussed in its national climate strategy and its NDC pledges, a massive decarbonization of the energy system is the major challenge. Additionally, the taxation of other greenhouse gases such as NH4 and N_2O could widen the tax base significantly.

A scaled up carbon tax with higher tax rates and a wider tax base could on the other hand create severe conflicts with development and social equity goals such as distributional and poverty outcomes. However, the final effect of environmental taxation on household welfare is less than straightforward as has been pointed out by Fullerton (2008, 2011). In the short-run, prices of fossil-fuel intensive products are likely to rise which affects the consumption costs of households, the so called "uses" side. For developed countries, a general finding is a regressive effect for household consumption, reflecting a negative relation between spending shares of carbon intensive items and total consumption expenditures (Brännlund and Nordström, 2004; Callan et al., 2009; Kerkhof et al., 2008; Metcalf, 2008; Rausch et al., 2011; Wier et al., 2005). A regressive effect is not found for every developed country though. Labandeira and Labeaga (1999) and Tiezzi (2005) do not find regressive effects of carbon tax scenarios for Spain and Italy respectively. For developing countries, the regressivity result does not need to hold as well, particularly due to often lower energy spending shares for the poor Shah and Larsen (1992). Still, empirical results are largely missing with some exceptions and mixed results for China. Brenner et al. (2007) find regressive effects while Liang and Wei (2012) and Liang et al. (2013) find carbon taxation to lead to progressive results.

Beyond the very short-run, more effects are gaining in importance. Depending on how factor demand changes through the price increase, the income of workers or capital owners will be affected through the “sources” side. Additionally, the distribution of resulting environmental benefits such as reduced air pollution, employment effects and the capitalization into asset prices may change the distributional burden over time. Empirical evidence for these mid- to long-term effects is missing but analytical and ex-ante general equilibrium modelling can provide some orientation. Fullerton and Heutel (2007) describe the effects of carbon taxation on the different factor prices and conclude they depend critically on the substitutability of capital, labor, and emissions. Eventually, redistribution of tax revenues has the potential to make any carbon tax reform progressive, although as Rausch et al. (2011) notes, this may come at the cost of efficiency.

For Mexico, we neither find ex-post evidence nor ex-ante simulation results for the effects of a carbon tax in the literature. Gonzalez (2012) uses an analytical general equilibrium model to simulate a stylized carbon tax scenario for Mexico and finds that the direction of the effect is determined by the way the tax revenue is recycled. Redistribution towards food subsidies would lead to an overall progressive effect.

With no empirical analysis available for Mexico and little evidence for low- and middle income countries in general, we try to fill the gap in the literature by simulating carbon tax scenarios for Mexico and examine poverty and distributional effects. The simulation is based on an input-output model to calculate carbon intensities of various product categories. We match the production side with consumption expenditure on the household level in order to determine the short-run impact of carbon tax scenarios on household welfare. Besides calculating welfare effects for the current tax regime in place, we add scenarios including more CO_2 emissions from natural gas, jet fuel and other greenhouse gas emissions from methane (CH_4) and nitrous oxide (N_2O). We also include redistribution scenarios and check for welfare effects of border tax adjustments.

The rest of the paper proceeds as follows. In section 2 we describe the methodology of the input-output model and the integration with the household consumption side used in the analysis. In section 3, we describe the data and general trends in emissions, energy use, consumption and poverty are supplied as background material for the analysis in section 4. We summarize results and provide some policy recommendations in section 5.

2 Methodology

Our analysis consists of two steps, which have been applied in the previous literature on the calculation of price effects of carbon taxes (Cornwell and Creedy, 1996; Labandeira and Labeaga, 2002; Proops et al., 1993; Symons et al., 1994). First, we calculate sector specific price changes following a taxation of CO_2 emissions by drawing on an environmentally extended input-output model. In the second step the price changes are translated into welfare effects on the household level.

2.1 Input-output analysis and price changes per sector

We obtain carbon intensities of production sectors (table 1) by combining input-output tables with energy and emission data taken from the World Input Output Database (Timmer et al., 2015).

The resulting carbon intensities per production sector contain direct as well as indirect emissions from other sectors.[1] By assumption, production is described by a Leontief production function which implies no substitution between sectors so that price increases are fully shifted towards consumers. The model is theoretically valid for small tax changes in the short-run but increases in uncertainty with time and the size of the tax. For calculating the carbon intensities we follow Proops et al. (1993) and distinguish between different fuel types as these naturally contain different amounts of CO_2 per physical unit.[2] Total fossil fuel use per energy carrier is represented by F_f, whereby f indicates the type of fuel and represents an element of the vector f showing the fuel quantities used in production per sector. The carbon content per physical unit of the respective fuel is e_f and multiplying this vector by f yields total production CO_2 emissions C_{ind}:

$$e'f = C_{ind} \tag{1}$$

The intensity of fuel use in production c_{if} is defined as the ratio of the quantity of fuel type f used in sector i, F_{if}, and the sector's i total output X_i:

$$c_{if} = \frac{F_{if}}{X_i} \tag{2}$$

The product of the transposed fuel intensity matrix C and the total demand

[1]The WIOD data contains 35 sectors, but we eliminate the 35th sector ("Private Households with Employed Persons") due to insignificant contribution to total production and energy use.

[2]Fossil fuels included are hard coal, brown coal, coke, diesel, gasoline, light fuel oil, fuel oil, naphtha, other petroleum and other gases excluding natural gas.

x gives the vector of production fossil fuel use f, i.e. $C'x = f$. Multiplying both sides by the carbon content per fuel unit e' and recalling equation 1 then describes the components of production CO_2 emissions:

$$e'C'x = e'f = C_{ind} \tag{3}$$

The elements of $e'C$ can be termed "direct carbon intensities" as they reveal how much CO_2 is emitted per unit of total output by each sector. The inclusion of CH_4 and N_2O in the analysis provides us with intensities of carbon equivalents, reflecting the gases global warming potential.[3] Since CH_4 and N_2O emissions are transformed to CO_2 equivalent emissions, we continue to use the term carbon also when other gases are included. Finally, economic policy is more concerned with final demand and not exclusively with production x. Equation 3 has thus to be transformed in terms of final demand using the Leontief inverse $(I-A)^1$. Recalling total production $x = (I-A)^1 y$ and substituting for x into equation 3 gives:

$$e'C'(I-A)^{-1}y = C_{ind} \tag{4}$$

The multiplication of the direct carbon intensities $e'C$ by the Leontief inverse $(I-A)^1$ then generates the indirect carbon intensities:

$$CI_{ind} = e'C'(I-A)^{-1} \tag{5}$$

Equation 5 provides us with a new vector of CO_2 intensities which contains the direct carbon emissions, resulting from direct production emissions in the respective sector, plus the indirect carbon emissions, caused by the release of carbon emissions in the production of intermediate inputs in the production process of goods, per unit of final demand y. In order to determine the carbon content of each fuel, the WIOD data takes CO_2 emission factors from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and from the United Nations Framework Convention on Climate Change (UNFCCC) emissions reporting, as especially the latter also report country specific emission factors. Additionally to production emissions, households have direct demand for fuels and associated direct emissions C_{dir} which are not captured in the input-output framework. Total emissions from household consumption is the sum of direct and indirect emissions from consumption and energy use:

[3]Global warming potential factors under the assumption of climate-carbon feedbacks and 100 year time horizons are 28 for CH_4 and 265 for N_2O (IPCC, 2013).

