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Distributional Impacts of Low-Carbon Policies in USA and Spain: Does One Size Fit All?

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Abstract: Distributional impacts of environmental policies have become an increasingly important consideration in policymaking, but current studies have focused on just a few countries individually. To evaluate the country-specific impacts of carbon pricing with different revenue recycling schemes, we integrate national economic models for the USA and Spain with household microdata that provides consumption patterns and other socio-economic characteristics for thousands of households in each country. Using these combined models, we explore the applicability of results from one country to other countries by focusing on different revenue recycling schemes. We find that, with some exceptions, the USA and Spain overall show similar patterns of distributional impacts for the two revenue recycling schemes, despite their differences in size, existing tax structure, energy sources and prices, level of income inequality, consumption patterns, etc. We find that in both countries an equal household rebate has progressive welfare impacts that are positive for the majority of income ventiles while the payroll tax reduction tends to be proportional or slightly regressive. We also explore welfare impacts for different household classifications, the impact of the policy design on overall inequality, and the role of inequality aversion on the social welfare implications of the policy design.

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1. Introduction

Carbon pricing, whether in the form of a carbon tax or emissions trading system, is a central component of many policy proposals aimed at addressing global climate change. While widely viewed as the most efficient approach to reduce emissions, carbon pricing can have wide-ranging distributional impacts on households depending on their income, consumption patterns, and region. The way revenue from carbon pricing is used also has varying distributional impacts, which largely drive the overall impact of a carbon price (Metcalf, 1999). There has been growing attention to distributional impacts in recent years, driven in part by the United Nations' Sustainable Development Goals and various social movements and pressure bringing attention to issues of equity. As such, it is increasingly important to consider these impacts in policy design and assessment.

Numerous studies have investigated the issue of who bears the cost of environmental and climate protection and explored the distributional impacts of different revenue recycling options (e.g. Böhringer *et al.* 2019; Caron *et al.*, 2018; Garcia-Muros *et al.* 2017; Rausch *et al* 2011; Parry and Williams, 2010; Burtraw *et al.*, 2009). However, the bulk of the distributional literature has focused only on regional or single-country analysis. There is a question as to whether a region-specific study can be generalized to other countries. To our knowledge, there has been no in-depth analysis comparing the distributional impacts of carbon pricing in different countries or considering the role of economy size or other characteristics of a country in determining distributional implications. Our paper contributes to the literature by analyzing and comparing the distributional impacts of different carbon-related revenue allocation schemes for the USA and Spain, and assessing the applicability and generalization of a region-specific study to other countries.

Although Spain and the USA differ in size, existing tax structure, energy sources and prices and level of income inequality [1], both countries have been reluctant to implement new climate-related measures. In both countries, concerns about policy impacts on workers and low-income households have been used as an argument against stringent climate policy. However, although early studies on distributional impacts showed regressive impacts of carbon policies (see for example, Poterba, 1991 or Pearson and Smith 1991), more recent works show that regressivity cannot be concluded as a rule, since it depends on the case study and the adoption of revenue-neutral schemes (see Alvarez 2019 for a meta-analysis on the distributional literature).

Using economy-wide multi-sector computable general equilibrium (CGE) models, we evaluate the impacts of different carbon-related revenue recycling schemes for the USA and Spain to assess the viability of generalizing a region-specific study to other countries. We integrate national CGE models for each country with microdata for households that provides consumption patterns and other socio-economic characteristics for thousands of households. Our approach captures a rich representation of the heterogeneity of households along with inter-sectoral and price-related effects, which are fundamental for analyzing the implications of low-carbon pathways. Our main objective is to asses if the impacts of climate mitigation policies on households are different in the USA and Spain, and we study the role that the existing tax structure, energy prices, income inequality, and consumption patterns can play. Our results can be relevant for decision-makers in their search for an efficient design of carbon-reducing policies.

The paper is organized in the following way. Section 2 describes the models and data we use for the analysis. Section 3 provides the scenarios of different revenue allocation schemes. In Section 4 we report the results and discuss them. Section 5 concludes.

2. Method of assessment: models and data

We integrate two national CGE models (for the USA and Spain) with detailed microdata for households. The resulting multi-household CGE models accommodate an economy-wide perspective, thereby accounting for policy-induced changes to commodity and factor prices throughout the economy, which in turn drive substitution and income effects. At the same time, the modelling framework features a detailed representation of household heterogeneity with respect to income and expenditure patterns. Below we describe the U.S. model, Spanish model, and the calibration of micro data for use in the multi-household CGE models.

2.1 MIT U.S. Regional Energy Policy (USREP) model

The U.S. Regional Energy Policy (USREP) model is a multi-sector multi-region economy-wide computable general equilibrium model of the U.S. economy designed to analyze energy and greenhouse gas policies (Yuan *et al.*, 2019). USREP has the ability to assess impacts of policies on regions, sectors and industries. It is built on a state-level economic dataset of the U.S. economy called IMPLAN (IMPLAN, 2008), which covers all transactions among businesses, households, and government agents for the base

1 For example, the USA is the largest economy in the world, whereas Spain has the 13th largest GDP. In terms of energy production, both countries are also very different—the USA is the largest global petroleum and natural gas producer, whereas Spain has a strong import dependency on fossil fuels. Finally, they also differ in terms of inequality—the Gini index is about 41% in the USA and 34% in Spain, according with latest data reported by the World bank database. See: https://data.worldbank.org/indicator/SI.POV.GINI

year 2006. The state-level database provides the flexibility to create different regional aggregations down to individual states. The main model version represents 30 states/regions, each with ten representative agents distinguished by income groups. For this paper, we focus on country-wide results. Below, we provide a short non-technical summary of the USREP model (for a detailed description of model structure and algebraic formulation of the fundamental model logic, see Yuan *et al.* 2019).

