

LETTER • OPEN ACCESS

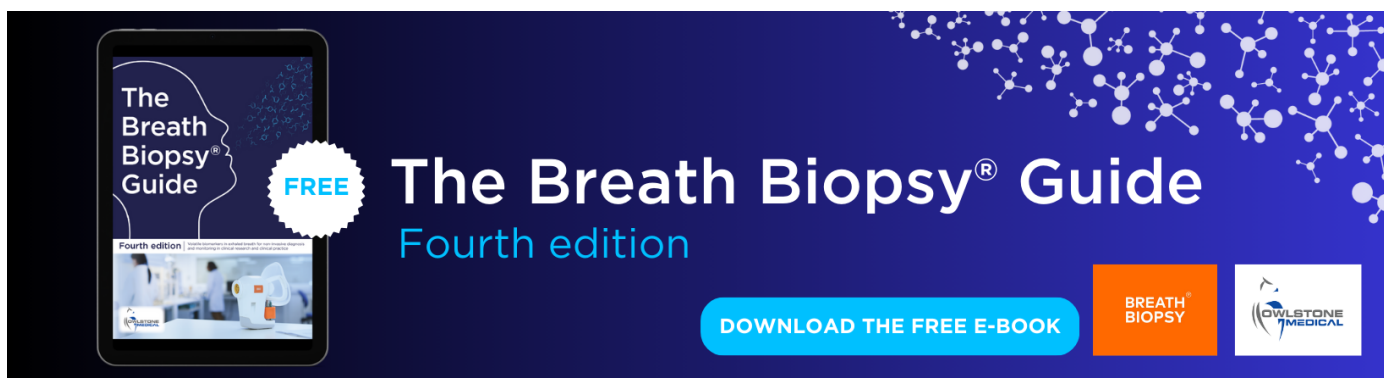
Carbon tax effects on the poor: a SAM-based approach

To cite this article: Joana Chapa and Araceli Ortega 2017 *Environ. Res. Lett.* **12** 094021

View the [article online](#) for updates and enhancements.

You may also like

- [Does carbon pricing reduce emissions? A review of ex-post analyses](#)
Jessica F Green
- [Will the use of a carbon tax for revenue generation produce an incentive to continue carbon emissions?](#)
Rong Wang, Juan Moreno-Cruz and Ken Caldeira
- [Revenue use and public support for a carbon tax](#)
Matthew C Nowlin, Kuhika Gupta and Joseph T Ripberger



The Breath Biopsy® Guide
Fourth edition

DOWNLOAD THE FREE E-BOOK

BREATH BIOPSY

OWLSTONE MEDICAL

Environmental Research Letters



LETTER

Carbon tax effects on the poor: a SAM-based approach

OPEN ACCESS

RECEIVED
24 January 2017

REVISED
17 May 2017

ACCEPTED FOR PUBLICATION
20 July 2017

PUBLISHED
19 September 2017

Joana Chapa¹ and Araceli Ortega^{2,3} 

¹ Universidad Autónoma de Nuevo León, Faculty of Economics, Av. Lázaro Cárdenas 4600, Monterrey, NL. CP 64930, Mexico

² Tecnológico de Monterrey School of Government and Public Transformation, Eugenio Garza Lagüera y Rufino Tamayo, Valle Oriente, San Pedro Garza García, N.L. CP. 66269, Mexico

³ Author to whom any correspondence should be addressed.

E-mail: araortega@gmail.com

Keywords: carbon tax, environmental policy, fossil fuels, greenhouse gas emissions, poverty

Original content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/).

Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

**Abstract**

A SAM-based price model for Mexico is developed in order to assess the effects of the carbon tax, which was part of the fiscal reform approved in 2014. The model is formulated based on a social accounting matrix (SAM) that distinguishes households by the official poverty condition and geographical area. The main results are that the sector that includes coke, refined petroleum and nuclear fuel shows the highest price increase due to the direct impact of the carbon tax; in addition, air transport and inland transport are the most affected sectors, in an indirect manner, because both employ inputs from the former sector. Also, it is found that welfare diminishes more in the rural strata than in the urban one. In the urban area, the carbon tax is regressive: the negative impact of carbon tax on family welfare is greater on the poorest families.

1. Introduction

For several years, climate change and global warming have worried society and policymakers worldwide. The international organizations and governments have conducted policies and actions to reduce greenhouse gas (GHG) emissions. The most abundant long-lived greenhouse gases are carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O), which are closely linked to human activities. According to the World Meteorological Organization (WMO), a specialized agency of the United Nations, CO₂ is the anthropogenic GHG that contributes the most to radiative forcing⁴, with 65% of the total. Atmospheric CO₂ has risen primarily from combustion of fossil fuels. So, a proposal to reduce CO₂ emissions is to apply a tax on the production of fossil fuels.

Different environmental issues, related to this topic, have been analyzed with multisectorial models. For instance, Perese (2010) and Siriwardana *et al* (2011) study the effect of a carbon tax, per metric ton of CO₂ emissions, in the United States and Australia, respectively. Perese (2010) uses an input–output price model in order to estimate the effect of a \$20 tax per metric ton of CO₂ emissions, the tax is levied on the

use of coal, oil and natural gas. He finds that sectors such as natural gas distribution, electricity and gasoline, report the highest price increments following the tax implementation, close to 10%, and the other sectors experience a rise in prices of around 1%. Siriwardana *et al* (2011) use a static and neoclassical general equilibrium model, focusing on the energy sector and using households classified by income. In the baseline simulation, the carbon tax decreases GDP by 0.68% and raises the consumer price index by 0.75%. Almost all sectors show production decrements, especially brown coal and electricity-brown coal industries. In contrast, the electricity renewable industry manifests an increment in production. Furthermore, it was found that the tax is regressive, meaning that it imposes a greater burden on the poorer households than on the richer ones.

Yusuf and Resosudarmo (2007) present an exhaustive bibliography on CGE models with households' disaggregation to analyze an impact of carbon tax, the literature is divided into analysis of developed countries where the carbon tax is found to be regressive, and few analysis of developing countries where there is a variety of results. For example, a carbon tax in Philippines slightly increases poverty, and in Pakistan is regressive, whereas in China the results are driven by the urban and rural strata, where the carbon tax is progressive given that the higher income households in the urban areas

⁴ Radiative forcing or climate forcing is defined as the difference of insolation (sunlight) absorbed by the Earth and energy radiated back to space.

make use of fossil fuels while lower income household in rural areas use firewood. The authors state that there is the need to analyze developing countries using CGE models that consider substitutability between fossil fuel and other energy commodities, and different schemes of expending government revenue; they calibrate a CGE Model for Indonesia with rural and urban households, and found that tax regressivity is fixed if the government gives back the collected tax as a uniform cut on commodities tax rate, or using uniform transfers to households. Rausch *et al* (2011), use a general equilibrium model implementing a \$20 USD carbon tax per ton, and analyze the effect of three different government expenditure policies to reverse the regressive effects of this tax. First, revenue is used to lower marginal income tax rates, the second policy distributes revenues in an equal per capita basis, and the third in an equal per capita income. The first and second revenue recycling do not solve the regressivity, and the third could diminish it if the main source of income of the lower income households is government transfers because they are neutral to carbon tax; while carbon tax affects wages and capital income, which is mainly the income source of middle and upper income households.