$$C = C_{dir} + C_{ind} \tag{6}$$

The carbon intensity of energy items with direct emissions such as fuels, could be calculated on the basis of observed quantities and physical emission factors. In the absence of observed quantities, we calculate these by using price per fuel unit data from the Instituto Nacional de Estadística y Geografía (INEGI), calculate direct emissions C_{dir} and obtain direct carbon intensities $CI_{dir}(tCO_2/MXN)$. Total demand carbon intensities per sector are then:

$$CI = CI_{dir} + CI_{ind} \tag{7}$$

For non-fuels, equation 7 simply reduces to CI_{ind}. Depending on the scenario, final demand can either exclude imports or include them in a border tax adjustment scenario. In the latter case, we assume imports exhibit the same carbon intensity in production and are taxed like domestic goods. In a next step, we receive a vector of sector specific carbon taxes by multiplying the general carbon tax rate μ with the sector specific CO_2 intensity:

$$t = \mu * CI \tag{8}$$

Each sector specific ad valorem tax rate t_i can be directly interpreted as the sector specific price change relative to the base price p_{i0}:

$$(1 + t_i)p_{i0} = p_{i1} \Leftrightarrow t_i = \frac{p_{i1}}{p_{i0}} - 1 \tag{9}$$

2.2 Effects on household welfare

The total effect on household welfare in our specification depends on the impact of sectoral price changes on expenditures. Household expenditures are taken from the 2014 Encuesta Nacional de Ingreso y Gasto de los Hogares (ENIGH) available from INEGI. To link the production with the consumption side, we assign all expenditure items to the 34 production sectors.[4] Matching is done on the basis of expenditures item names and assigned description from the questionnaire. In order to assess distributional implications we calculate first-order welfare effects relative to total expenditures per household.[5] This is done by multiplying the

[4]Available upon request.

[5]Second-order effects, including substitution away from and between goods, are naturally a superior measure of welfare effects. Since our analysis is mostly concerned with the energy and

consumption category specific carbon taxes with household expenditure shares:

$$\Delta w_{hi} = w_{hi} * t_i \quad (10)$$

to obtain the change in budget shares per consumption category. We use the sum of changes $\sum w_{hi}$ as the welfare loss, defined as the percentage share of total household expenditures. For the effects on poverty, we calculate absolute welfare effects and subtract them from household income, since domestic poverty lines are constructed with current income measures (CONEVAL, 2014). All absolute effect are calculated on a per capita basis to facilitate the analysis across different household sizes.

3 Data and descriptive results

The analysis is based on two main data sources. First, input-output data is used to determine the carbon intensity of production sectors in Mexico. Secondly, these carbon intensities are applied to consumption data on the household level.

3.1 Input-output and environmental accounts

Input-output tables as well as information on sector specific carbon emissions are taken from the World Input-Output Database (WIOD, Timmer et al. 2012). We use the national input-output table for Mexico, which contains transactions for 35 sectors of the economy (table 1).

Although the most recent year for the national Mexican input-output table is for 2014, data on energy use and emissions are only available up to 2009. We therefore use data for 2009 and convert prices to 2014 levels. As input-output tables are delivered at base prices, they are converted to consumer prices using data on the net tax rates per sector provided in WIOD's national supply and use tables. Data on emissions are from the environmental satellite accounts of the WIOD database (Genty et al., 2012). In order to determine the carbon content of each fuel, the WIOD data takes CO_2 emission factors from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and from the United Nations Framework Convention on Climate Change (UNFCCC) emissions reporting, as especially the latter also report country specific emission factors. On the same

carbon content of goods, estimating demand elasticities for a system of 34 sectors based on the IO classification is beyond the scope of this paper.

Table 1: WIOD sector description

sector	sector description
1	Agriculture, Hunting, Forestry and Fishing
2	Mining and Quarrying
3	Food, Beverages and Tobacco
4	Textiles and Textile Products
5	Leather and Footwear
6	Wood and Products of Wood and Cork
7	Pulp, Paper, Printing and Publishing
8	Coke, Refined Petroleum and Nuclear Fuel
9	Chemicals and Chemical Products
10	Rubber and Plastics
11	Other Non-Metallic Mineral
12	Basic Metals and Fabricated Metal
13	Machinery, Nec
14	Electrical and Optical Equipment
15	Transport Equipment
16	Manufacturing, Nec; Recycling
17	Electricity, Gas and Water Supply
18	Construction
19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
22	Hotels and Restaurants
23	Inland Transport
24	Water Transport
25	Air Transport
26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
27	Post and Telecommunications
28	Financial Intermediation
29	Real Estate Activities
30	Renting of M&Eq and Other Business Activities
31	Public Admin and Defence; Compulsory Social Security
32	Education
33	Health and Social Work
34	Other Community, Social and Personal Services

sectoral level as the input-output table, it offers emissions data for CO_2, CH_4 and N_2O. We convert CH_4 and N_2O emission to CO_2 equivalents based on IPCC (2013).

3.2 Household data and poverty lines

We exploit micro data from the National Survey of Household Incomes and Expenditures (Encuesta Nacional de Ingresos y Gastos de los Hogares (ENIGH)) provided by the Mexican National Institute for Statistics and Geography (INEGI). It is a nationally representative household survey, covering about 20000 households in 2014. The different expenditure categories included 744 distinct items which are assigned to the 34 sectors of the input-output table. The expenditure data was complemented by information on the sociodemographic features of the individual households to enable a distinction between different household groups based on various characteristics such as age, household size and gender. Although the welfare effects in our model depend on expenditure patterns, poverty effects finally depend on the definition of poverty lines as well. We calculate Foster-Greer-Thorbecke (FGT) poverty indices on the basis of poverty lines provided by the Consejo Nacional de Evaluacion de la Politica de Desarrollo Social (CONEVAL, 2014). Two distinct poverty lines are used. The first describes a minimum well-being standard of an individual which corresponds to the value of the food basket per person per month (Bienestar minimo - Canasta alimentaria). The population below this poverty line cannot afford enough food to ensure adequate nutrition which represents extreme poverty. 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 well-being standard (Bienestar - Canasta alimentaria y no alimentaria) which represents more moderate poverty. Each poverty line is calculated for rural and urban individuals in monthly income per capita values in current prices which allows for a distinction between rural and urban poverty in the calculations. In the analysis, the average of the indicated monthly values over the year 2014 was used.

3.3 Descriptive findings

As indicated in figure 1, total CO_2 emissions have been rising despite the decline in CO_2 intensity. Carbon emissions and intensities per production sector reveal more detailed dynamics in light of the overall slight decline (table 2). The utilities sector including electricity, gas and water supply has the highest emission total as well as emission intensity in 2009. Other sectors with high carbon intensities like water transport are less important in terms of direct emissions and even less so for household consumption. Inland and air transport play a bigger role but the latter is excluded from the current carbon tax legislation which implies zero price changes for households. The observed overall decline in the carbon intensity can mainly be ascribed to the utilities sector, which exhibits a large decrease in absolute terms and of 34 percent relatively from 1995 to 2009. This decline is mainly caused by a shift from oil to gas in the power sector IEA (2016). Based on the analysis of overall carbon intensities, we would not expect the carbon intensity to change by great amounts from 2009 to 2014 and use the 2009 carbon intensities, deflated to the 2014 price level, for further analysis. Finally, a decline in the carbon intensity is no guarantee for decreasing emissions as can be observed from table 2. However, total emissions would have been higher without reductions in the carbon intensity, which has mainly happened in the energy and manufacturing sectors.

