Toward a Just Energy Transition: A Distributional Analysis of Low-Carbon Policies in the USA

Xaquin García-Muros [a,b], Jennifer Morris [a] and Sergey Paltsev [a]

[a] MIT Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology, Cambridge, MA, USA
[b] Basque Centre for Climate Change (BC3), Leioa, Spain.

Abstract

Distributional impacts of environmental policies have become an increasingly important consideration in policymaking. To evaluate the distributional impacts of carbon pricing with different revenue recycling schemes for the USA, we integrate national economic model for the USA with household microdata that provides consumption patterns and other socio-economic characteristics for thousands of households. Using this combined model, we explore the distributional impacts and the possible trade-offs between equity and efficiency of different revenue recycling schemes. We find that the choice of revenue recycling scheme has a limited effect on efficiency of the policy, but significant distributional impacts. Our analysis indicates that policy makers can mitigate negative distributional impacts with positive synergies on efficiency.

Keywords: Carbon pricing, distributional impacts, microsimulation, computable general equilibrium

JEL classifications: D3, D58, H23, Q58

DO NOT CITE, COPY OR DISTRIBUTE

1. Introduction

After a change in the U.S. administration in 2021, USA has re-joined the Paris Agreement and declared an increased ambition of 50-52 percent greenhouse gas (GHG) emission reduction in 2030 relative to 2005 levels. Imposing some form of carbon penalty (e.g., carbon pricing, carbon tax and dividend, etc) can be a crucial component for addressing carbon emissions in the USA (e.g., Mathur and Morris, 2012; Kaufman and Krause, 2016). However, carbon pricing policy needs a support from a general public, which, in turn, may be converted to a support by policy makers. For example, if carbon pricing would be designed (or perceived as) to increase the gap between rich and poor households or reduce the affordability of energy services for wide segments of society, including the poorest households, there is a risk that carbon pricing will be rejected by the public opinion, and therefore, attempts to tackle climate change would be less efficient. Distribution of revenue from carbon pricing can play an important role to reduce possible regressive (i.e., worse impacts on lower-income individuals than on the wealthy) effects, but there is a corresponding risk that these redistributive measures might reduce the efficiency of the economy. Therefore, there is a vital need to assess the potential effects of the climate mitigation policies design that can implemented in the coming years, especially their impacts on individual groups within society, environmental justice and inequality, which is further exacerbated by the COVID crisis.

Carbon pricing, whether in the form of a carbon tax or emissions trading system, can be a central component of policies aimed at addressing global climate change. In the U.S., California began operating a cap-and-trade program in 2013, several states participate in the Regional Greenhouse Gas Initiative (RGGI), and the city of Boulder enacted a carbon tax. These market-based approaches offer a good start that can be expanded in terms of sectoral and regional coverage and the stringency of emission reduction targets. While widely viewed as the most efficient approach to reduce emissions (e.g., Parry and Williams, 2010; Rausch et al., 2011), carbon pricing can have wide-ranging distributional impacts on households depending on their income and consumption patterns. 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). In addition, in recent years, increasing attention has been paid to distributional impacts, driven in part by the United Nations' Sustainable Development Goals (UN, 2015), various social movements and the increased inequality experienced in most countries (which is further impacted by the COVID crisis).

One of the main reasons for the reluctance to include new climate-related measures in the U.S. is the threat of possible regressive impacts for low-income households, as well as potential efficiency losses if compensatory measures are included in emission reduction programs. Being aware of the risks of potential negative impacts to vulnerable communities, the U.S. government promotes the environmental justice plan, which establishes the need for a just transition and takes into account how burdens are distributed among all populations (EPA, 2011, 2020).

Our paper contributes to the literature that reflects such distributional concerns and the possible trade-offs between efficiency and equity of different recycling schemes. In our paper we investigate the economic impacts of a carbon price. We assess four alternative revenue recycling measures for the US. In particular, we analyse the following two isolated revenue recycling measures: (i) the introduction of an indirect refunding of revenues via a proportional reduction in payroll taxes, which seeks to achieve efficiency gains based on the double-dividend theory, and (ii) a direct rebate system by which all households regardless of their status receive a transfer of funds from the new revenues collected based on the possible distributional issues.