Gemechu *et al* (2012) employ an input-output model for estimating GHG emission intensities by economic sector for Spain. They calculate environmental tax rates by sectors, based on the estimations of both CO₂ and total GHG emissions. The highest environmental tax rate in both cases is for the cement industry.

Regarding the works that have been made for Mexico, Castillo (2010) and Bravo *et al* (2013) built general equilibrium models in order to analyze different alternatives to reduce CO₂ emissions. Castillo (2010) studies the economic effects of a tax in the energy sector, especially for the activities: coal and its derivatives; oil extraction; oil refining; and electricity, gas and water. The results indicate that extraction of petroleum and gas sector is the most affected in all the simulations, besides, the reduction in emissions is accompanied with a decrease in the consumer welfare and the GDP. Bravo *et al* (2013) analyze the economic and redistributive effects of environmental taxes on the energy inputs. Taxes are simulated for each energy sector and for all together. There are two assumptions about the elasticity of substitution between energy and other inputs: when it is rigid and when it is flexible. The results vary with each case, but in general, with this policy there are no important redistributive effects.

Another work, using multi-sectorial models for Mexico, was developed by Chapa and Ortega (2017), in which they identify the economic activities that are CO₂ direct emitters and those that are final users of highly CO₂ polluting products. The main results show that construction, electricity, gas and water supply, inland transport and food, beverages and tobacco are the major generators of CO₂ emissions through their intermediate consumption. Furthermore, they estimate the CO₂ emissions multipliers of the economy,

finding that the sector of water transport generates the highest emissions with an exogenous monetary injection; while among household types, the food poverty families in the urban areas show the highest emissions multiplier.

In this work, we developed a social accounting matrix (SAM)-based price model (see Roland-Holst and Sancho 1995) for Mexico in order to analyze the effects of a carbon tax on production costs and welfare. The model permits to assess the impact on the consumer price indexes and consumption by household type, classified according to poverty condition and strata.

With respect to public policy, it is quite important to analyze the incidence of the carbon tax according to the poverty condition of households. Poor families account for 55.1% of the population of Mexico, from which the geographical division accounts for 50.6% of the population in urban areas and 62.7% in rural areas. A carbon tax which affects transport and fuel in rural areas would affect most of the population whose budget is mostly expend on commodities and services that will be affected by the tax. In the case of urban areas, private transport and services may be the direct channel to which the household budget will be affected.

Mexico, due to its geographical location and economic development, is very vulnerable to the effects of climate change, particularly impacted by the climatic phenomena. Mexico's population vulnerability is found in the isolated rural communities as well as those that are living in the heavily populated cities. A significant global increment of temperature (+2 °C) will endanger the lives of thousands of people, their welfare and property, and limit the opportunities of development in the short and long terms.

'From 1999 to 2011 the human losses and economic damage derived from hydro meteorological phenomena are estimated in an annual average of 154 deaths and \$21 368 million pesos. It is also estimated that the cumulative cost of climate change for this century may be between 3.2% and 6% of the gross domestic product.' (SEMARNAT 2012). With this perspective, it is important to strengthen measures to mitigate GHG emissions in order to reduce the consequences of its impacts. Carbon Tax represents an important measure that discourages the use of fossil fuels. The tax rate, which was enacted since 2014, is estimated according to the official information of Mexican government for sectors producing fossil fuels. Mexico is ranked 12 among all countries contributing to global emissions, it contributes only with 417 metric ton (Mton) CO₂ which represent 1.4% of global emissions of CO₂ derived from burning fossil fuels, according to (IEA 2012). The principle of the international agreement signed in Paris is precisely that all countries have to contribute to decrease carbon tax independently of their current emissions levels. Therefore, even though the impact as a country alone is low, actions per country contribute to the global reduction.

Table 1. Carbon tax by fossil fuels.

Fossil fuels	2014	2015	Units
Propane	5.91	6.15	Cents per litre
Butane	7.66	7.97	Cents per litre
Gasoline and aviation gasoline	10.38	10.81	Cents per litre
Jet fuel and other kerosene	12.4	12.91	Cents per litre
Diesel	12.59	13.11	Cents per litre
Fuel oil	13.45	14	Cents per litre
Petroleum coke	15.6	16.24	Pesos per tons
Cooking coal	36.57	38.09	Pesos per tons
Mineral coal	27.54	28.68	Pesos per tons
Other fossil fuels	39.8	41.45	Pesos per tons

Source: Published in the Mexico Federal Official Gazette (DOF), December 11th, 2013; and December 22th, 2014.

The main results suggest that, the highest impacts on prices are in the sectors of coke, refined petroleum and nuclear fuel; air transport; and inland transport. The rural households are more affected by the carbon tax than the urban ones, this is because rural families spend a higher proportion of their income on the final goods that show price increment. With respect to the distributional effects of the carbon tax, it is found that the tax is regressive in urban strata.

The document is delineated as follows. Section 2 describes the carbon tax applied in Mexico and the way in which the official carbon tax per unit are converted into tax rates applied on production. In section 3 the model is specified. In section 4 the results are discussed. The conclusions are presented in section 5.

2. Carbon tax in Mexico

In 2014 the Mexican Congress approved a fiscal reform that includes a carbon tax on CO₂ emissions from manufacturing, selling and burning fossil fuels in order to discourage activities which harm the environment, improve air quality and reduce respiratory illness. The justification for this tax was to internalize the social cost of the negative externalities of CO₂ emissions from fossil fuels and incentive the use of clean renewable energies. The carbon taxes are applied to fossil fuels sales, expressed in monetary units per litre or tons. The tax in pesos per unit applied in 2014 and 2015 are shown in table 1.

In order to convert the taxes per unit into tax rates applied on the output of the sectors that sell the taxed fossil fuels, we use the GHG emissions of the Mexican WIOD Release 2013 from European Commission, which involves energy use by sector and energy commodity for 40 countries for the period 1995–2009, Mexico is among these countries⁵.

The WIOD 2013 Release allows the identification of the consumption of diesel, gasoline, jet fuel, coke and coal of the Mexican economy in 2008. These data are presented in Tera joules, therefore, in order to

calculate the carbon tax base, we transform the consumption of diesel, gasoline and jet fuel from Tera joules to litres and, the use of coke and coal from Tera joules to tons, based on its high heating value (*HHV*) and density (*Dens*)⁶. This is done by applying the conversions described by equations (1) to (3)

$$EC_{Kg}^{FF} = \frac{EC_{Tj}^{FF} * 1000000}{HHV_{Mj/Kg}^{FF}} \quad (1)$$

$$EC_{Tons}^{FF} = \frac{EC_{Kg}^{FF}}{1000} \quad (2)$$

$$EC_{Lts}^{FF} = \frac{EC_{Kg}^{FF} * 1000}{Dens_{Gr/Lts}^{FF}} \quad (3)$$

where:

EC_{Tj}^{FF} = consumption of fossil fuel *FF* expressed in Tera joules

$HHV_{Mj/Kg}^{FF}$ = high heating value of fossil fuel *FF* expressed in Megajoules per Kilogram

EC_{Kg}^{FF} = consumption of fossil fuel *FF* expressed in kilograms

EC_{Tons}^{FF} = consumption of fossil fuel *FF* expressed in metric tons

$Dens_{Gr/Lt}^{FF}$ = density of fossil fuel *FF* expressed in grams per liter

EC_{Lt}^{FF} = consumption of fossil fuel *FF* expressed in liters.