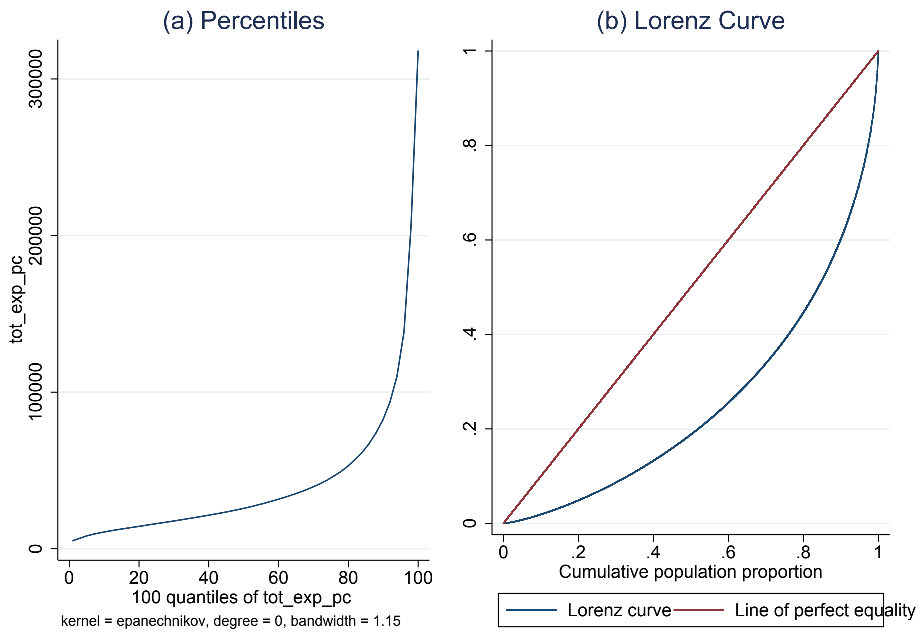

Figure 2: Household per capita expenditures Mexico (2014=

For the calculation of welfare effects relevant consumption expenditures are quite unequally distributed over the population. In 2014, total consumption expenditures of the top 10 percent of households are about 20 times higher than the bottom 10 percent expenditures (figure 2 a). We find that 50 percent of the

Table 2: Sectoral CO_2 production emissions and CO_2 intensities (Scenario B)

sector	CO2 (kt)			CO2 intensity (kt/MXN)		
	2009	change 1995-2009	% change	2009	change 1995-2009	% change
1	20829.2	3310.59	18.9	36.52	0.48	1.32
2	28501.36	12996.07	83.82	26.17	1.65	6.74
3	4742.34	-986.9	-17.23	17.48	-5.39	-23.58
4	2654.53	70.84	2.74	24.26	-0.15	-0.62
5	411.09	-115.36	-21.91	15.64	-1.92	-10.92
6	442.26	-275.22	-38.36	23.52	-6.81	-22.45
7	3102.72	636.81	25.82	24.03	1.57	6.97
8	31112.55	5502.69	21.49	52.5	-21.26	-28.82
9	9650.42	-3377.63	-25.93	27.93	-8.52	-23.37
10	1481.2	-83.21	-5.32	23.39	-4.6	-16.44
11	24279.19	7282.68	42.85	107.12	8.23	8.32
12	14053.75	-794.34	-5.35	38.5	-12.59	-24.63
13	816.03	101.63	14.23	15.35	-3.44	-18.3
14	3068.47	729.92	31.21	11.23	-1.56	-12.19
15	1721.49	395.03	29.78	10.1	-1.55	-13.33
16	2955.43	850.44	40.4	23.87	-2.15	-8.25
17	107813.29	32436.2	43.03	290.91	-151.67	-34.27
18	11732	6325.56	117	20.33	-3.34	-14.12
19	2118.31	737.27	53.39	17.25	-0.46	-2.58
20	2800.13	960.17	52.18	7.63	-1.14	-12.99
21	8708.97	3109.77	55.54	12.1	-1.12	-8.47
22	6039.58	1313.3	27.79	24.78	-2.83	-10.24
23	23689.76	8221.65	53.15	29.36	-2.1	-6.66
24	2237.76	266.55	13.52	147.31	-5.01	-3.29
25	8254.4	2006.94	32.12	86.15	-45.9	-34.76
26	1965.47	523.14	36.27	18.45	-4.58	-19.87
27	2074.73	569.84	37.87	8.23	-2.38	-22.44
28	907.06	417.77	85.38	4.16	0.65	18.65
29	826.02	344.42	71.52	3.59	-0.62	-14.69
30	5427.32	3451.16	174.64	9.13	-1.14	-11.08
31	5222.88	1301.03	33.17	15.48	-5.24	-25.27
32	6886.26	1976.5	40.26	11.69	-4.36	-27.16
33	2509.07	798.18	46.65	10.89	-2.24	-17.07
34	2244.8	402.36	21.84	14.99	-2.73	-15.4

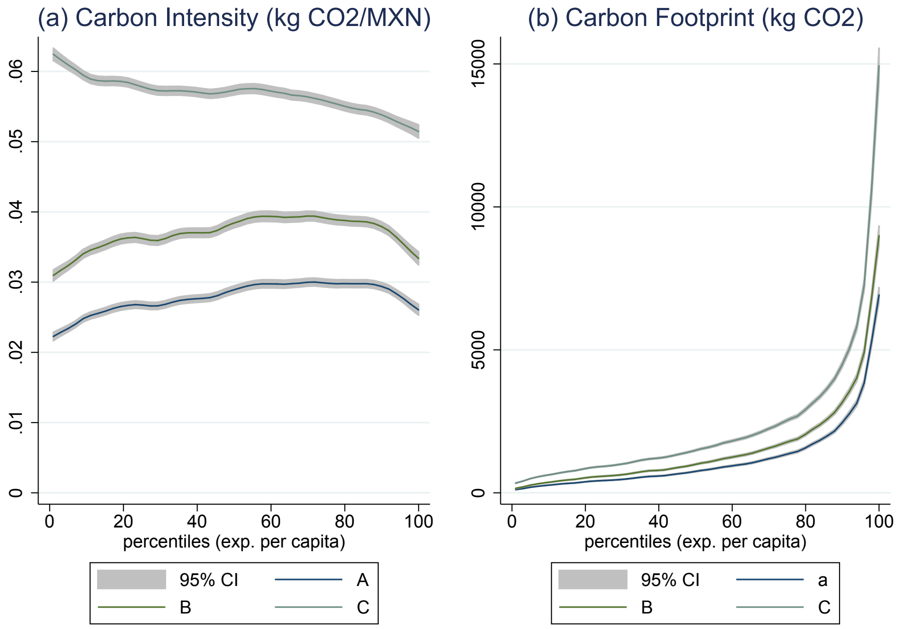

Figure 3: CO_2 intensity of expenditures and CO_2 footprints Mexico (2014)

population have less than a 20 percent share of total expenditures (figure 2 b), over 60 percent of all expenditures can be accounted to just 10 percent of the population at the top of the expenditure distribution. High expenditure inequality already provides an indication for distributional impacts of consumption taxes in absolute terms. In relative terms, tax payments grow in proportion to the carbon intensity of consumption. We check the latter by calculating household specific carbon footprints for our three scenarios and relate these to household expenditures. The carbon intensity of consumption increases until the 50th percentile when only CO_2 emissions from energy use are taxed (Scenario A and B).[6] It decreases again at the 90th percentile, reflecting a shift to more service and less energy intensive consumption items (figure 3 a). This decline is quite moderate and cannot make up for the quantity increase in consumption, reflected in high carbon footprints for high expenditure households (figure3 b). Remarkably, the carbon intensity declines over the expenditure distribution when CH_4 and N_2O are taxed additionally to CO_2 emission from energy. The importance of CH_4 and N_2O intensive goods such as food in the consumption basket declines with income. Although the welfare effects in our model depend on expenditure patterns, poverty effects finally depend on the definition of poverty lines as well.