Production of conventional commodities is captured by nested constant-elasticity-of-substitution (CES) cost functions describing the price-dependent use of capital, labor, energy, and materials in production. In each region and for each sector, a representative firm chooses a level of output and quantities of capital, labor, depletable and renewable resources and intermediate inputs from other sectors to maximize profits subject to the constraint of its production technology.

Final consumption is determined by representative households, which maximize their utility subject to a budget constraint. Each representative household chooses between leisure, consumption and residential and non-residential capital subject to a budget constraint given by the income level. The representative households receive income from non-residential capital, residential capital, labor (including leisure time measured at the opportunity cost of labor), fossil fuel resources and household-specific transfer income. Finally, in each region, a single government entity approximates government activities at all levels—federal, state, and local. Government consumption is paid for with income from tax revenue net of any transfers to households.

Bilateral trade follows the Armington (1969) approach of product heterogeneity where domestic and foreign goods are distinguished by their origins. Sectoral output produced in each region is converted through a constant elasticity of transformation (CET function) into goods destined for the regional, national and international markets.

The USREP is a dynamic model. There are five critical features of USREP that contribute to the evolution of the economy over time. These are the rate of capital accumulation, population and labor force growth, changes in the productivity of labor and energy, fossil fuel resource depletion, and the availability of initially unused "backstop" energy-supply technologies. For comparability with the Spanish model (described below), we calibrate the USREP model to 2015.

2.2 Spanish CGE model

For the analysis of carbon policy impacts in Spain, we draw on a static multi-sector open-economy CGE model (Böhringer *et al.* 2019) calibrated to the Spanish data for 2014 (INE, 2020a). Below, we provide a short non-technical summary of the basic model structure (for a detailed algebraic formulation of the fundamental model logic see Böhringer *et al.* 2019).

Like the USREP, the Spanish CGE model also uses nested CES cost functions to capture the production of commodities. The nested CES functions describe the price-dependent use of capital, labor, energy, and materials in production at three levels. At the top level, a CES composite of intermediate materials demand trades off with an aggregate of energy, capital, and labor. At the second level, a CES function describes the possibilities of substitution between intermediate demand for the energy aggregate and a value-added composite of labor and capital. Finally, at the third level, a CES function captures the possibilities of capital and labor substitution within the value-added composite, while different energy inputs (coal, gas, oil, and electricity) enter the energy composite subject to a CES. Exceptions to this three-tier formulation are fossil fuels. For the production of fossil fuels, all inputs, except the sector-specific fossil fuel resource, are aggregated in fixed proportions; this aggregate then trades off with the sector-specific fossil fuel resource in a CES nest.

Final consumption is determined by a representative household, which maximizes utility subject to a budget constraint with fixed investment and exogenous government provision of public goods and services. The representative household receives income from three primary factors: labor, capital, and fossil fuel resources (coal, gas and crude oil). Final consumption is modeled as a CES aggregate of composite non-energy consumption and composite energy consumption. Both the non-energy consumption composite and the energy consumption composite are CES functions of more disaggregate non-energy and energy commodities.

Similar to the USREP, bilateral trade follows the Armington (1969) approach of product heterogeneity, where domestic and foreign goods are distinguished by their origins. A balance of payment constraint incorporates the base-year trade deficit or surplus. All goods used on the domestic market in intermediate and final demand correspond to a CES composite that combines domestically produced goods and the goods imported from other regions.

2.3 Coupling the Economy-Wide Models with Household Microdata

In this section, we explain how we integrate microdata for households into the USREP and the Spanish CGE to represent rich detail in households. Although we are using two different CGE models, to ensure that our results are comparable we follow the same approach to integrate micro households in a single country CGE model. For both models we follow the methodology described in Rausch *et al.* (2011), where the difference between the national and the aggregated micro data is assigned to a residual household, which represents the expenditure and income not collected by the microdata. We use this approach to ensure that we do not modify the household data collected by the different official statistical institutions (INE for the Spanish data, and the Bureau of Labor Statistics for the USA).

For the U.S. household microdata, we use the Consumer Expenditure Survey (CEX) from 2006 (Bureau of Labor Statistics, 2006). For the Spanish CGE, we use data from the Spanish Household Budget Survey (SHBS) (INE, 2020b) for 2014. We choose these surveys for consistency with the years represented by the underlying economic data in our CGE models. Both surveys are nationwide household consumption surveys that collect yearly information on consumption patterns as well as socio-economic characteristics, such as age, sex, household size, education level of members, employment status, type of employment, etc. The CEX survey collects data from around 15,000 households whereas the SHBS covers around 22,000 households.

To integrate the microdata into CGE model structures, data from other sources and additional assumptions are needed. One challenge is sectoral allocation. CEX reports expenditures according to Personal Consumption Expenditure (PCE) categories (see Bureau of Labor Statistics, 2006), whereas output sectors in the IMPLAN data used in USREP are based on the North American Industry Classification System (NAICS)[2]. Therefore, we have to map the expenditures from PCE to NAICS using a bridge matrix from the Bureau of Economic Analysis (2007). In the Spanish case, output per sector is represented in the model I-O table according to statistical classification of economic activities in the European Community (NACE) (Eurostat, 2008), while household consumption in the SHBS is reported as consumer spending categories based on the Classification of Individual Consumption by Purpose (COICOP) (United Nations Statistics Division, 2018). The two are linked using a conversion matrix developed by Cazcarro *et al.*, 2020.