The converted taxes applied in 2014 to 2008 constant prices are shown in tables 2 and 3.

Then, we compute the potential carbon tax collection for each fossil fuel ($CTRec^{FF}$) by multiplying the tax in 2008 constant prices (table 3) and the consumption in 2008 by fossil fuel (table 2), and

⁵ This data base can be consulted in the site: www.wiod.org/new_site/data.htm.

⁶ The calorific power and density were obtained from appendix A of Biomass Energy Data Book—2011—<http://cta.ornl.gov/bedb> and <http://webserver.dmt.upm.es/~isidoro/bk3/c15/Fuel%20properties.pdf>, respectively.

Table 2. Consumption of fossil fuels in Mexico for 2008.

Fossil fuel	EC (Terajoules)	HHV (Mj Kg ⁻¹)	EC (Tons)	Dens (Gr Lt ⁻¹)	EC (Litres)
HCOAL	289558	23.968	12081005		
BCOAL	42	27.267	1551		
COKE	2493	29.865	83475		
DIESEL	577606	45.766	12620864	837	15085300016
GASOLINE	1497546	46.536	32180377	745	43212458058
JETFUEL	85694	43.200	1983654	785	2526945563

Source: own calculations with data from WIOD Release 2013, Biomass Energy Data Book (2011) and <http://webserver.dmt.upm.es/~isidoro/bk3/c15/Fuel%20properties.pdf>.

Table 3. Carbon tax (2008 constant prices).

Fossil fuel	Price 2008	Price 2014	Price change 2008 vs. 2014	Tax 2014	Tax 2008
Diesel	6.23	13.21	212.02	12.59	5.94
Gasoline	8.10	13.00	160.46	10.38	6.47
Jet fuel	10.19	18.66	183.12	10.38	5.67
Coke	4.61	4.59	99.53	36.57	36.74
Coal	0.50	0.41	81.92	27.54	33.62

Source: own calculations with data from PEMEX and SHCP.

Notes: Diesel, gasoline and jet fuel prices: pesos per litre. Coke and coal prices: pesos per kilogram. Diesel, gasoline and jet fuel taxes: cents per litre. Coke and coal carbon taxes: pesos per metric tons.

Table 4. Carbon tax calibration.

Fossil Fuel	Economic sector	Potential Tax collection*	Gross Output*	Tax rate (%)
Coal	Mining and quarrying	406	1 238 359	0.03
Diesel				
Gasoline	Coke, refined petroleum and nuclear fuel	3837	772 412	0.50
Jet fuel				
Coke				

Source: own calculations.

Notes: *Constant prices, millions of 2008 pesos.

converting into millions of pesos, using equations (4) and (5)

$$RevCTax^{FF} = \frac{EC_{Tons}^{FF} * Tax_{Pesos/Tons}^{FF}}{1000000} \quad (4)$$

for coal and coke.

$$RevCTax^{FF} = \frac{EC_{Lt}^{FF} * Tax_{Cents/Lt}^{FF}}{100000000} \quad (5)$$

for diesel, gasoline and jet fuel.

The sectoral detail used in the SAM base of the model follows the WIOD 2013 Release⁷. Coal is classified into the WIOD sector 'Mining and Quarrying'; and the coke, refined oils and nuclear fuel are aggregated in the WIOD sector 'Coke, Refined Petroleum and Nuclear Fuel'. Therefore, the potential carbon tax collection caused by the consumption of coal is expressed as a percentage of gross output of the sector mining and quarrying; and the potential carbon tax collection caused by the consumption of refined oils

and coke as a percentage of gross output of the sector coke, refined petroleum and nuclear fuel⁸. These calculations are contained in table 4. Note that the carbon tax is equal to a tax rate of 0.03% on mining and quarrying's gross output and a tax rate of 0.5% on coke, refined petroleum and nuclear fuel's gross output.

3. SAM-based price model

A SAM-based price model is formulated to measure the effects of a carbon tax on the sectors that produce fossil fuels. The model considers 37 economic activities according to NACE; eight types of households, classified by poverty condition and geographical area; three labour types differentiated by schooling levels; two capital types, private and public; a general government; and an aggregate of the rest of the world. The description of these classifications can be consulted in the annex 1. In general, it is assumed Leontief production functions for the economic activities, and the Cobb–Douglas

⁷ WIOD Release 2013 considers 37 economic sectors according to NACE rev 1. The Statistical Classification of Economic Activities in the European Community is known as NACE for its acronym in French.

⁸ The carbon tax rate is different among fossil fuels, being higher for coal and coke. Therefore, this sectoral disaggregation is a limitation of our study but also of many others that have used the WIOD 2013 Release.

Table 5. Population distribution by poverty condition and geographical area in Mexico 2014 (percentage).

	Inclusive			Exclusive		
Type of poverty	National	Urban	Rural	National	Urban	Rural
Food	20.5	14.7	30.0	20.5	14.7	30.0
Capabilities	29.1	23.6	38.2	8.6	8.9	8.2
Patrimony	55.1	50.6	62.7	26	27	24.5

Source: Own calculations using ENIGH 2014 and CONEVAL (2010) definitions.

utility function for the preferences of households and government. Therefore, price elasticity of demand for each final product is unitary. The model specification is contained in the annex 2.

The poverty condition of the household is based on their income to buy goods and services. The food poverty accounts for the people that even when expending all their money cannot buy the food basket (20.5%), whereas the capabilities poverty considers the food basket plus health and education services (29.1%). The patrimony poverty considers the food basket, health, education and transport services, plus house and dressing (53.2%). If we alienate each type of poverty, we have that food poverty includes 20.5% of the population, capability poverty only is 8.6% of the population, and patrimony poverty is 24.1% of the population in Mexico for the year 2014 (table 5).

Also, in this type of model, two main assumptions are built: (i) a price shock on an industry i can be completely and instantaneously transmitted to downstream industries; therefore, the effects could be overestimated; (ii) the technical coefficients are fixed, so the cost reduction efforts made by manufacturers through technology change are not taken into account.⁹ The model parameters are calculated with the method known as calibration, based on the SAM made by Chapa and Ortega (2017) for the Mexican economy, with reference to the year 2008¹⁰. This method assumes that the SAM represents a

benchmark equilibrium, where initial prices are equal to one, so that the model replicates the data of the SAM. Figure 1 presents a schedule of the effects that the model allows to calculate and analyze. The carbon tax increases the unit costs and prices of mining and petroleum products, directly; then the unit costs and prices of the downstream industries also rise; goods prices and wages in rural and urban strata increase; the wages increment is transmitted to unit costs and prices; then, there are two contrary effects on household's consumption demands, the wage increment (positive) and the goods prices increment (negative); finally, the tax collection increases and therefore the public income and expenditure (surplus is fixed)¹¹.

4. Results

The simulation takes into account two opposite carbon tax effects on consumption, saving and welfare: the price effect related to rising products and services prices (negative) and the income effect associated to wages increment (positive). The carbon tax implies a direct increment of 0.03% on the mining and quarrying's unit cost and an increase of 0.5% on the coke, refined petroleum and nuclear fuel's unit cost.