[6]Nonparametric distributional curves are calculated with kernel-weighted local polynomial smoothing using an epanechnikov kernel function with degree 0 and bandwith 1.15

The calculated poverty indices differ quite strongly over rural and urban areas, while the total value is dominated by the large urban population. The poverty headcount using the wellbeing poverty line is 45 percent overall while 54 and 42 percent in rural and urban areas respectively (table 3).[7] The Gini coefficient is at a relatively high level of 0.52 in international comparison and lower within urban and rural areas, reflecting an urban-rural income gap.

Table 3: FGT poverty indices and Gini index (2014)

Poverty line	Index	National	Rural	Urban
Minimum Wellbeing	FGT 0	0.14	0.23	0.11
	FGT 1	0.04	0.08	0.03
	FGT 2	0.02	0.04	0.01
Wellbeing	FGT 0	0.45	0.54	0.42
	FGT 1	0.17	0.23	0.15
	FGT 2	0.08	0.13	0.07
	Gini	0.52	0.45	0.5

Eventually, merging two conceptually different data sources calls into question the comparability of the data. Credibility of household survey data, as well as national accounts data, is heavily debated in the literature (Datt and Ravallion, 2011; Deaton, 2005). The usual problem is that household survey data aggregates are considerably smaller than calculated in national accounts data. With the data used in our analysis, we can confirm the huge spread between consumption in the micro household and in the input-output data. Since a thorough analysis of this difference is beyond the scope of this paper, we provide some orientation on the magnitude of the problem and restrict ourselves mostly to relative welfare effects. The consumption aggregate in the IO data for the most recent available year 2011 is 2.7 times greater than in the survey data for the year 2014, although economic growth rates have been around 2.5 percent on average from 2011 to 2014 (World Bank, 2016). If consumption by households grew with the same rate, the survey data covers only 35.5 percent of the IO consumption aggregate resulting in a factor of 2.81. For relative welfare measures, this scaling procedure has no effect on results but absolute changes and total tax revenue would have to be multiplied with the scaling factor if the IO data is assumed to be more credible.

[7] Differences to poverty statistics published by CONEVAL are due to equivalence scales, which we do not use since our focus is on poverty changes trough different tax rates and not through family composition

4 Results

4.1 Scenarios

Apart from the expenditure shares on certain goods and the size of the tax, welfare effects finally depend on the tax base, which is the share of emissions covered by the tax regime. The current legislation taxes CO_2 emissions from energy sources and excludes natural gas, jet fuel and non-energy emissions. The Mexican Congress approved different tax rates for distinct fossil fuel types with prices ranging between 5.80 - 46.42 Mexican Pesos (MXN) per tCO_2 (0.45 - 3.63 USD) (Belausteguigoitia, 2014). This implies a weighted average of MXN 43.10 per tCO_2 (USD 3.37).[8] The first scenario (A) reflects this current legislation scheme in a simplified version. Instead of working with a number of single fuel taxes, we set a uniform carbon tax of 3.5 USD/tCO_2 which is close to the implicit tax in place and facilitates comparisons with larger tax rates and other carbon tax regimes in the international context.[9] Since natural gas is a major energy source in the electricity sector, we simulate the inclusion in the second scenario (B). Thirdly, reflecting the fact that climate change is a result of rising greenhouse gas emissions and not exclusively of energy CO_2 emissions alone, we add methane (CH_4) and nitrous oxide (N_2O) plus jet-fuel and non-energy CO_2 emissions to the calculation. Besides the share of greenhouse gas emissions by a tax, the actual tax size is crucial in each scenario. Setting the tax rate to an amount that captures marginal damages resulting from climate change has created major dispute in the literature (Pindyck, 2013). Considering the contested calculation of the social cost of carbon we offer lower and upper bound tax rates of 20 and 50 USD per ton CO_2/CO_2e. The USD 20 tax can be seen as a short term interpretation of the carbon tax as a major policy tool to achieve Mexico's Nationally Determined Contribution (NDC). The upper bound of USD 50 contributes to the understanding of how larger, although currently politically infeasible tax rates affect household welfare. We calculate total tax revenues on the basis of the carbon intensity vector and the 2014 consumer expenditures. Our derived tax estimates are therefore a projection for 2014 and exclude the taxation of exports, which is in line with our model assumptions.[10] Two redistribution scenarios are simulated, which

[8] Annual average exchange rate 13.29 MXN/USD (International Monetary Fund, 2016)

[9] We also simulated the "real" carbon tax by calculating sector specific price changes based on the multiple of fuel taxes. As results do not differ significantly, we did not report them but they are available from the authors upon request.

[10] Official Mexican government estimates are slightly different due to differences in the calculation method,e.g. exports are taxed.

includes a stylized lump-sum transfer per household over the entire population and a transfer of the entire tax revenue to recipients of the social welfare program PROSPERA (formerly known as Oportunidades and rebranded as PROSPERA in 2014).

4.2 Results

The different carbon tax rates and tax bases generate a wide variety of price changes for households. Reflecting the carbon intensity of the respective production sector, price increases can be expected to rise from Scenario A to C, although with differences in sectors. The carbon intensity for electricity and utilities, calculated by excluding natural gas, jet fuel and non-energy emissions in scenario A, is considerably smaller than in Scenario B (table 4). Resulting price changes are small for the current tax rate and moderate for higher tax rates. With a tax of 3.5 USD per ton CO_2, the price change in the electricity sector is well below one percent and rises up to 10 percent with 50 USD per ton. The largest price change in the current tax regime can be expected from refined petroleum products such as gasoline. Including natural gas in the taxation of CO_2 emissions (Scenario B) naturally increases the price for electricity and since the emissions covered increase by almost 100 percent, the carbon intensity and associated price changes with a similar magnitude relative to Scenario A. Electricity price changes now dominate fuel price increases. For other sectors, the inclusion of natural gas slightly increases price changes. As expected, including CH_4 and N_2O in taxation lead to strong price increases for agricultural products and to a lesser extent for processed food reflected in larger carbon intensities for these sectors. Other sectors are less affected in Scenario C and show carbon intensities and price increases similar to Scenario B. Resulting welfare effects also increase with the coverage of emissions from Scenario A to C and with the tax rate. For the currently implemented tax rate close to 3.5 USD/ t CO_2 the welfare effects are generally slightly progressive and small below 0.2 percent of total expenditures for most households. Welfare effects increase to a maximum of 4.2 percent of total expenditures for the poorest households in Scenario C for a tax rate of 50 USD/t CO_2.