Another issue of household microdata in CEX is that capital income is underestimated if we compare to the total capital income provided by other national accounting sources (see Metcalf *et al.*, 2010). Therefore, following Metcalf *et al.*, (2010), we recalibrate capital according to the capital income shares by income deciles provided by the 2007 Survey of Consumer Finances (SCF) (Federal Reserve, 2007).

Unlike CEX data, the Spanish consumption survey (SHBS) does not include information on the income sources of different households. Therefore, to complete the income information of the Spanish households, we use household expenditure as a proxy for income (Poterba, 1991) with information from the Living Conditions Survey (INE, 2020c). In both models, savings is calculated as a residual to ensure that income balance is satisfied in the benchmark equilibrium. Therefore, we ensure that pre-tax household income is equal to the sum of consumption expenditures, tax payments, and savings.

For each country, we use the microdata to develop a "Micro" model that simulates the behavior of all households represented in the microdata. We then iteratively link each country model with its Micro model based on the decomposition method described by Rutherford and Tarr (2008). According to this method, we first run each CGE model with a single representative household (by each region in the case of USREP) in order to evaluate policy impacts on prices for consumer goods and production factors. The Micro model then takes these prices as inputs and simulates household income and consumption at the given prices for the thousands of households. Based on the Micro model simulation, the behaviour of the representative household in the CGE model is recalibrated to reproduce aggregate consumption at given prices. With the recalibrated expenditure function of the representative household, the CGE models are solved again and then they pass new commodity and factor prices for the next iteration to the Micro model. By repeatedly re-solving the CGE and Micro model, the models converge towards an overall consistent solution. Thus, the coupled CGE-Micro models produce identical results as would a stand-alone CGE model with all heterogeneous households represented. The combined CGE–Micro approach has the advantage of increased numerical tractability and reduced computer processing time given the large number of households in our income-expenditure surveys (Rutherford and Tarr 2008).

3. Scenarios

Since the main goal of the paper is to analyze and compare the distributional impacts of different carbon-related revenue allocation schemes for the USA and Spain and to assess the applicability and generalization of a region-specific study to other countries, we have introduced the same CO_2 price for both countries and design two recycling scenarios. Based on the average global carbon price for 2020 reported by the Intergovernmental Panel on Climate Change (IPCC)[3] for the scenario consistent with 2°C stabilization ($44/tonne of CO_2), we choose a similar level of the carbon tax in our scenarios ($40/tonne of CO_2)[4]. Moreover, this price is in line with the average price reported by the Energy

2 North American Industry Classification System (NAICS) Definitions are available at: https://www.census.gov/eos/www/naics/2017NAICS/2017_Definition_File.pdf

3 See the database: https://tntcat.iiasa.ac.at/AR5DB.

4 Given that the Spanish model is a static CGE model calibrated for 2014, we have calibrated the USREP for 2015, making the effects in both countries comparable.

Modelling Forum (EMF) 36 on Carbon Pricing After Paris (Böhringer *et al.*, this issue) for the USA[5].

We then explore two revenue allocation measures. In the first revenue recycling scenario, which is based on the double dividend theory (Goulder, 1995), we introduce an indirect refunding of revenues via a proportional reduction in payroll taxes (*Payroll* scenario). The literature on double dividend has examined various ways of returning revenues from environmental taxes indirectly to the economic system, such as reductions in taxes on earnings from capital, in social security contributions, or in indirect taxes such as value-added taxes (see Anger *et al* 2010, for a meta-analysis on the double dividend literature or Freire-González 2018, for a critical review on double dividend in CGE models). Under the double dividend theory (Goulder 1995, Carraro *et al* 1996, Majocchi 1996), neutrality in revenues would help to improve the environment and also the economy by generating more activity and creating more jobs. This hypothesis has also been analysed in various studies covering Spain (Manresa 2005, Labandeira *et al* 2004, Markandya *et al* 2013) and the USA (Rausch and Reilly 2015, Glomm *et al.* 2008, Carbone *et al* 2013, Jorgenson *et al* 2013) This approach has also been widely implemented in different countries, especially in the late 90s, when several countries introduced environmental tax reforms focused on reducing taxes on labor, particularly social contributions (Labandeira and Linares, 2013).

Double dividend recycling schemes could have positive effects on the economy, but they have a disadvantage of being less visible to the public than direct rebates, and directly benefiting only certain groups (businesses, Social Security contributors, workers, persons who submit personal income tax returns, etc.). Therefore, in our second recycling scenario, we model a direct rebate system by which all households regardless of their status receive a transfer of funds from the new revenues collected (*House-Bonus* scenario). This approach has the advantage that the public can actually see a transfer from the government into their accounts, which may increase acceptability of the policy. Prior knowledge of the measure and the availability of a certain level of liquidity each year can also help households to adapt and provide an incentive to support environmental protection.

We simulate a rebate of the same amount for all households, regardless of how many members they have, their income level, their labor situation or their ages. This scenario is aligned with the proposal emerged in the USA to overcome political divisions concerning the introduction of taxes to reduce climate change, known as the "carbon fee and dividend"[6]. Finally, in the international context, this approach is beginning to be explored by other countries, such as Canada, where in 2019 a revenue-neutral carbon tax was implemented, in which the revenue is recycled through direct rebates to citizens. **Table 1** summarizes the scenarios that we explore.