4.1. Price effect

The carbon tax impacts directly the prices of the suppliers of fossil fuels, such as coke, refined petroleum and nuclear fuel (0.529%) and mining and quarrying (0.044%). In fact, the petroleum products sector shows the largest price increment; in contrast, the mining and quarrying price increases little because the crude oil is its main product and it is tax exempt, while the coal is taxed but this has low weight in the mining gross output (table 6).

Air transport, inland transport, electricity, public administration and other non-metallic mineral sectors are impacted indirectly. Their prices increase because

⁹ See Wu *et al* (2013) for an interesting discussion about the implications of these assumptions in the case of an input-output price model.

¹⁰ The last official Mexican IO table built from surveys is for 2008. There is an OI table for 2012, but it was derived from the IOT 2008 applying the RAS method. For determining how different the IOT 2008 and the IOT 2012 are, we computed the output multipliers, the input multipliers and the distribution of private consumption disaggregated by 73 economic sectors, for 2008 and 2012. We did this for a larger sectoral disaggregation in order to get a better idea if the productive structure changes or not. While the absolute values are different, the ranking of the economic sectors are similar. In order to visualize and get an idea of the similarity of the resulted ranking, Spearman correlation coefficient (SCC) was computed and the corresponding value t-student was estimated to assess the significance level of our numbers. The results indicate a strong correlation, with a significance level of 99%, between (i) the output multipliers per economic sectors for 2008 and the corresponding multipliers for 2012, the $SCC = 0.93416$; between (ii) the input multipliers per economic sector for 2008 and the corresponding multipliers for 2012, bringing a $SCC = 0.995677$; and between (iii) the distribution of private consumption per economic sector for 2008 and for 2012, bringing a $SCC = 0.997154$. However, according to CONEVAL, the poverty in urban strata increased in the period 2008–2012. Therefore, even the economic structure is very similar; to use a SAM for 2008 could be a limitation in special with respect to income and consumption patterns of urban families.

¹¹ In the base scenario, we assumed that the government expends the carbon tax revenue on goods and services. We chose this closure rule because according to the Law of the Special Tax on Products 2017, in the article 2o., fraction I, incise H, the prices per unit to be taxed on carbon are specified, and they enter to the global Government Revenue, they are no labeled to be expended in Renewable Technologies or a Green Fund, which of course would be the ideal. In the programmable expenditure of the Decree of Expenditure Budget of the Federal Government there is not a rule to expend in alternative ways to decrease carbon tax emissions.

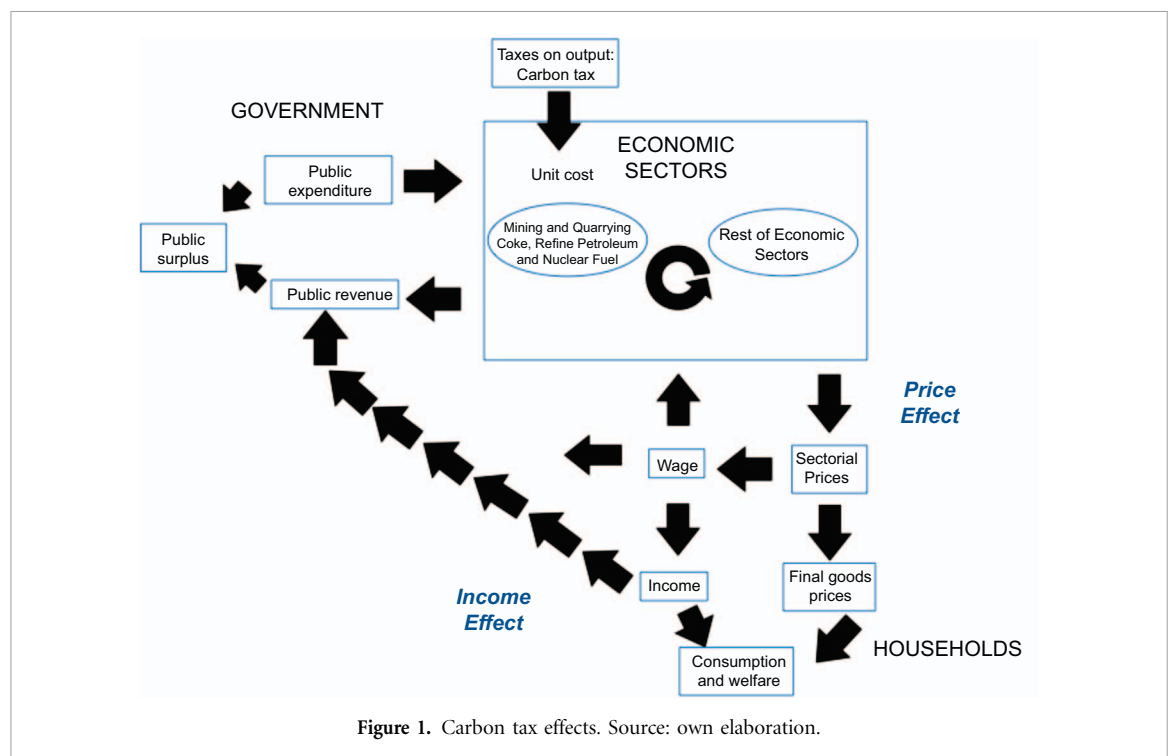


Table 6. Carbon tax effects on prices by economic sector.

Economic sector	Price effect (%)	Direct or indirect effect (fuel input)
Coke, Refined Petroleum and Nuclear Fuel	0.529	Direct
Air Transport	0.202	Indirect (Jet fuel)
Inland Transport	0.112	Indirect (Diesel, Gasoline)
Electricity	0.080	Indirect (Coke, Refined Petroleum and Nuclear Fuel)
Public Admin and Defence, Compulsory Social Security, and Extraterritorial and International Organizations	0.052	Indirect (Coke, Refined Petroleum and Nuclear Fuel)
Other Non-Metallic Minerals	0.046	Indirect (Coke, Refined Petroleum and Nuclear Fuel)

Source: own calculations.

Table 7. Carbon tax effects on families (percentages).

Description	h1	h2	h3	h4	h5	h6	h7	h8
Household price index	0.057	0.060	0.066	0.060	0.053	0.055	0.053	0.046
Disposable income	0.013	0.017	0.018	0.013	0.017	0.020	0.021	0.015
Total consumption	−0.041	−0.039	−0.044	−0.043	−0.033	−0.032	−0.030	−0.029
Saving				−0.018				−0.016
Welfare	−0.041	−0.039	−0.044	−0.041	−0.033	−0.032	−0.030	−0.027

Source: own calculations.

they face higher production costs since they use as inputs the products sold by mining and quarrying, and coke, refined petroleum and nuclear fuel sectors. The cost of living increases more in the rural strata (0.057%) than in the urban strata (0.042%). The wages show the same pattern since it is assumed that salaries are fully indexed to the consumer price indexes for each geographical area.

Into each strata, the cost of living increment by household type shows an inverted U pattern, but the family type that exhibits the largest increment is different. In the rural strata, the families with patrimony poverty condition face the highest incre-

ment in living cost; in the urban sector, this happens to families with capabilities poverty condition (table 7).