Table 4: Carbon intensities and price changes

	Scenarios									
	A				B			C		
	price changes in % for carbon tax rates (in USD)									
Sector No	CI (t/Mio MXN)	3.5	20	50	CI (t/Mio MXN)	20	50	CI (t/Mio MXN)	20	50
1	29.07	0.13%	0.72%	1.80%	32.39	0.80%	2.00%	172.93	4.28%	10.70%
2	3.57	0.02%	0.09%	0.22%	25.37	0.63%	1.57%	31.80	0.79%	1.97%
3	12.50	0.05%	0.31%	0.77%	16.46	0.41%	1.02%	43.72	1.08%	2.71%
4	12.75	0.06%	0.32%	0.79%	17.30	0.43%	1.07%	23.63	0.58%	1.46%
5	9.06	0.04%	0.22%	0.56%	12.86	0.32%	0.80%	19.44	0.48%	1.20%
6	14.06	0.06%	0.35%	0.87%	18.13	0.45%	1.12%	47.12	1.17%	2.92%
7	10.45	0.05%	0.26%	0.65%	18.59	0.46%	1.15%	20.03	0.50%	1.24%
8	202.26	0.88%	5.01%	12.52%	216.90	5.37%	13.42%	222.20	5.50%	13.75%
9	5.24	0.02%	0.13%	0.32%	13.85	0.34%	0.86%	21.57	0.53%	1.33%
10	7.20	0.03%	0.18%	0.45%	12.81	0.32%	0.79%	15.22	0.38%	0.94%
11	40.40	0.18%	1.00%	2.50%	55.74	1.38%	3.45%	100.26	2.48%	6.21%
12	8.79	0.04%	0.22%	0.54%	20.51	0.51%	1.27%	27.79	0.69%	1.72%
13	3.40	0.01%	0.08%	0.21%	5.37	0.13%	0.33%	6.28	0.16%	0.39%
14	4.67	0.02%	0.12%	0.29%	7.76	0.19%	0.48%	9.50	0.24%	0.59%
15	5.21	0.02%	0.13%	0.32%	7.92	0.20%	0.49%	9.58	0.24%	0.59%
16	12.85	0.06%	0.32%	0.80%	22.32	0.55%	1.38%	26.51	0.66%	1.64%
17	158.43	0.69%	3.92%	9.81%	290.01	7.18%	17.95%	296.62	7.34%	18.36%
18	13.04	0.06%	0.32%	0.81%	17.82	0.44%	1.10%	23.27	0.58%	1.44%
19	14.19	0.06%	0.35%	0.88%	17.23	0.43%	1.07%	18.92	0.47%	1.17%
20	5.54	0.02%	0.14%	0.34%	7.77	0.19%	0.48%	9.59	0.24%	0.59%

	Scenarios								
	A			B			C		
	price changes in % for carbon tax rates (in USD)								
Sector No	CI (t/Mio MXN)	3.5	20	50	CI (t/Mio MXN)	20	50	CI (t/Mio MXN)	20	50
21	10.15	0.04%	0.25%	0.63%	12.23	0.30%	0.76%	13.95	0.35%	0.86%
22	19.43	0.08%	0.48%	1.20%	24.61	0.61%	1.52%	26.49	0.66%	1.64%
23	21.24	0.09%	0.53%	1.31%	29.34	0.73%	1.82%	31.21	0.77%	1.93%
24	143.45	0.62%	3.55%	8.88%	146.67	3.63%	9.08%	151.90	3.76%	9.40%
25	8.69	0.04%	0.22%	0.54%	12.73	0.32%	0.79%	74.78	1.85%	4.63%
26	15.97	0.07%	0.40%	0.99%	18.10	0.45%	1.12%	19.10	0.47%	1.18%
27	6.41	0.03%	0.16%	0.40%	8.22	0.20%	0.51%	9.23	0.23%	0.57%
28	3.01	0.01%	0.07%	0.19%	3.91	0.10%	0.24%	4.90	0.12%	0.30%
29	2.29	0.01%	0.06%	0.14%	3.56	0.09%	0.22%	3.82	0.09%	0.24%
30	7.08	0.03%	0.18%	0.44%	8.87	0.22%	0.55%	10.06	0.25%	0.62%
31	11.06	0.05%	0.27%	0.68%	14.66	0.36%	0.91%	15.96	0.40%	0.99%
32	10.37	0.04%	0.26%	0.64%	11.61	0.29%	0.72%	12.04	0.30%	0.75%
33	8.07	0.03%	0.20%	0.50%	10.98	0.27%	0.68%	12.83	0.32%	0.79%
34	10.18	0.04%	0.25%	0.63%	13.42	0.33%	0.83%	101.27	2.51%	6.27%

For Scenario A, relative welfare losses rise until the 60th percentile, stay constant until the 80th percentile and decline afterwards (figure 4). The absolute effect rises along the expenditure distribution as already indicated in the description of the expenditures and the carbon footprint. A more ambitious climate policy with higher tax rates of 20-50 USD/t CO_2 would come with the same relative distributional pattern, although progressivity is more visible. With a larger tax rate of 50 USD/t CO_2, welfare losses are at 1.5 percent for the bottom part of the expenditure distribution. Poverty indices are hardly affected from the lower rates, whereas a 50 USD tax would increase the national minimum wellbeing and wellbeing poverty rates by 0.6 and 0.9 percentage points respectively (tables 5 and 6), mainly driven by gasoline and electricity prices. For both poverty lines, rural poverty increases more than urban poverty.

Including natural gas in the taxation of emissions (Scenario B), a 50 USD tax rate increases welfare losses up to 2.1 and 2.6 percent for low and high income households respectively (Figure 5). The currently implied tax rate of 3.5 USD would still create small welfare losses below 0.2 percent of total expenditures for all households. The maximum wellbeing poverty rate increase is 1.2 percentage points with a 50 USD tax (table 6). In this scenario, extremely poor rural households are hit worse than their urban counterparts. At the wellbeing poverty line, differences between urban and rural poverty impacts are less pronounced.

The story changes essentially with the inclusion of CH_4 and N_2O in the taxation of emissions (Scenario C). The price increase for agricultural and processed food products not just leads to higher welfare losses it also increases regressivity since poorer households spend relatively more on food products (figure 5). This is reflected in an increase in the minimum wellbeing poverty rate on the national level of 1.5 percentage points for a 50 USD tax (table 5). More pronounced than in scenarios where only energy related emissions are taxed, is also the increase of poverty intensity and severity. With large food price changes, households above the poverty line will fall below the poverty line but also households below the poverty line face increasing difficulties to escape poverty. This holds particularly for rural households, which are already severely affected by price increases for energy items.

Reflecting the large rural urban income gap and despite the smaller poverty impacts, urban households face slightly higher welfare losses than rural households in scenario A and B when only energy emissions are taxed. Urban households spend relatively more on direct energy goods such as electricity. In Scenario C, rural low income households face higher welfare losses than their urban counterparts. For most socioeconomic groups, welfare effects lie within a 95 percent confidence interval of the average percentile consumption and are thus mostly statistically insignificant over the income distribution for all scenarios. We do not find any significant difference in welfare effects between female and male headed households and small differences due to family sizes. Age plays some role for consumption decisions, households with older household heads suffer slightly higher welfare losses. This finding can be explained by relatively higher expenditures for emission intensive utilities compared to households with younger household heads.

To understand the role of the single sectors in shaping welfare effects, we provide a graphical overview of sector specific carbon intensities, welfare effects and household expenditure shares for a USD 20 tax rate on CO_2 emissions from energy use (Scenario B). For the bottom 10 percent of the expenditure distribution, agricultural products, processed food, refined petroleum and utilities make up the largest part of the welfare loss (figure 6). Agricultural products are not very energy intensive but households spend a large share of their income on processed foods. The carbon intensity for the utilities and refined petroleum products are the highest, which make them main contributors for the welfare loss despite a relatively low expenditure share. Expenditure patterns are different for the top 10 percent of the expenditure distribution, who spend relatively more on rent and service oriented goods such as hotels and restaurants (figure 9, appendix) but also on refined petroleum products such as gasoline. The latter becomes the consumption item causing the largest welfare loss and the main driver behind the progressive distributional effect in taxing CO_2 emission from energy use.

Additionally to finding differences in welfare effects across the expenditure distribution with different tax scenarios, we find spatial heterogeneity within the country. In line with our findings over the expenditure distribution, northern states, which generally exhibit above average expenditures per capita have higher average welfare losses in scenarios covering energy emissions only (Figure 7). The reason can be found in higher budget shares for electricity and fuels in northern states. With CH_4 and N_2O emissions included, this spatial heterogeneity mostly vanishes since associated food price increases particularly lead to large welfare losses in southern states.