We also explore possible synergies of the combined recycling scenarios that can have a progressive effect together with efficiency gains: iii) a carbon rebate but only for the lower and middle income groups, whereas the remaining revenue is recycled via a proportional reduction in payroll taxes, and iv) a higher rebate for poor households, simulating programs to fight poverty, whereas the remaining revenues are also recycled via a proportional reduction in payroll taxes. To quantify the distributional impacts of these recycling schemes and the possible trade-offs between efficiency and equity they may have, we have used a large-scale multi-region multi-sector computable general equilibrium (CGE) model for the USA (Yuan et al., 2019, 2021), which for this study we have integrated with extensive information on household microdata.

The remainder of this paper is organised as follows. Section 2 overviews the literature on distributional impacts and the debate on different recycling options. Section 3 describes the model and data we use for the analysis. Section 4 describes the scenarios of different revenue allocation schemes. In Section 5 we discuss the results and Section 6 concludes.

2. Recycling Options and Distributional Impacts: Literature Review

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 (see, e.g., Böhringer et al. 2019; Burtraw et al., 2009; Caron et al., 2018; Parry and Williams, 2010; or Rausch et al 2011). Although, early studies on distributional impacts showed regressive impacts of carbon policies (see, e.g., Pearson and Smith, 1991 or Poterba, 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).

DO NOT CITE, COPY OR DISTRIBUTE

Much of the literature that has analyzed recycling schemes for carbon pricing revenues has focused on potential double dividends. 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 (Carraro et al., 1996; Goulder, 1995; 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 the USA (see, e.g., Carbone et al., 2013; Glomm et al., 2008; Jorgenson et al., 2013; Rausch and Reilly, 2015). 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, and directly benefiting only certain groups (businesses, Social Security contributors, workers, persons who submit personal income tax returns, etc.), and thus, numerous studies have proved the regressive impacts of this recycling schemes (see, e.g., Böhringer et al., 2019, De Bruin et al., 2019, Dinan and Rogers, 2002 or Rausch et al. 2011). Therefore, due to growing concern about inequality, there is a higher attention on recycling mechanism that can attenuate possible regressive impacts and, therefore, increase the policy acceptability, such as carbon rebates through direct transfer. This recycling approach 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"[1]. Different studies have showed how direct rebate can attenuate possible regressive impacts (see, e.g., Gago et al., 2020, Pomerleau and Asen, 2019, or Rausch and Reilly, 2015). Hence, the carbon rebate through direct rebate can also increase the acceptability of carbon pricing and reducing the risk of public rejection (Klenert et al. 2018), which can be especially relevant on the policy arena after the riots in France, Chile or Ecuador due higher energy taxation or the rejection of the Swiss climate law at ballot box. In the international context, evidence from the literature, together with growing concerns about inequality and public rejection of carbon pricing, have made this approach more attractive to 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.

[1] https://citizensclimatelobby.org/carbon-fee-and-dividend/

DO NOT CITE, COPY OR DISTRIBUTE

Although direct rebates can be more attractive for the public opinion and being less harmful for low income households, they are less efficient than other recycling schemes (see, e.g., Klenert et al. 2018, Rausch et al., 2011; Rausch and Reilly, 2015), showing a clear trade-off between efficiency and equity. Different studies have proven that only a small part of the revenue is necessary to compensate vulnerable households and reduce adverse incidence impacts (Berry, 2018, Dinan, 2015, Gago et al., 2020, Morris and Mathur, 2014; Vivid Economics, 2012). Hence, partial programs to compensate low-income households would allow the remaining revenues to be used to reduce other distortionary taxes, as proposed by the double dividend theory. However, the bulk of the distributional literature has mainly focused on impacts of isolated revenue recycling schemes and have less explored the effect of combined revenue recycling measures. Some recently studies (see, e.g., Berry, 2018, Dinan, 2015, Gago et al., 2020, Morris and Mathur, 2014) have showed the possible distributional gains of revenue recycling measures that only compensate a fraction of the population, but have been conducted primarily using partial equilibrium approaches and, therefore, have not explored the possible trade-offs between efficiency and equity of these combined recycling programs.