This is because rural families spend a higher proportion of their income on the final goods that show price increment (table 8). For example, the inland transport service share of expenditure is high and this service shows a high price increment due to the carbon tax. In the rural strata, the inland transport service (J24) share is between 12% and 17%, and in the urban strata, it is between 6% and 13%. In the rural area, the pattern of this share by household type follows an inverted U shape, similar to the pattern of the cost of living. In the urban area, the inland

Table 8. Consumption expenditure distribution by household type and economic sector (percentages).

Product /service	h1	h2	h3	h4	h5	h6	h7	h8
J1	5.476	4.020	4.137	2.273	2.638	2.436	2.060	1.155
J2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
J3	2.594	2.378	2.267	2.270	1.706	2.073	1.932	1.794
J4	0.115	0.109	0.124	0.096	0.159	0.183	0.188	0.122
J5	0.006	0.021	0.013	0.013	0.022	0.037	0.030	0.054
J6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
J7	29.544	27.154	29.174	18.528	21.385	21.037	19.791	11.520
J8	1.557	1.433	1.707	1.402	0.945	1.000	1.056	1.163
J9	0.628	0.559	0.676	0.473	0.388	0.408	0.402	0.336
J10	0.077	0.056	0.065	0.070	0.036	0.035	0.044	0.053
J11	0.877	0.710	0.809	0.494	0.767	0.717	0.622	0.330
J12	4.534	4.659	5.567	4.603	4.504	4.705	4.345	2.869
J13	4.532	3.970	4.730	4.585	2.863	2.883	3.231	3.477
J14	0.375	0.430	0.592	0.874	0.186	0.262	0.286	0.504
J15	0.423	0.288	0.533	0.971	0.167	0.152	0.253	0.573
J16	0.764	0.847	0.861	0.716	0.388	0.483	0.566	0.481
J17	0.008	0.016	0.010	0.045	0.010	0.012	0.013	0.038
J18	0.248	0.235	0.300	0.531	0.179	0.204	0.278	0.549
J19	0.367	0.535	1.299	1.149	3.383	5.163	3.636	2.931
J20	1.056	0.774	0.894	0.956	0.494	0.476	0.606	0.732
J21	15.381	18.637	5.613	7.425	6.571	9.034	8.274	6.158
J22	0.654	0.090	2.585	8.910	1.514	1.257	3.035	7.234
J23	0.702	1.006	0.918	3.170	0.324	0.648	0.733	2.671
J24	13.194	14.949	16.660	12.032	12.785	12.716	12.784	6.844
J25	0.000	0.002	0.003	0.073	0.002	0.035	0.011	0.129
J26	0.002	0.007	0.013	0.303	0.009	0.145	0.045	0.532
J27	2.135	1.070	1.305	0.772	0.250	0.105	0.196	0.563
J28	1.666	1.905	2.627	4.161	2.159	2.910	3.337	4.777
J29	0.391	1.508	0.504	4.128	0.354	0.336	0.814	6.239
J30	2.775	3.489	4.317	6.025	27.704	22.463	21.645	21.956
J31	0.280	0.162	0.384	1.010	0.295	0.341	0.365	1.429
J32	1.449	1.507	1.703	1.492	1.814	1.429	1.812	1.789
J33	1.488	1.366	2.024	1.849	0.600	1.098	1.056	1.728
J34	2.652	1.671	2.060	3.281	1.461	1.636	1.812	3.638
J35	3.969	4.291	5.342	4.789	3.910	3.512	4.604	4.555
J36	0.004	0.026	0.076	0.480	0.022	0.042	0.122	1.063
J37	0.076	0.120	0.107	0.051	0.008	0.025	0.013	0.013
Total	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000

Source: made by the authors.

transport service share of the three poor family types is very similar, around 12.7%; in contrast, for the non-poor families, the share is 6.84%. Something similar is observed with respect to the petroleum products (see table 8).

4.2. Income effect

The income effect is higher in urban strata than in rural strata. Also, into each strata, the income effect by household poverty condition shows an inverted U pattern, the income effect is larger for families with capabilities and patrimony poverty condition in comparison with food poverty condition and non-poor households, as it is shown in table 7.

This result is explained by two facts. First, it is assumed that capital rent is fixed and, the wages are fully indexed to consumer prices. Second, in both strata, the labour share of income by household poverty condition shows an inverted U pattern. For

example, in the rural area, the labour share is 0.30 for household with capability poverty condition and 0.315 for families with patrimony poverty condition, meanwhile labour share is 0.23 for food poverty condition families and non-poor families (table 9)¹².

Maybe this is because, in the model, the mixed income is included into the capital income, and this mixed income includes the rent of self-employers and non-paid family workers. In countries with a large informal labour, such as Mexico, these types of occupation are relevant in low income families.

4.3. Impact on consumption, saving and welfare

The final impact on consumption and welfare by household type differs according to the geographical area. In the rural strata, there is not a clear pattern, but

¹² These shares are calculated based on income after capital gains taxes.

Table 9. Household income sources.

Family type	Labour	Capital	Transfers	Remittances	Total
H1	23.1%	58.9%	8.5%	9.5%	100.0%
H2	30.0%	54.0%	6.4%	9.6%	100.0%
H3	31.5%	48.4%	5.0%	15.1%	100.0%
H4	22.7%	69.1%	2.2%	6.0%	100.0%
H5	41.2%	53.5%	2.5%	2.8%	100.0%
H6	47.6%	45.1%	2.0%	5.3%	100.0%
H7	49.1%	45.9%	1.8%	3.2%	100.0%
H8	36.5%	59.9%	2.2%	1.5%	100.0%

Source: made by the authors with SAM data.

the households in capability poverty conditions are the most affected. Meanwhile, in the urban strata, the carbon tax is regressive, as the families income decreases, the carbon tax impact on consumption and welfare increases; this is a consequence of the expenditure pattern of the households, the poor families spend more than the non-poor families in services and products that exhibit the largest price increment (tables 7 and 8).

Non-poor households diminish their savings in lower proportion than consumption, because the investor price index increment (0.031%) is lower than the general consumer price index (0.046%).

4.4. Impact on government revenue and expenditure

The carbon tax collection is 4212.5 million pesos. This is 0.7% lower than the potential tax collection, because the consumption of fossil fuels decrement. The government revenue increases by 0.33%. Since the closure rule of the simulation regards public deficit as fixed, then public expenditure varies in the same direction and quantity of public revenue.

Also, in the simulation, it is assumed that the government assigns its additional revenue to buy goods and services. Therefore, in absolute terms, the government spending in services from the following sectors increases the most: public administration and defence, education, and health and social work.

The effects could change with alternative assumptions about how the government spends the carbon tax revenue. For space limitations, we do not present the results of each alternative, but we comment the general results of the most interesting policy combination: the carbon tax revenue is spent on the program ‘Oportunidades’ which objective is to alleviate poverty (now, this program is named Prospera). The results suggest that the net effect of this policy combination (carbon tax and transfers) is an increase on private consumption and welfare for all the household types, except for the non-poor families in the urban area. Also, it is found that the rural families are more beneficiated than urban ones. An important result is that in both, rural and urban areas, the welfare impact diminishes as the poverty condition improves¹³.

¹³ They can be made available upon request.