Finally, a redistribution simulation of projected tax revenues for our three scenarios is an elementary part for the analysis of distributional effects. Transferring total tax revenues in a lump-sum fashion per household in Scenario B with a 20 USD tax results in average welfare gains for the bottom 85 percent of the distribution (figure 8). Welfare gains for households at the lower end of the distribution are large with a magnitude of up to three times the effect of the counterfactual welfare loss. This large redistribution effect occurs despite the fact that low income households benefit less from the redistribution than high income households on a per capita basis due to larger family sizes. Poverty indicators decrease across all dimensions but more so for rural areas, where the combined tax and lump-sum redistribution scheme would lead to poverty rate declines of about half a percentage point at both poverty lines. Redistribution of full tax revenues via PROSPERA has the potential to generate huge welfare gains for PROSPERA recipients more than 10 percent of total household expenditures. Surprisingly, a nonsignificant share of households above the median income benefit from PROSPERA although they are not classified as poor. Poverty reductions are much stronger in this case, particularly at the minimum wellbeing poverty line and for rural households (table 5).

In all other simulated scenarios with redistribution, distributional patterns become even more progressive with higher tax revenues, particularly for PROSPERA scenarios. The urban poverty rate on the other hand remains either constant or increases slightly in all PROSPERA scenarios, which leads to moderate national poverty reductions despite massive improvements for rural households. Two reasons are behind this finding. First, PROSPERA is mainly targeted at very poor, particularly rural households. Urban households close to the wellbeing poverty line are less likely to be recipients of PROSPERA. Second, the urban wellbeing poverty line is significantly larger than the rural poverty line. Generally all redistribution simulations clearly reverse the regressive into a progressive overall effect.

Inequality indices such as the Gini Index hardly react to the magnitude of welfare effects caused by the different tax rates in our analysis (table 7). The distributional effects of carbon taxes are not severe enough to create significant changes in the income distribution on the national level, not even with high tax rates and a broad tax base. However, redistribution of tax revenues via targeted cash transfer programs can decrease income inequality within rural areas or keep it constant when smaller shares of tax revenues are used for redistribution. If the tax is accompanied with border tax adjustments makes no significant difference, welfare effects remain largely unaffected. Although 9.5 percent of consumption goods get imported, these are mainly goods from less carbon intensive sectors such as the processed food and transport equipment sectors.