4. Results and discussion

This section presents and discusses the results that emerge from the scenarios. Results are broken down as follows: 1) Distributional impact by income groups; 2) Distributional effects on alternative household classifications; 3) Inequality analysis, and 4) Possible trade-offs between equity and efficiency.

4.1 Distributional effects on income groups

This subsection analyzes the impact of the carbon price with each of revenue recycling scheme on different income groups. **Figure 1** shows the impact on welfare (measured in terms of equivalent variation[7]) in 2015 for twenty different income groups (ventiles)— Group V1 contains the households with the lowest incomes and Group V20 those with the highest. This figure enables us to analyze whether revenue recycling scenarios are regressive (i.e., it has a worse impact on lower-income individuals than the wealthy), progressive (i.e., it has a better impact on higher-income individual than low-income individuals), or proportional (i.e., it has the same impacts on all income categories).

The first significant conclusion that can be drawn from these results is that the *House-Bonus* scenario tends to be progressive regardless of the country analyzed, whereas the *Payroll* recycling scheme tends to be proportional in

5 The average price for the USA reported by the EMF 36 is \$42.37/tonne of CO_2.

6 https://citizensclimatelobby.org/carbon-fee-and-dividend/

7 Equivalent Variation (EV) measures how much a consumer is willing to spend to acquire goods before their price changes.

Table 1. Summary of scenarios for the USA and Spain

CO_2 price	Recycling scenarios and acronyms	
40\$ per ton of CO_2	*House-Bonus*:	Direct rebates from revenues to households via lump-sum transfers
	Payroll:	Indirect refunding of revenues via a proportional reduction in payroll taxes

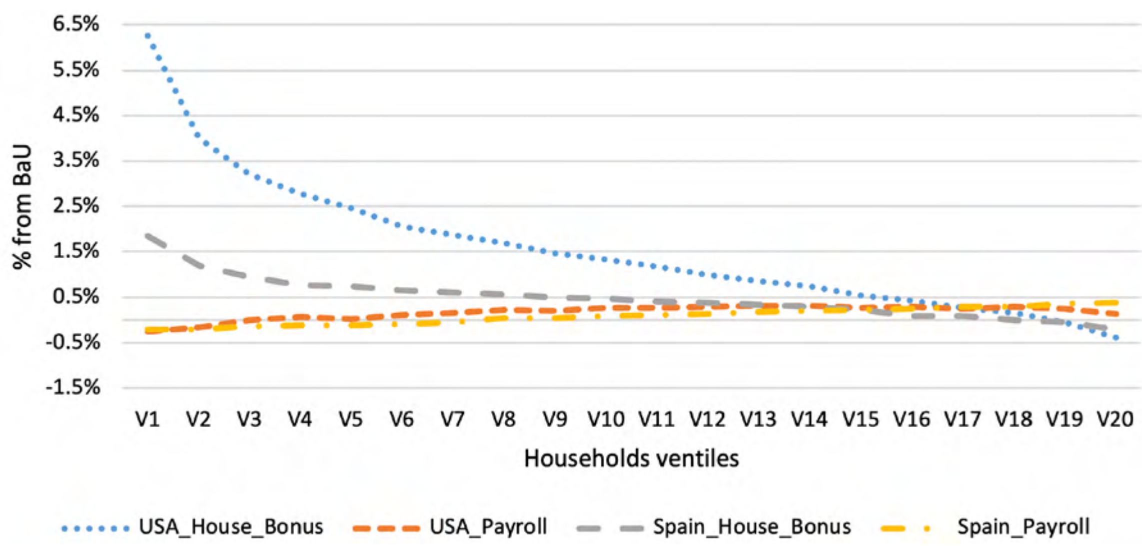

Figure 1. Welfare impacts per income group (% of Hicksian equivalent variation (HEV) in income).

both countries or even slightly regressive. This finding indicates that concerns about the potential regressivity of carbon taxes can be addressed by revenue recycling schemes, which, depending on their design, can ensure that the overall impact of the policy is proportional or progressive.

The second main conclusion is that, in both countries, the *House-Bonus* scenario results in positive welfare impacts for the majority of household ventiles (from v1 to v19), while in the *Payroll* scenario only the lower income groups (from v1 to v4-11) have negative impacts. In the *House-Bonus* scenario, the same rebate amount is transferred to each household regardless of type and income level, but its impact on each household is not the same. The amount of the per- household rebate in each country depends on the total revenue accrued from the carbon price. That revenue depends on the amount of emissions that are released with the carbon price paid rather than abated. In 2015, the USA polluted more than 5,700 $MtCO_2$, whereas in Spain the carbon emissions were around 232.5 $MtCO_2$. This explains why in Spain the resulting per- household rebate is around \$370, whereas in the U.S it is around \$1,400. However, in both countries, for the lowest income households, those rebates provide a major boost in disposable income, and can offset any negative impacts of the carbon price itself. As a result, the lowest income households have the greatest welfare benefit from the carbon tax with the per-household rebate, seeing up to a 6% welfare improvement from the policy in the USA, and a 2% improvement in Spain. However, in both countries, for the wealthiest households the rebate is not such a significant amount and cannot not offset the negative impacts of the carbon price itself.