Therefore, there still is a question as to whether combining recycling schemes can create positive synergies that achieve progressive policies and at the same time reduce the risk of possible efficiency losses. Our paper seeks to contribute to the existing literature by analyzing and comparing the distributional impacts and the possible trade-offs between equity and efficiency of different carbon-related revenue allocation schemes for the USA. Moreover, we have developed an integrated CGE-Micro model that quantifies the incidence of policy regulation across heterogeneous households through the expenditure and income channels in an economy-wide framework, allowing a deeper analysis on the incidence and the efficiency impacts.

3. Method of assessment: model and data

We integrate a national multi-region multi-sector economy-wide energy-economic CGE model with detailed microdata for households (CGE-Micro). The resulting multi-household model accommodates 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 model and the calibration of micro data for use in the multi-household CGE-Micro model.

DO NOT CITE, COPY OR DISTRIBUTE

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

For our study, we enhance the U.S. Regional Energy Policy (USREP) model of the U.S. economy designed to analyze energy and greenhouse gas policies (Yuan et al., 2019, 2021). 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, which covers all transactions among businesses, households, and government agents for the base year 2006 (IMPLAN, 2008) and the model is further calibrated to represent the recent historic data (Yuan et al., 2021). The state-level database provides the flexibility to create different regional aggregations down to individual states. The model represents 12 regions of the U.S.: New England, New York, North East, South East, Florida, North Central, South Central, Texas, Mountain, Pacific, California and Alaska. 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. Leisure is derived according to Sheppard's lemma, i.e., derivative of expenditure function with respect to price of labor. Following Ballard (2000) and Babiker et al. (2003), labor-leisure choice is introduced by calibrating the benchmark value of leisure and the elasticity of substitution between consumption and leisure by specifying labor supply elasticities[2]. Finally, in each region, a single government entity collects 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. In the USREP, scenarios and policies keep national government revenue and consumption constant through different revenue recycling options. Therefore, one option is to introduce a lump-sum rebate

[2] The values are described in the USREP model documentation (Yuan et al, 2019). They are as follows: share of labor in the total value of labor and leisure = 0.8, labor supply elasticity = 0.25, elasticity of substitution between leisure and consumption = 1.

DO NOT CITE, COPY OR DISTRIBUTE

to households. Another possible option is to reduce the rate of taxes, such as payroll tax, corporate tax or personal income tax. The rate reduction and the lump sum are treated as an endogenous variable.

That is, the change in tax revenue collected by government is offset by a lump sum transfer between government and household. Specifically, an emission cap/tax policy as described in 6.1 may lead to a reduction in total tax revenue collected from personal income, corporate income, payroll taxes and sales taxes. A portion of the carbon revenue collected by the intermediary agency in USREP will be set aside to replace the lost tax revenue such that government revenue is held equal to that in the reference case.

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. For intra-national regional trade, we distinguish between three different representations depending on the type of commodity. First, bilateral flows for all non-energy goods are represented as Armington goods, where like goods from other regions are imperfectly substitutable for domestically produced goods. Second, domestically traded energy goods, except for electricity, are assumed to be homogeneous products. This assumption reflects the high degree of integration of intra-U.S. markets for natural gas, crude and refined oil, and coal. Third, we differentiate six regional electricity pools that are designed to provide an approximation of the existing structure in the U.S. We assume that within each regional pool traded electricity is a homogenous good and that there is no electricity trade between regional pools.

The USREP is a recursive-dynamic model. There are several 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 our quantitative impact assessment, we recalibrated USREP to replicate the economic situation of 2015 and we use it as a reference year.[3]

[3] The USREP is a recursive-dynamic model that resolves over a five-year time step and, therefore, the quantitative framework could be performed taking 2020 as the reference year. However, due to the high uncertainty and outliers in the 2020 data due to the COVID crisis, the results and conclusion could be biased by this outlier year. Therefore, we have opted for the previous year available in our modelling approach, 2015, as the reference year.