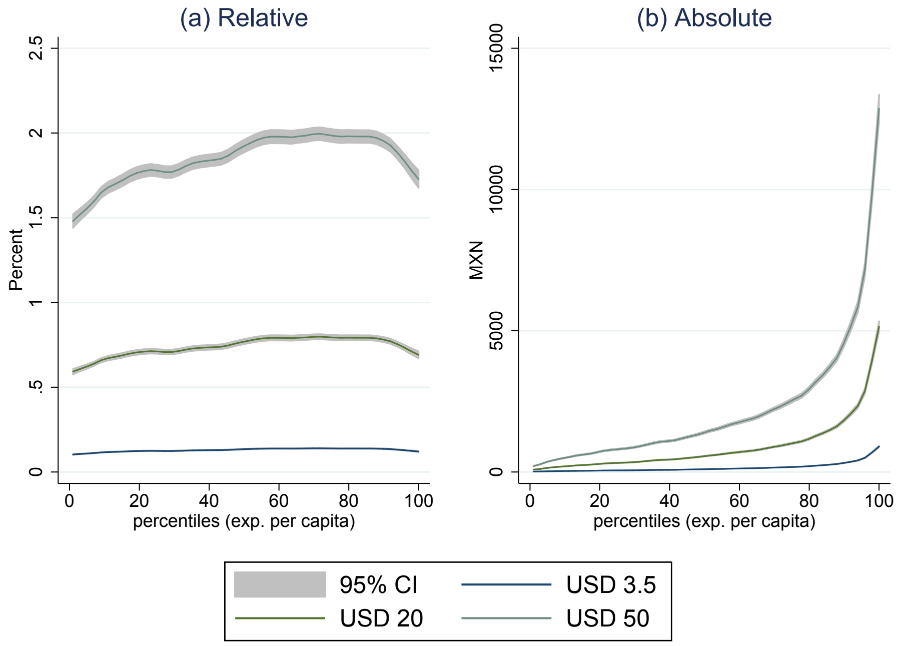

Figure 4: Relative (a) and absolute (b) welfare effects Scenario A

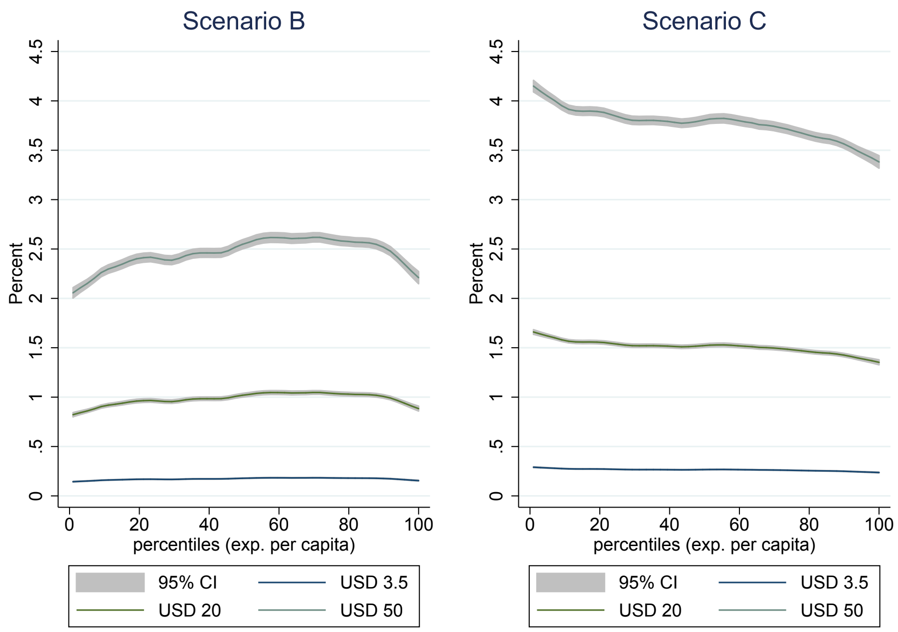

Figure 5: Relative welfare effects scenario B and C

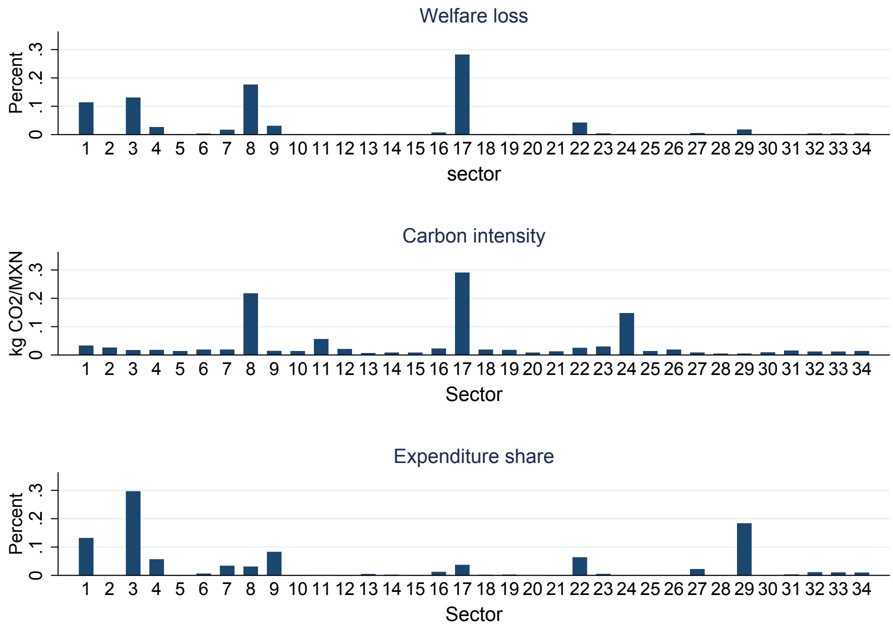

Figure 6: Decomposition welfare loss, bottom 10 percent

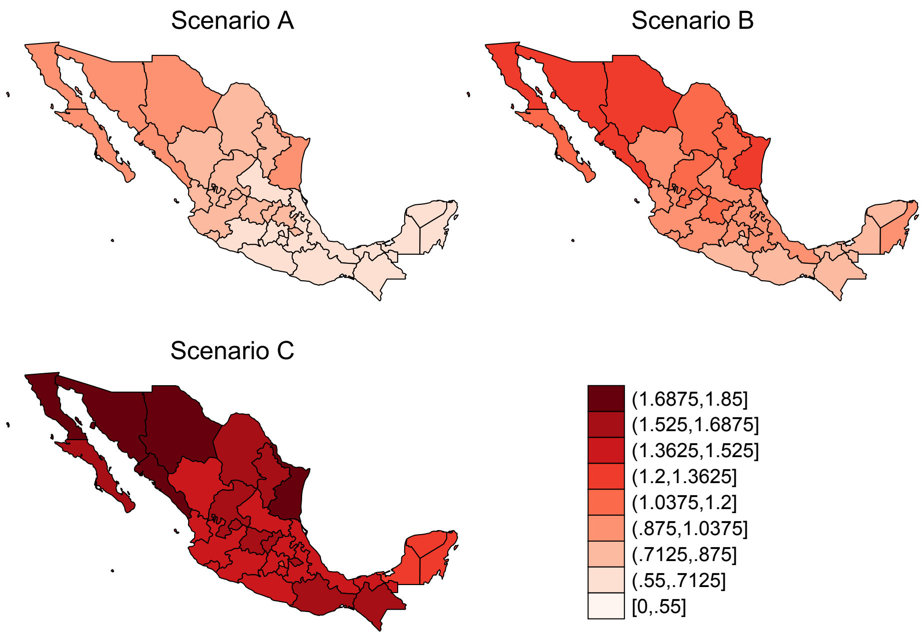

Figure 7: Average relative welfare losses per federal state

Table 5: Minimum Wellbeing FGT poverty indices (in %), changes from baseline

		Scenarios								
		A			B			C		
Scenario	FGT	National	Rural	Urban	National	Rural	Urban	National	Rural	Urban
II (USD 20)	0	0.307	0.379	0.287	0.372	0.495	0.338	0.557	0.880	0.466
	1	0.090	0.140	0.076	0.122	0.187	0.104	0.219	0.382	0.173
	2	0.047	0.086	0.036	0.064	0.115	0.050	0.120	0.246	0.084
II (USD 20) Lump-Sum	0	-0.071	-0.167	-0.044	-0.404	-0.683	-0.325	-0.523	-0.773	-0.452
	1	-0.046	-0.142	-0.020	-0.175	-0.429	-0.104	-0.229	-0.546	-0.140
	2	-0.030	-0.095	-0.012	-0.103	-0.276	-0.054	-0.132	-0.344	-0.073
II (USD 20) Oportunidades	0	-0.103	-0.480	0.002	-0.912	-2.621	-0.432	-1.333	-3.684	-0.673
	1	-0.064	-0.303	0.004	-0.482	-1.555	-0.182	-0.644	-2.098	-0.236
	2	-0.046	-0.207	-0.001	-0.285	-0.975	-0.091	-0.364	-1.262	-0.112
III (USD 50)	0	0.616	0.818	0.559	0.833	1.049	0.773	1.489	2.111	1.315
	1	0.231	0.358	0.196	0.315	0.479	0.269	0.573	0.996	0.454
	2	0.123	0.224	0.095	0.169	0.303	0.132	0.322	0.658	0.228
III (USD 50) Lump-Sum	0	-0.195	-0.495	-0.111	-0.961	-1.700	-0.753	-1.319	-2.388	-1.019
	1	-0.112	-0.348	-0.046	-0.419	-1.031	-0.248	-0.535	-1.281	-0.326
	2	-0.071	-0.228	-0.027	-0.241	-0.644	-0.127	-0.302	-0.783	-0.167
III (USD 50) Oportunidades	0	-0.229	-1.246	0.056	-2.190	-6.230	-1.056	-2.723	-8.246	-1.172
	1	-0.141	-0.712	0.019	-0.941	-3.101	-0.335	-1.083	-3.723	-0.342
	2	-0.099	-0.471	0.005	-0.492	-1.743	-0.141	-0.518	-1.943	-0.119

Table 6: Wellbeing FGT poverty indices (in %), changes from baseline

		Scenarios								
		A			B			C		
Scenario	FGT	National	Rural	Urban	National	Rural	Urban	National	Rural	Urban
II (USD 20)	0	0.369	0.298	0.389	0.499	0.448	0.513	0.770	0.795	0.763
	1	0.205	0.243	0.194	0.276	0.322	0.263	0.452	0.596	0.411
	2	0.133	0.171	0.122	0.179	0.227	0.166	0.305	0.441	0.266
II (USD 20) Lump-Sum	0	0.034	-0.037	0.054	-0.285	-0.729	-0.161	-0.444	-1.035	-0.278
	1	-0.043	-0.168	-0.008	-0.270	-0.579	-0.183	-0.369	-0.759	-0.260
	2	-0.044	-0.143	-0.016	-0.208	-0.458	-0.138	-0.279	-0.590	-0.191
II (USD 20) Oportunidades	0	0.135	-0.427	0.292	-0.410	-2.497	0.176	-0.567	-3.494	0.255
	1	-0.003	-0.341	0.092	-0.599	-2.106	-0.176	-0.834	-2.940	-0.243
	2	-0.037	-0.303	0.038	-0.510	-1.666	-0.186	-0.690	-2.270	-0.247
III (USD 50)	0	0.918	0.978	0.902	1.237	1.203	1.246	1.750	1.652	1.778
	1	0.520	0.616	0.492	0.701	0.820	0.668	1.154	1.520	1.052
	2	0.338	0.435	0.311	0.459	0.580	0.425	0.786	1.140	0.687
III (USD 50) Lump-Sum	0	0.046	-0.322	0.149	-0.767	-1.693	-0.508	-1.072	-2.037	-0.800
	1	-0.105	-0.414	-0.018	-0.661	-1.416	-0.450	-0.898	-1.839	-0.634
	2	-0.107	-0.351	-0.038	-0.504	-1.106	-0.335	-0.666	-1.403	-0.460
III (USD 50) Oportunidades	0	0.396	-0.632	0.684	-1.088	-5.785	0.230	-1.547	-8.292	0.346
	1	0.005	-0.824	0.238	-1.319	-4.638	-0.388	-1.701	-6.078	-0.472
	2	-0.077	-0.715	0.103	-1.043	-3.439	-0.371	-1.273	-4.302	-0.424