One of the main strengths of CGE models is that they can capture different channels of welfare impacts. For carbon pricing, the main impact channels are expenditure and income. In terms of expenditures, carbon pricing increases the price of carbon-intensive commodities (e.g. fossil fuel-based energy for electricity, heating, cooling or vehicles, and goods produced using fossil energy), disproportionately impacting households that spend larger than average shares of their income on those commodities. Regional differences in the composition of energy sources also affect the carbon content of various commodities, and therefore the impact of a carbon price on households via expenditures. In terms of income, carbon pricing has an impact on factor prices, which can negatively impact households that rely heavily on income from factors whose prices fall relative to other factor prices as a result of the carbon price. When carbon revenue is rebated directly to households, that is also an income effect.

The CGE approach linked with household microdata allows us to investigate the drivers of the differential policy impacts for the different households included in our microdata. Following Böhringer *et al.* (2019), we can decompose the welfare impacts. In the case of homothetic preferences, household utility u can be expressed by income m divided by the price of utility p. The impacts of policy interference on utility can be decomposed into expenditure and income effects with:

$$\frac{du}{u} = \frac{d(m/p)}{m/p} = \frac{\frac{m+dm}{p+dp} - \frac{m}{p}}{m/p} = \frac{\frac{m}{p+dp} - \frac{m}{p}}{m/p} + \frac{\frac{dm}{p+dp}}{m/p} = \underbrace{\left(\frac{1}{1+\hat{p}} - 1\right)}_{\text{Expenditure effect}} + \underbrace{\frac{\hat{m}}{1+\hat{p}}}_{\text{Income effect}} \quad (1)$$

where relative changes in variable υ are denoted by: $\hat{\upsilon} = \frac{d\upsilon}{\upsilon}$

Figure 2 decomposes the welfare impact for each country and each revenue recycling scheme into its income and expenditure components. For the sake of simplicity, we focus in our exposition on results for income quintiles, where Group Q1 contains the households with the lowest incomes and Group Q5 those with the highest.

Figure 2 shows how welfare impacts from the income or expenditure channel differ depending on the scenario and the income group analyzed. In both countries and under both scenarios, the carbon price has negative expenditure welfare impacts that tend to be largely proportional across income groups. The reasoning can be traced back to the expenditure patterns of Spanish households and USA households, as shown in **Figure 3**. Carbon prices mainly increase the price of energy-related goods such as heating, electricity, fuel or transport (see **Table 2**). Although low-income households spend a larger proportion of their income on heating and electricity (around 6% of their total spending in Spain and 5.5% in the USA, for the first quintile), higher income households tend to spend more on transport in both countries and more on fuel in Spain. As a result, expenditure welfare impacts are rather proportional, or very slightly regressive.

The negative expenditure welfare impacts under the *House-Bonus* scenario are more than offset for most quintiles by the positive income welfare impacts. The income effect of the rebate is positive and is greatest for lower income households. As such, the positive and progressive welfare impacts of the household rebates seen above in Figure 1 are driven by the income effect. Prices are key drivers in explaining the welfare and incidence effects (i.e.

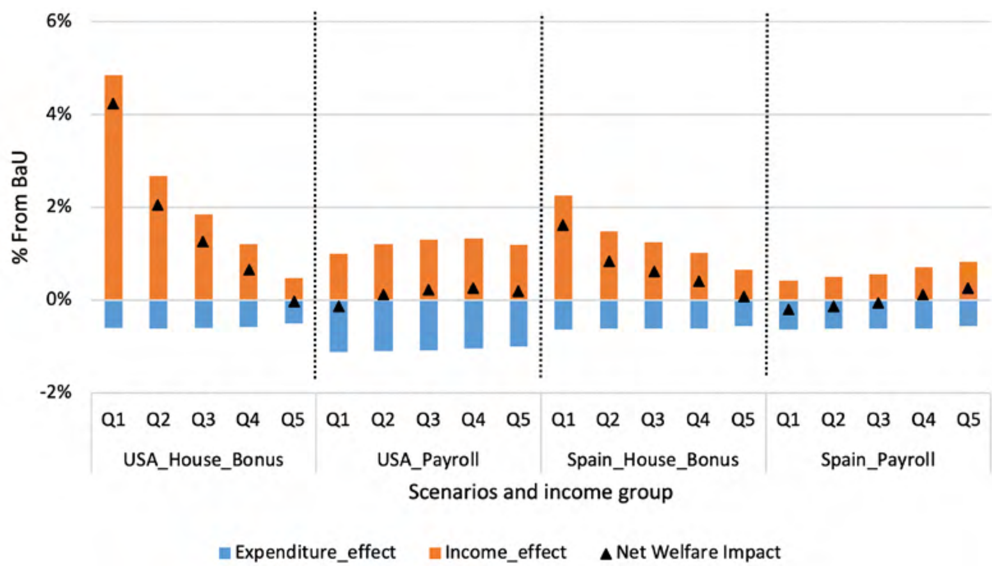

Figure 2. Expenditure, income and net welfare impacts per quintile (in % of Hicksian equivalent variation (HEV) in income).