5. Conclusions

In this work a SAM-based price model was built for the Mexican economy, in order to assess the impact of a carbon tax on production cost, consumer prices, household consumption and government revenue. There is no antecedent of any model of this kind that considers households by the official poverty condition and geographical area.

According with the tax law approved by the Mexican Congress for the CO₂ emissions from manufacturing, selling and burning fossil fuels, the tax rates estimated for this model are 0.5% for the coke, refined petroleum and nuclear fuel sector, and 0.03% for the sector of mining and quarrying.

The highest rise in price is for the sector ‘coke, refined petroleum and nuclear fuel’, due to the direct impact of the tax; but by indirect effect, the most affected sectors are air transport and inland transport; because of their close relationship with the former sector.

The carbon tax effect on consumption and welfare by household poverty condition differs by strata. In the rural strata, it is not a defined pattern. However, in the urban strata, the carbon tax is regressive, consumption and welfare reductions are higher as the household income decreases. This is caused by the household expenditure pattern: expenditure share in inland transport and petroleum products, services and products that show larger price increments, are higher as the household income decreases.

Given the importance that public transportation has on the expenditure share of the poor households, and it is part of one feature of passing from capability to patrimonial poverty, it will be a twofold beneficial public policy to transfer subsidies for those transport services using clean energies and it will operate like a subsidy for the poor and non-poor households when they use clean energy services. The carbon tax revenues that Mexico can raise from carbon pricing could be used to reduce poverty, over and above reducing the policy’s regressive impact on low-income groups. Future analysis should be done using CGE models like Yusuf and Resosudarmo (2007), to account for different model simulations where alternative means to recycle carbon tax revenue is allowed; for the time being we have advanced in this

area of study by first performing an analysis using an I-O model, then the current paper uses a SAM-based price model and further research will incorporate a CGE analysis.

Therefore, this research contributes to the discussion with its regressive thesis which is contrary to Boyd and Ibarrarán (2002) who found progressive effects on welfare, Bravo *et al* (2013) who found non-redistributive effects, and Ibarrarán *et al* (2011) who found a U shape in costs for four different types of households.

The results of this research are conditioned to the following assumptions: there is no substitution between fossil fuels and renewable resources and price elasticity demand is unitary. However, substitutability of fossil fuel by renewable energy seems unlikely in Mexico in the short term. By the end of 2014, the installed capacity of renewable energies reached 25% (16 240 MW) and the generation of renewable energy and efficient co-generation represented 18% (55 003 GWh) of the total (SENER 2015). Investment in technologies for renewable energy will be possible in near future with more transparent regulation given that in the administrative period of 2006–2012, three

regulatory instruments were published, creating the legal framework for the use of renewable energy: the Law for Sustainable Use of Energy, the Law for the Use of Renewable Energies and for the Financing of Energy Transition, and the Law for the Promotion and Development of the Bioenergy.

In the future, any development on our model could be improved with a new disaggregation, currently coal is included in the sector ‘Mining and Quarrying’, and this has low weight in the gross output of the sector, therefore, the carbon tax effects associated to coal production could be overlooked, particularly, in the sector of other non-metallic minerals where the cement production is classified. Coal is not employed in electricity generation in Mexico. However, at least in qualitative terms, the model achieves to capture the main economic sectors that are fossil fuels intensive such as transport services, electricity and other non-metallic minerals.

Annex 1: Institutional sectors included in the model

Identifier	Description	Identifier	Description
j1	Agriculture, Hunting, Forestry and Fishing	j26	Air Transport
j2	Mining and Quarrying	j27	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
j3	Electricity	j28	Post and Telecommunications
j4	Water	j29	Financial Intermediation
j5	Gas	j30	Real Estate Activities
j6	Construction	j31	Renting of M&Eq and Other Business Activities
j7	Food, Beverages and Tobacco	j32	Education
j8	Textiles and Textile Products	j33	Health and Social Work
j9	Leather, Leather and Footwear	j34	Other Community, Social and Personal Services
j10	Wood and Products of Wood and Cork	j35	Hotels and Restaurants
j11	Pulp, paper, paper, Printing and Publishing	j36	Private Households with Employed Persons
j12	Coke, Refined Petroleum and Nuclear Fuel	j37	Public Admin and Defence; Compulsory Social Security and Extraterritorial and International Organizations
j13	Chemicals and Chemical Products	l1	Workers with less than complete secondary education
j14	Rubber and Plastics	l2	Workers with complete secondary or incomplete high school education
j15	Other Non-Metallic Mineral	l3	Workers with complete high school or higher education level
j16	Basic Metals and Fabricated Metal	k1	Private Capital
j17	Machinery, Nec	k2	Public Capital
j18	Electrical and Optical Equipment	h1	Food poverty in the rural area
j19	Transport Equipment	h2	Capabilities poverty in the rural area
j20	Manufacturing, Nec; Recycling	h3	Patrimony poverty in the rural area
j21	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	h4	Non poor in the rural area
j22	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	h5	Food poverty in the urban area
j23	Wholesale Trade of Motor Vehicles and Motorcycles, Retail Sale of Fuel and Motor Vehicles and Motorcycles and Sale, Maintenance and Repair of Motor Vehicles and Motorcycles	h6	Capabilities poverty in the urban area
j24	Inland Transport	h7	Patrimony poverty in the urban area
j25	Water Transport	h8	Non poor in the urban area

Source: Mexican SAM 2008, Chapa and Ortega (2017).

Annex 2: Model specification

A2.1. Unit cost functions: prices

The SAM-based price model assumes that each sector or economic activity produces only a good or a service using a Leontief technology, with constant returns to scale, that employs in fixed proportions other goods or services (domestic or imported), as well as primary factors (labour and capital). The production function is:

$$Y_j = \text{Min} \left(\frac{X_{ij}}{a_{ij}}, \frac{M_j}{m_j}, \frac{LA_{lj}}{la_{lj}}, \frac{KA_{kj}}{ka_{kj}} \right)$$

where Y_j is the total production of the economic activity j ; X_{ij} is the expenditure made for the sector j to buy inputs from the sector i ; M_j is the imports of the sector j ; LA_{lj} are the remunerations paid by sector j to the type of work l ; KA_{kj} is the capital payment made by sector j to the type of capital k ; a_{ij} is the percentage of the total production dedicated by the sector j to get inputs from the sector i , also known as technical coefficient; m_j is the production percentage of sector j used to buy foreign goods (technical coefficients associated to imports); la_{lj} is the production proportion of sector j employed for paying to the type of work l ; and ka_{kj} the production proportion of sector j dedicated to pay to the type of capital k .

According with these assumptions, the profits earned by each economic activity are zero, so that the price of the goods sold by sector j is equal to the unit cost after taxes, see equation (6)

$$PY_j = \frac{\left(\sum_{i=1 \forall i \neq j}^{37} a_{ij} * PY_i + m_j * (PM_j + TM_j) + (1 + TSB_j + TPN_j) * \sum_{e=1}^2 \sum_{l=1}^3 la_{lj} * W_e * n_{el} + \sum_{k=1}^2 ka_{kj} * R \right) * (1 + TPS_j + CTax_j)}{(1 - a_{ij \forall i=j} * (1 + TPS_j + CTax_j))} \quad (6)$$

where TPS_j is the net tax rate on products for sector j ; $CTax_j$ is the carbon tax on gross output of sector j ; PM_j is the aggregate price of imported goods of sector j (it is considered exogenous); TM_j is the import tariff rate paid by sector j ; W_e is the wage for the area e (rural or urban); n_{el} is the l type work proportion in the area e ; TSB_j is the rate of employer contribution paid by sector j ; TPN_j is the net tax on production; and R is the capital yield.