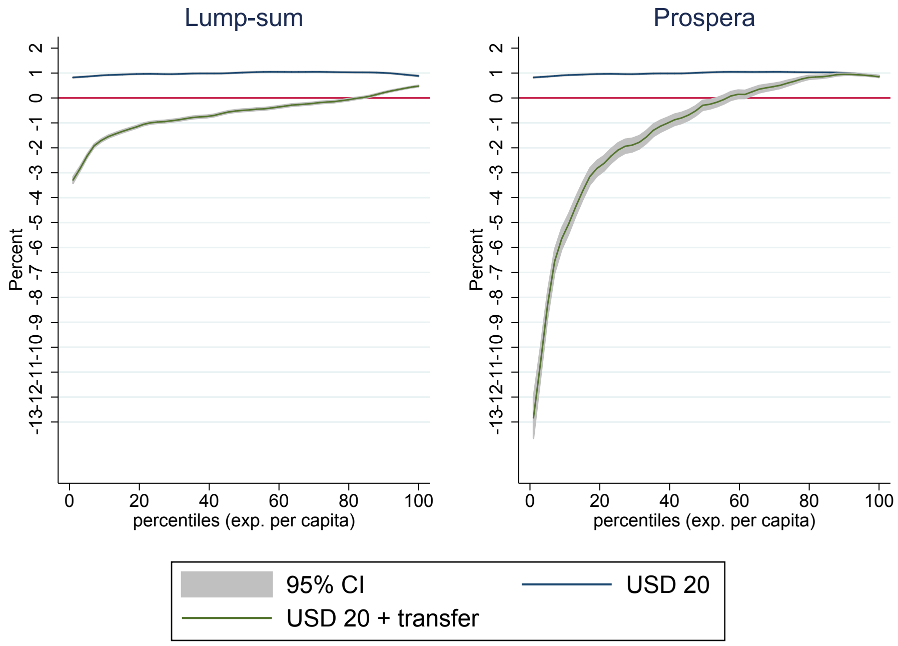

Figure 8: Welfare effects lump-sum vs. PROSPERA redistribution Scenario B

5 Conclusions and Policy Implications

Our analysis offers a detailed view on potential welfare effects of different carbon tax scenarios for Mexico. The current rate of the carbon tax is small enough not to create much impact for household welfare. Although we are not able to calculate resulting emission reductions, the current effect can expected to be negligible with the currently implemented tax regime. Adding to it, natural gas remains tax exempt but accounts for 25 percent of energy related CO_2 emissions which renders the policy partly inefficient. As we show, including natural gas increases the welfare losses due to higher electricity prices. Although the inclusion of aviation fuels in the carbon tax would naturally increase efficiency, these effects are negligible since jet fuel emissions are only 2 percent of total energy related emissions. To have a supposedly measurable effect on national CO_2 emissions, the necessary higher tax rates are projected to have negative effects on household welfare and related poverty outcomes on its own. The exact magnitude and distributional outcome indeed depends on the tax rate but also on the share of taxed emissions. In the case of the highest simulated tax rate of 50 USD/tCO_2e and including CH_4 and N_2O in the taxation, we find overall effects to be regressive with relative welfare losses at 4.2 and 3.4 percent of total expenditures for the poorest and richest households respectively. For carbon tax rates of 20 USD/tCO_2 exclusively taxing CO_2 from energy use, which might be more realistically expected in climate policies, welfare losses are progressive and around 1 percent of total expenditures for all households. Naturally, the reason for this progressivity is a rising carbon intensity of consumption over the expenditure distribution up to a certain income level, driven by transport fuels such as gasoline. In contrast, the top decile demands more service oriented, low carbon intensive goods which lessens the progressivity of carbon taxes to some extent. Nevertheless, absolute tax payments strictly rise with income. Although welfare effects are generally moderate for low tax rates, total tax revenues allow for relatively high transfers to low income households which render the policy clearly progressive. National poverty incidence is more sensitive at the wellbeing poverty line in scenarios covering only energy related CO_2 emissions. Additionally, low income rural households are also at higher risk than their urban counterparts. In the case of food price increases through taxation of CH_4 and N_2O, poverty is much stronger affected which demonstrates the importance of a well thought through redistribution mechanism. Nevertheless, since distributional results are calculated on average per expenditure percentile, they hide an important fact. In scenarios with redistribution not every poor household benefits through the PROSPERA system. The share of PROSPERA recipients in the lowest percentile is about 70 percent and declines to 13 percent at the 50th percentile, resulting in a substantial number of households below the minimum wellbeing and other households close to the bienestar poverty line not covered, particularly in urban areas. Despite the on average promising redistribution outcome, targeting must be improved to achieve poverty reductions for the entire population.

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A Appendix

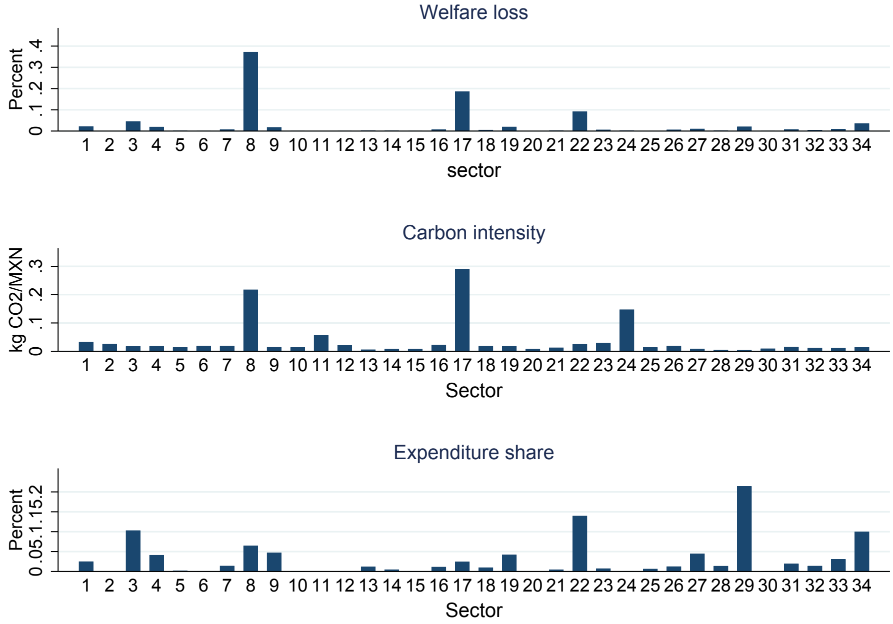

Figure 9: Decomposition welfare loss, top 10 percent

Table 7: Inequality effects (Gini Index)

Scenario	National	Rural	Urban
Baseline	0.518	0.452	0.505
A			
I (USD 3.5)	0.518	0.452	0.505
II (USD 20)	0.519	0.452	0.505
II (USD 20) + lump-sum	0.516	0.449	0.503
II (USD 20) + PROSPERA	0.514	0.440	0.503
III (USD 50)	0.519	0.453	0.506
III (USD 50) + lump-sum	0.514	0.444	0.501
III (USD 50) + PROSPERA	0.509	0.425	0.501
B			
I (USD 3.5)	0.518	0.452	0.505
II (USD 20)	0.519	0.452	0.505
II (USD 20) + lump-sum	0.516	0.448	0.503
II (USD 20) + PROSPERA	0.513	0.436	0.503
III (USD 50)	0.520	0.453	0.507
III (USD 50) + lump-sum	0.513	0.442	0.500
III (USD 50) + PROSPERA	0.507	0.419	0.500
C			
I (USD 3.5)	0.518	0.452	0.505
II (USD 20)	0.519	0.454	0.506
II (USD 20) + lump-sum	0.515	0.447	0.502
II (USD 20) + PROSPERA	0.511	0.431	0.502
III (USD 50)	0.521	0.457	0.508
III (USD 50) + lump-sum	0.510	0.440	0.498
III (USD 50) + PROSPERA	0.502	0.410	0.498