DO NOT CITE, COPY OR DISTRIBUTE

3.2. Coupling the Economy-Wide Model with Household Microdata.

In this section, we explain how we integrate microdata for households into the USREP model to represent rich details in household characteristics. To ensure that we do not alter the household data collected by different official statistical institutions (the Bureau of Labor Statistics for the USA), we follow the methodology described in Rausch et al. (2011), where the difference between the macro data and the aggregated micro data is assigned to a residual household, which represents the expenditure and income not collected by the microdata. Since the CEX survey includes information on the region of the household, the integration of the microdata has been done through a residual household for each region included in the model[4].

For the household microdata, we use the Consumer Expenditure Survey (CEX) from 2006 (Bureau of Labor Statistics, 2006). We choose these surveys for consistency with the year represented by the underlying economic data in our CGE model. CEX is a nationwide household consumption survey that collect yearly information on consumption patterns and income 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.

To integrate the microdata into CGE model structures, data from other sources and additional assumptions are needed. In CEX surveys, expenditures are reported 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)[5]. Therefore, we create a mapping of the expenditures from PCE to NAICS using a bridge matrix from the Bureau of Economic Analysis (2007).

Another issue of household microdata in CEX is that capital income is underestimated in comparison to the total capital income provided by other national accounting sources (see Metcalf et al., 2010, for a corresponding discussion). 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).

Finally, we use the microdata to develop a "Micro" model that simulates the behavior of all households represented in the microdata. In this "Micro" model the household's behavior follows a similar

[4] This process has been done for all the regions, except for Alaska since the CEX survey is not representative for the state of Alaska (see: Bureau of Labor Statistics, 2006).

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

approach to the representative household in the USREP. Therefore, each household maximizes their utility subject to a budget constraint. Each household chooses between leisure, consumption and residential and non-residential capital subject to a budget constraint given by the income level. As in the case of the representative household in the USREP model, the leisure demand of micro households is derived according to Sheppard's lemma, i.e. the derivative of the expenditure function with respect to the price of labor. For all households we follow Ballard (2000) to calibrate the elasticities of substitution between consumption and leisure and the benchmark value of leisure for each household. Thus, using initial uncompensated and compensated labor supply elasticities (0.05 and 0.3, respectively) we obtain the benchmark value of leisure for each household. Given the calibrated value of leisure in the benchmark, we estimate the elasticities of substitution between consumption and leisure for each household that are used in the household utility function[6].

We iteratively link the USREP model with the Micro model based on the decomposition method described by Rutherford and Tarr (2008). According to this method, we first run USREP with a single representative household (by each region 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 incomes 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 model is solved again and then it passes new commodity and factor prices for the next iteration to the Micro model. By repeatedly re-solving the CGE and Micro model, the model converges towards an overall consistent solution (as described by Rutherford and Tarr, 2008). Thus, the coupled CGE-Micro model produces 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.

4. 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, we have introduced a CO_2 price and design different recycling scenarios. Based on the average global carbon price for 2020 reported by the Intergovernmental Panel on Climate Change (IPCC)[7] for the scenario consistent with 2°C stabilization

[6] See Ballard (2000) for a more explicit and algebraic explanation of the approach followed.
[7] See the database: https://tntcat.iiasa.ac.at/AR5DB.

DO NOT CITE, COPY OR DISTRIBUTE

($44/tonne of CO_2), we choose a similar level of the carbon tax in our scenarios ($40/tonne of CO_2). Moreover, this price is in line with the average price reported by the Energy Modelling Forum (EMF) 36 on Carbon Pricing After Paris (Böhringer et al., this issue) for the USA[8].

We then explore four revenue allocation measures. The first two scenarios are based on the debate about trade-offs between efficiency and equity of recycling scenarios that can alleviate potential regressive impacts or recycling scenarios that seek to improve the efficiency of the economy. Whereas the remaining two scenarios are combined recycling schemes which look for an efficiency improvement with a reduction of the inequality. Therefore, 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). 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.