On the other hand, the wage W_e , described by equation (7), for the area e is indexed to the consumer price index CPI_e of the area e :

$$W_e = 1 + g_e * \Delta CPI_e \quad (7)$$

where g_e indicates the degree which wages are indexed, taking a value between 0 and 1 (0 when the wage is exogenous to the model and 1 when it is endogenous);

and ΔCPI_e is the change in the consumer price index of the area e .

The consumer price index CPI_e for the area e is calculated with the prices of the final goods, using equation (8)

$$CPI_e = \sum_{j=1}^{37} \vartheta_{ej} * PY_j \quad (8)$$

where ϑ_{ej} is the percentage that final good j represents from the total consumption of area e .

At the benchmark equilibrium all prices are equal to one: the goods prices, the price of imported goods, the wages, and the yield of capital.

A2.2. Consumption demands

Households make their decisions of consumption and savings following a process of optimization in three levels. In all the levels, the households preferences are represented by Cobb-Douglas utility functions, that are homogeneous of degree one. First, households determine the aggregate consumption and saving that maximize their utility, subject to their disposable income. The consumer problem is the following:

$$\text{Max} HC_h^{\gamma_h} S_h^{(1-\gamma_h)}$$

$$\text{s.t. } DI_h = PHC_h * (1 + VAT_h + TPSH_h) * HC_h + PS * S_h$$

where HC_h is the aggregate consumption of household h ; VAT_h is the value added tax rate that each

household h pays; $TPSH_h$ is the tax rate on products paid by household h ; S_h is the saving of household h ; PHC_h is the price of aggregate consumption of household h ; PS is the price of saving and; DI_h is the disposable income of household h .

Therefore, the optimal levels of consumption in equation (9) and savings in equation (10) are in function of the prices and the disposable income:

$$HC_h = \frac{\gamma_h * DI_h}{PHC_h(1 + VAT_h + TPSH_h)} \quad (9)$$

$$S_h = \frac{(1 - \gamma_h) * DI_h}{PS} \quad (10)$$

On the other hand, the price of savings depends on the percentage of private investment assigned to

each economic activity (ϕ_j) and the sectoral prices (PY_j) calculated using equation (11):

$$PS = \sum_{j=1}^{37} \phi_j * PY_j \quad (11)$$

where $\sum_{j=1}^{37} \phi_j = 1$.

While the disposable income also can be expressed as a function of the factor payments, as in equation (12), which are taxable; the government transfers and the foreign transfers:

$$DI_h = (W_e * LH_h + R * KH_h) * (1 - TIN_h) + Trans_h + Rem_h \quad (12)$$

where LH_h is the labour endowment of the household h ; W_e is the wage of strata e , households 1 to 4 are in the rural strata and the remaining in the urban strata; KH_h is the capital endowment of household h ; R is the capital yield; TIN_h is the income-tax paid by the household h ; $Trans_h$ are the government transfers to household h ; and Rem_h are the remittances to household h .

In the second level of the optimization process, households choose how much to consume in domestic and foreign goods, subject to the aggregate consumption determined in the previous step. The optimization problem is the following:

$$\begin{aligned} & \text{Max } d_h DC_h^{\beta_h} MH_h^{(1-\beta_h)} \\ \text{s.t. } & HC_h = GPI_h * DC_h \\ & + PMC * (1 + TMC_h) * MH_h \end{aligned}$$

where DC_h is the domestic consumption of household h ; MH_h are the total imports of household h ; d_h is the Cobb–Douglas utility function coefficient; GPI_h is the price of domestic consumption; PMC is the price of imports of consumption goods, that is exogenous; and TMC_h is the import tariff paid by household h .

Then, the optimal levels of domestic consumption and imports depend on their prices and the aggregate consumption, see equations (13) and (14) respectively:

$$DC_h = \frac{\beta_h * HC_h * PHC_h}{GPI_h} \quad (13)$$

$$MH_h = \frac{(1 - \beta_h) * HC_h}{PMC * (1 + TMC_h)} \quad (14)$$

The price of aggregate consumption (PHC_h) results from introducing the optimal levels of domestic consumption and imports into the unit consumption expenditure function of equation (15)

$$\left(\frac{1}{d_h}\right) * \left(\frac{GPI_h}{\beta_h}\right)^{\beta_h} * \left[\frac{PMC * (1 + TMC_h)}{(1 - \beta_h)}\right]^{(1-\beta_h)} \quad (15)$$

In the third level of the optimization process, households decide how much they consume of each final good, maximizing their utility, given the prices of final goods (PY_j), subject to the domestic consumption chosen before:

$$\begin{aligned} & \text{Max } b_h \prod_{j=1}^{37} GC_{jh}^{\alpha_{jh}} \\ \text{s.t. } & DC_h = \sum_{j=1}^{37} PY_j * GC_{jh} \end{aligned}$$

where $\sum_{j=1}^{37} \alpha_{jh} = 1$, and b_h is the coefficient of the Cobb–Douglas function. Besides, GC_{jh} is the household h consumption of good j and; DC_h is the domestic consumption of household h .

So the optimal level of domestic consumption of good j is calculated using equation (16)

$$GC_{jh} = \frac{\alpha_{jh} * DC_h * GPI_h}{PY_j} \quad (16)$$

In order to estimate the price of domestic consumption of household h (GPI_h), which is a kind of consumer price index, the optimal levels of GC_{jh} are introduced into the unit domestic consumption expenditure function as in equation (17)

$$GPI_h = \frac{1}{b_h * \prod_{j=1}^{37} \left(\frac{\alpha_{jh}}{PY_j}\right)^{\alpha_{jh}}} \quad (17)$$

It can be noted that the consumption side is linked to the production side through the prices of final goods, the wages, and the return on capital.

A2.3. Government consumption and public finances

The government behaves like any other consumer in the model. It follows a process of optimization in two levels, and its preferences are represented by a Cobb–Douglas utility function, that is homogeneous of degree one. In the first level, it determines domestic consumption and imports, subject to the total spending in goods and services. The government maximization problem is the following:

$$\text{Max } DGvC^\varepsilon MG^{(1-\varepsilon)}$$

$$\text{s.t. } TGvC = PGovC * DGvC + PMC * MG$$

where $DGvC$ is the government spending in domestic goods and services; MG are the imports; $TGvC$ is the total spending in goods and services; $PGovC$ is a weighted average price which is compound of domestic goods and services prices that the government consumes; and PMC is the price of imports.