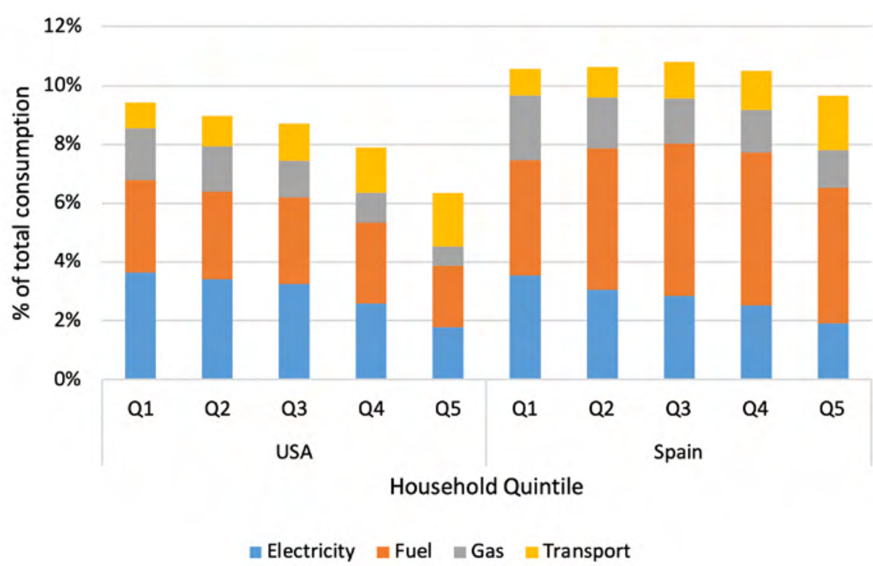

Figure 3. Shares of Energy consumptions by income group (% of total consumption).

the income channel is led by the income sources impacts) (Table 2). Greater impacts on income sources more related to low-income households would tend to lead to greater impacts on the poorest households. In terms of income composition, labor and transfer payments follow a similar path in both countries. Transfer payments are progressive, whereas labor income is more important for middle and higher income groups. The main difference in the income composition stems from capital, which is proportionally distributed in Spain and is more regressive in the USA. Hence, the progressive effect of *House-Bonus* is dominated by the higher transfer payments, whereas the positive labor prices on the *Payroll* scenario in both countries drive the regressive impact on the income side.

4.2 Welfare effects on different household classifications

When considering the distributional impacts of a policy, impacts across income groups is not the only relevant measure, welfare impacts for different household classifications also matter. **Figure 4** shows the impacts on welfare for the following four household types: couples with children, single-mother households, retired couples and retirees living alone. Overall, both countries show similar patterns of welfare impacts under the revenue recycling schemes.

There is a close correlation between the impact per household type and household income. Households that are made up of single-retirees and single-mothers tend to belong to lower income brackets, which explains why the rebates (*House-Bo-*

Table 2. Energy consumption prices and factor price

Nominal Factor prices (in % from *BaU*)				
	USA		**Spain**	
	House_Bonus	*Payroll*	*House_Bonus*	*Payroll*
Capital	-2.29	-1.38	-1.05	-0.92
Labor	-0.51	1.39	-1.06	1.08
Transfers[1]	2.41	0.11	4.3	-0.58
Energy consumption prices (in % from *BaU*)				
	USA		**Spain**	
	House_Bonus	*Payroll*	*House_Bonus*	*Payroll*
Electricity	6.75	7.18	2.70	2.69
Fuel	11.06	11.74	5.33	5.33
Heating	12.11	12.70	10.03	9.95
Transport	1.46	1.98	1.27	1.27

1 In *House-Bonus* scenario, transfer include the impact of the rebate

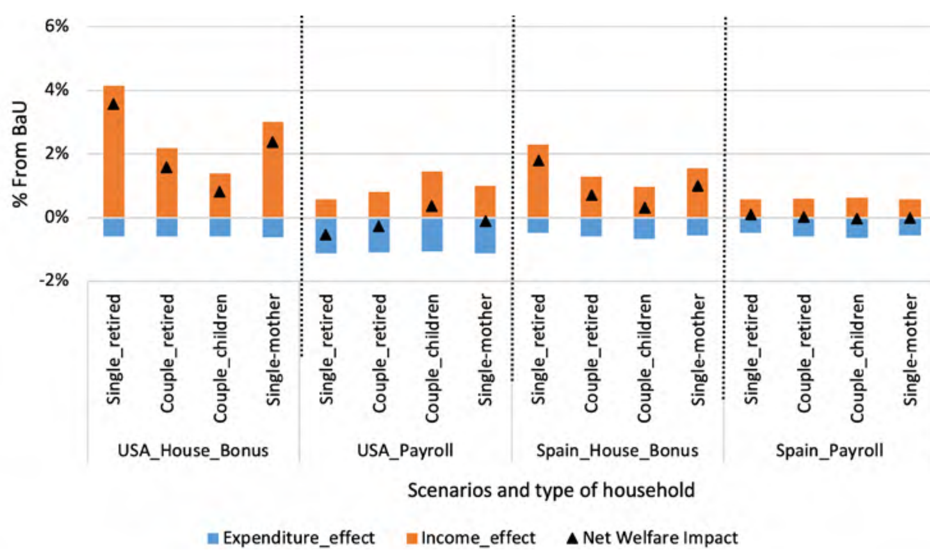

Figure 4. Expenditure, income and net welfare impacts by household type (% HEV in income).

nus scenario) increase their welfare. However, couples with children tend to belong to the middle and higher income brackets, and therefore the rebate has a lower impact on their welfare. For the *Payroll* scenario, couples with children have higher income welfare impacts since labor is one of the main income sources for them, especially in the USA case.

Figure 5 shows the welfare impacts by location of households—urban vs. rural. In the *House-Bonus* scenario, the income welfare impacts follow a similar path in the USA and Spain with rural households having greater positive welfare impacts than urban households, since in both counties, rural households tend to belong to low-income brackets and thus, in line with the above results, their welfare benefits are higher when rebates are introduced. However, while the negative welfare impacts are proportional in the USA, they differ by household location in Spain, with rural households bearing a greater welfare cost. In Spain, the expenditure of rural households on the goods most affected by the policy is relatively high, especially in terms of fuel expenditure. The *Payroll* scenario results in almost negligible welfare impacts for both urban and rural households in both countries, since the negative expenditure impacts are offset by positive income impacts, driven by the higher wages which are similarly distributed in urban and rural household.

4.3 Inequality analysis

Policy concerns about the distributional impacts of energy transitions have been increasingly directed to the possible negative impacts on inequality. To analyze inequality, we have identified different inequality measures that offer us a complete picture of the inequality impacts in both countries. The measures and inequality indices are summarized in **Table 3**.

Table 4 shows the results for each inequality measure under each revenue recycling scenario in both the USA and Spain. Under the *House-Bonus* scenario, all inequality measures improve in both countries. As expected, lower income households have greater welfare benefits when the per-household rebates are introduced, and therefore, inequality results improve. The *Payroll* scenario has less of an impact on inequality and the impact depends on the measure analyzed. These results are in line with the proportional impacts shown in Figure 1 for the *Payroll* scenario. The inequality results indicate that recycling the CO_2 revenues through the direct rebates may benefit inequality, regardless of the country and the inequality measure analyzed.

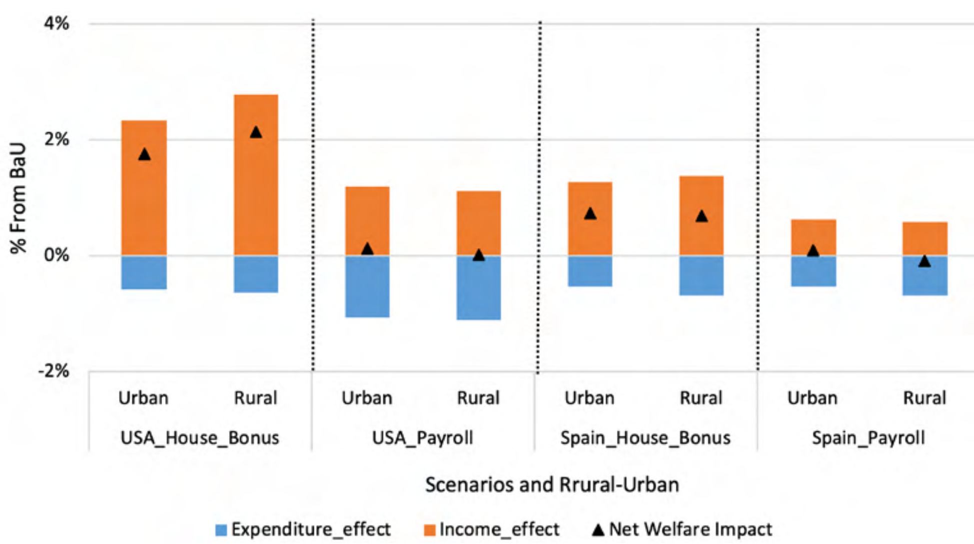

Figure 5. Expenditure, income and net welfare impacts by location of households (% HEV in income).

Table 3. Inequality measures included in the analysis

Top 1%	The share of all income received by the Top 1% households with highest disposable income
Top 10%	The share of all income received by the Top 10% households with highest disposable income
Ratio 80/20	The share of all income received by the top 20% of households compared to the bottom 20% of households.
Palma Ratio	The share of all income received by the top 10% of households compared to the bottom 40% of households.
Gini Index	Measures the deviation of income distribution among households within an economy from perfectly equal distribution.

Table 4. Inequality impacts by country and measure

	USA			Spain		
	BaU	*House_Bonus*	*Payroll*	*BaU*	*House_Bonus*	*Payroll*
Top 1%	8.62%	8.54%	8.64%	3.84%	3.80%	3.84%
Top 10%	32.37%	31.97%	32.31%	24.87%	24.75%	24.84%
Ratio 80/20	7.73	7.32	7.70	6.74	6.57	6.72
Palma Ratio	1.96	1.89	1.96	1.43	1.40	1.42
GINI	41.19%	40.46%	41.13%	34.44%	34.12%	34.43%

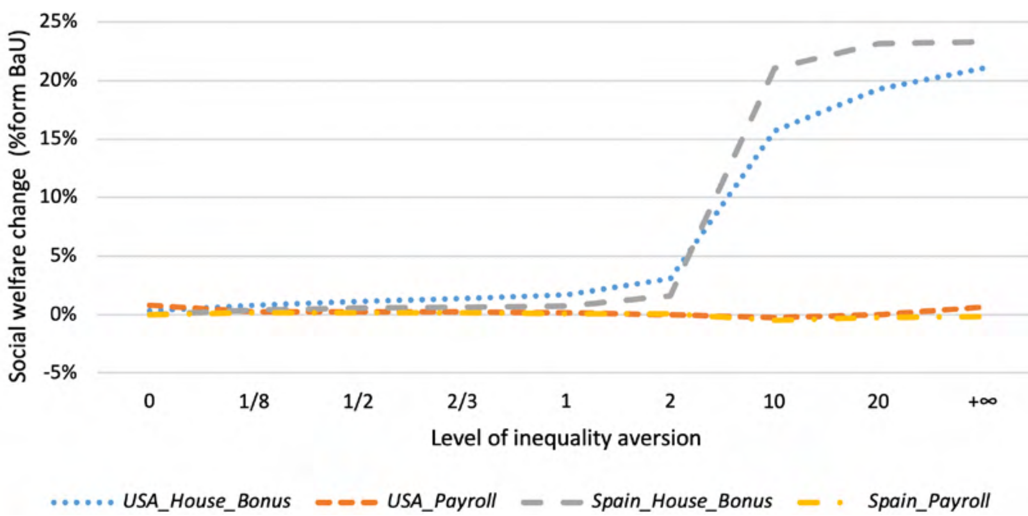

Figure 6: Atkinson Social Welfare change by scenario and country (% from BaU).