The optimal levels of government domestic consumption and imports are a function of the prices and the total spending in goods and services are calculated using equations (18) and (19)

$$DGvC = \frac{\varepsilon * TGvC}{PGovC} \quad (18)$$

$$MG = \frac{(1 - \varepsilon) * TGvC}{PMC}. \quad (19)$$

In the second level, the government maximizes its utility by deciding how much consume of every domestic good/service, subject to government domestic consumption obtained before:

$$\begin{aligned} & \text{Max } f \prod_{j=1}^{37} GovC_j^{\delta_j} \\ \text{s.t. } & DGvC = \sum_{j=1}^{37} PY_j * GovC_j \end{aligned}$$

where $\sum_{j=1}^{37} \delta_j = 1$, and f is the coefficient of the Cobb–Douglas function. In addition, $GovC_j$ is the government consumption of final good j .

Then, using equation (20), the optimal level of government consumption in good j is:

$$GovC_j = \frac{\delta_j * DGovC}{PY_j}. \quad (20)$$

The price of government domestic consumption ($PGovC$) is estimated by introducing the optimal levels of consumption of final goods into the unit government domestic expenditure function, see equation (21)

$$PGovC = \frac{1}{f * \prod_{j=1}^{37} \left(\frac{\delta_j}{PY_j} \right)^{\delta_j}}. \quad (21)$$

On the other hand, the total spending in consumption can be expressed as the difference between the government income (GvI) and the sum of the government balance ($GvBal$) and transfers to households ($Trans_h$), see equation (22):

$$TGvC = GvI - (GvBal + \sum_{h=1}^8 Trans_h). \quad (22)$$

While the government balance and the transfers to households are exogenous variables, the government income depends on its capital gains and its collection of various taxes calculated as in equation (23):

$$\begin{aligned} GvI = R * \sum_{j=1}^{37} KA_{2j} &+ RevTSB + RevTPN \\ &+ RevCTax + RevTPS + RevTM \\ &+ RevVAT + RevTPSH + RevTIN \\ &+ RevTMC + RevOt \end{aligned} \quad (23)$$

where KA_{2j} is the public capital used in the economic activity j ; R is the return on capital; $RevTSB$ is the tax collected from the employer contribution; $RevTPN$ is the revenue from the tax on production paid by economic activities; $RevCTax$ is the revenue from carbon tax paid by economic activities; $RevTPS$ is the revenue from the tax on products paid by economic activities; $RevTM$ is the revenue from the import tariffs paid by economic activities; $RevVAT$ is the revenue from the value added tax; $RevTPSH$ is the revenue from the tax on products paid by households; $RevTIN$ is the revenue from the income tax; $RevTMC$ is the revenue from the import tariffs paid by households; and $RevOt$ is the revenue from other taxes, that is an exogenous variable.

The tax collection is the result of multiplying the taxable base by the tax rate. For the tax collection from the employer contribution and the revenue from the tax on production paid by economic activities, remunerations are the taxable base using equations (24) and (25) respectively:

$$RevSB = TSB_j * LA_j \sum_{e=1}^2 \vartheta_j^e w^e \quad (24)$$

$$RevTPN = TPN_j * LA_j \sum_{e=1}^2 \vartheta_j^e w^e \quad (25)$$

where ϑ_j^e is the share of labor employed in sector j that corresponds to strata e . For the revenue from the tax on products and carbon tax paid by economic activities, the tax base is the gross output, see equations (26) and (27):

$$RevTPS = \sum_{j=1}^{37} \frac{TPS_j * PY_j * Y_j}{(1 + TPS_j + CTax_j)} \quad (26)$$

$$RevCTax = \sum_{j=1}^{37} \frac{CTax_j * PY_j * Y_j}{(1 + TPS_j + CTax_j)}. \quad (27)$$

For revenue from the import tariffs paid by economic activities and households, the respective imports are the tax base, described by equations (28) and (29):

$$RevTM = \sum_{j=1}^{37} TM_j * PM_j * M_j \quad (28)$$

$$RevTMC = \sum_{h=1}^8 TMC * PMC * MH_h. \quad (29)$$

For the revenue from the value added tax and the revenue from the tax on products paid by households, the taxable base is the consumption of the final goods, calculated using equations (30) and (31):

$$RevVAT = \sum_{h=1}^8 \frac{VAT_h * PHC_h * DC_h}{(1 + VAT_h + TPSH_h)} \quad (30)$$

$$RevTPSH = \sum_{h=1}^8 \frac{TPSH_h * PHC_h * DC_h}{(1 + VAT_h + TPSH_h)}. \quad (31)$$

Finally, for the revenue from the income tax, the taxable base is the payment for labour and capital endowments, calculated using equation (32):

$$RevTIN = \sum_{h=1}^8 TIN_h * (W_e * LH_h + R * KH_h). \quad (32)$$

Acknowledgments

We thank the research assistance of Erika Casamadrid and Esther Santos.

ORCID iDS

Araceli Ortega  <https://orcid.org/0000-0003-3537-7812>

References

- Boyd R and Ibararán M E 2002 Costs of compliance with the kyoto protocol: a developing country perspective *Energy Econ.* **24** 21–39
- Bravo H, Castro J and Gutiérrez M 2013 Efectos distributivos de la aplicación de un impuesto a la demanda de combustibles fósiles *Economía Mexicana Nueva Época, Cierre de Época* **2** 407–39
- Castillo Y 2010 Incidencia económica de un impuesto a las emisiones de CO₂ en el sector energía en un modelo de equilibrio general computable para México *Doctoral Thesis*, Universidad Autónoma de Barcelona
- Chapa J and Ortega A 2017 Identifying the main emitters of CO₂ in Mexico: a multi-sectoral study *Economía* **17** 135–72
- Consejo Nacional de Evaluación de la Política de Desarrollo Social 2010 *La Pobreza por Ingresos en México* (México: D.F. CONEVAL)
- Gemechu E D, Butnar I, Llop M and Castells F 2012 Environmental tax on products and services based on their carbon footprint: a case study of the pulp and paper sector *Energy Policy* **50** 336–44
- IEA 2012 International Energy Agency: CO₂ Emissions from Fuel Combustion
- Ibararán M E, Boyd R and Moreno L 2011 Costly commitments: climate change policy in Mexico *Lat. Am. Policy* **2** 222–33
- Perese K 2010 Input-Output Model Analysis: Pricing Carbon Dioxide Emissions (working paper series) Congressional Budget Office
- Roland-Holst D and Sancho F 1995 Modeling prices in a SAM structure *Rev. Econ. Stat.* **77** 361–71
- Rausch S, Metcalf G and Reilly J 2011 Distributional impacts of carbon pricing: a general equilibrium approach with micro data for households (Published on VOX, CEPR's Policy Portal (<http://voxeu.org>))
- SEMARNAT 2012 *Climate Change Adaptation in Mexico: Vision, Elements, and Criteria for Decision-making* (México: INECC)
- SENER 2015 Report on the share of renewable energy in the generation of electricity in Mexico to December 2014 (www.gob.mx/cms/uploads/attachment/data/file/227/2doSemestre2013.pdf)
- Siriwardana M, Meng S and McNeill J 2011 The impact of a carbon tax on the Australian economy: results from a CGE model *Bus. Econ. Public Policy* (working papers) University of New England 2
- Wu L, Li J and Zhang X 2013 Inflationary effect of oil-price shocks in an imperfect market: a partial transmission input-output analysis *J. Policy Model.* **35** 354–69
- Yusuf A A and Resosudarmo B 2007 On the distributional effect of carbon tax in developing countries: the case of Indonesia *Econ. Environ. Network* (working paper) EEN0706