4.4 Possible trade-offs between equity and efficiency

CGE models linked with household microdata is an appropriate approach for evaluating the trade-off between equity and efficiency. CGE models enable us to analyze low-carbon policies from efficiency-based and macro-economic perspectives, whereas microdata provides detailed information about households and the heterogeneity of different economic agents, allowing us to widen the distributional analysis and to focus on the households most affected by policies. Using the well-known social welfare function (SWF) proposed by Atkinson (1970), we can investigate this trade-off under the alternative revenue recycling scenarios. Following Böhringer *et al.* (2012), in this analysis, we present welfare changes as changes in the equally distributed equivalent income (Y_{ede}) as defined by Atkinson (1970):

$$Y_{ede} = \left[\frac{1}{N}\sum_h Y_h^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}, \qquad if\ \varepsilon \neq 1 \tag{2}$$

$$Y_{ede} = \prod_h Y_h^{\frac{1}{N}}, \qquad if\ \varepsilon = 1 \tag{3}$$

Where Y_h represents the real income level in household h, ε is the inequality-aversion coefficient, and N denotes the population.

Figure 6 depicts the social welfare impacts across our recycling scenarios for different degrees of inequality aversion. "0" captures the extreme where the distributional impacts across households do not matter (Benthamite perspective) and society is only considered better if there is an improvement in efficiency. On the other side, "+∞" captures the other extreme where only the poorest household in our dataset matters (Rawlsian perspective), and so society is only considered improved if the poorest household is made better off. Entries listed in between these two extreme cases describe results based on intermediate values of ε ranging from zero to infinity.

The results in Figure 6 show that regardless of the country, the welfare effects of the different revenue recycling scenarios are low when inequality-aversion is low. These results are not surprising, since, although the carbon price may introduce distortions into the economy, the recycling schemes of the carbon revenues can soften the net welfare impacts of the policies. Therefore, from a policy perspective, policy-makers may choose between the different revenue recycling designs without significant efficiency concerns.

However, as inequality-aversion becomes more important, the direct rebates schemes perform much better than *Payroll* revenue recycling. As discussed, the lowest income households are more prone to have welfare benefits when direct rebates are introduced. These findings are in line with the previous distributional and inequality analysis that shows the progressive effect of the *House-Bonus* revenue recycling schemes compared with the proportional impacts of the *Payroll* schemes. Finally, these results show the relevance of including distributional issues in the analysis. Although the choice of revenue recycling scheme may have little effect on the efficiency of the policy, it can have a significant effect on the distributional impacts of the policy, which should be factored into the policy maker's decision.

5. Conclusions

Our study highlights the relevant role that revenue recycling design plays in the final distributional impacts of environmental policies. By analyzing and comparing the distributional impacts of different revenue recycling schemes for the USA and Spain, we provide insights into the applicability and generalization of a region-specific study to other countries. With some exceptions, the USA and Spain overall show similar patterns of distributional impacts for the different revenue recycling schemes, despite their differences in size, existing tax structure, energy sources and prices, level of income inequality, consumption patterns, etc. Overall, results suggest that, regardless of the country in question, the rebate revenue recycling scheme has better distributional impacts.

Although we used two different models to analyze the impact of the environmental taxes reform in the two countries, we show that the main distributional impacts are driven by the initial consumption and income patterns. Therefore, we show that concerns about the regressivity of carbon pricing can be offset by using different revenue recycling schemes. For both countries, we find the household rebate to have progressive welfare impacts that are positive for the majority of income ventiles, and the payroll tax reduction to have proportional slightly positive to slightly negative welfare impacts.

We also explore distributional impacts beyond income groups by looking at different types of households. For the most part, the patterns across household types were similar for both the USA and Spain. However, the different revenue recycling schemes have different impacts on households depending on whether they are comprised of people who are single, married, retired or have children, as well as whether households are urban vs. rural. Impacts on these different household types should also be factored into decisions about policy design.

The distributional impacts from different revenue recycling schemes also drive the impact of the policy on overall inequality metrics. Across all metrics, the rebate revenue recycling improves inequality more than payroll recycling schemes. Further, as the level of inequality aversion increases, rebate recycling schemes perform much better than payroll schemes in terms of social welfare impacts.

Ultimately, the integration of CGE models with household microdata creates a powerful tool that can provide important insights into differences among households. In addition to calculating distributional impacts, these combined models provide the ability to explore other important questions, such as how projected energy consumption may vary by household type and potential relationships between inequality and energy use and/or emissions. Our study shows an applicability and limits of generalization of a country-specific study to other countries. Further research focused on different countries is needed to provide policy makers with robust strategies to mitigate distributional impacts of a just transition to a low-carbon economy.

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