The remaining two scenarios combine the previous recycling schemes, simulating programs to compensate through direct rebates low income households and using the remaining revenue to introduce a reduction in payroll taxes. The first combined scenario (*Bonus-D5* scenario) includes a rebate similar to *House-Bonus* but only for the lower and middle income groups (from decile 1 to decile 5), whereas the remaining revenue is recycled via a proportional reduction in payroll taxes. Since the objective of the rebates scenario is to reduce inequality and compensate possible vulnerable households, the last combined scenario (*Bonus-Poor* scenario) included a rebate that doubles the *House-Bonus* rebate, but only for those household that are at risk of poverty. As in the previous scenario, the remaining revenue is recycled via a proportional reduction in payroll taxes. In all scenarios the revenue and budget for the national government holds constant. In scenarios with reductions in payroll taxes (*Payroll, Bonus-D5 and Bonus-Poor),* we introduce an indirect refunding of revenues via a proportional reduction in payroll taxes that holds constant the government budget. The rate reduction is treated as an endogenous variable acting as a multiplier to adjust the current tax rates. Under the *House-bonus* scenario, revenue-neutrality is achieved through a lump-sum rebate to households. In this case, the lump-sum is treated as an endogenous variable that ensure the revenue-neutrality condition. Table 1 summarizes the four recycling options (with their short names).

Table 1: Summary of scenarios

[8] The average price for the USA reported by the EMF 36 is $42.37/tonne of CO_2.

DO NOT CITE, COPY OR DISTRIBUTE

Type of recycling	Recycling scenarios	
Isolated recycling policies	*House-Bonus*:	Direct rebates from revenues to households via lump-sum transfers
	Payroll:	Indirect refunding of revenues via a proportional reduction in payroll taxes
Combined recycling policies	*Bonus-D5*:	Direct rebates from revenues to households in in the lowest five income deciles (D1-D5). Remaining revenue are refunding via a proportional reduction in payroll taxes
	Bonus-Poor:	Direct rebates (double than Household-Bonus) to poor households. Remaining revenues are refunding via a proportional reduction in payroll taxes

The revenue to recycle depends on the amount of emissions that are released with the carbon price paid rather than abated. For example, in 2015 the USA polluted around 4,700 $MtCO_2$ (which, depending on the scenario, is between 5% and 4.7% lower) and the $40 dollars per ton of CO_2 pricing would result in a revenue of around $180,000 M. For the *House-Bonus* scenario this revenue corresponds to a per- household rebate of around $1,400, which is also applied for the households in the first five deciles in the scenario *Bonus-D5*, whereas in the *Bonus-Poor* scenario, where we simulate ambitious programs to reduce poverty in the US, the rebate simulated for the poor households is equivalent to around $2,800 (the amount, which is doubled in comparison to the rebate in the *House-Bonus* and *Bonus-D5* scenarios). To identify the poor households that benefit from the rebate in *Bonus-Poor*, we use the official poverty thresholds by the size of family and the number of related children provided by the US Census Bureau (Census, 2020).

In the *Payroll* scenario, as well the remaining revenue after the direct rebates in the *Bonus-Poor* and *Bonus-D5* scenarios, the revenues are refunded via a proportional reduction in payroll taxes. In our benchmark data, the payroll taxes rates are around 15% of the wages payed by different sectors (although they differ in each US region of the USREP model). Therefore, according to our simulation, revenues from carbon taxes would allow reducing payroll taxes by -3.15% in the *Payroll* (from 15% to approximately 14.5%), while the reduction in the combined *Bonus-D5* and *Bonus-Poor* scenarios (after carbon transfer rebates) is -2.1% and -2.6%, respectively. One of the main limitations of our modelling approach is that in the USREP model the wage changes produced by the payroll tax cut are proportional for all households and their income effects will depend on the initial income structure. Moreover, the labor market distortion introduced in our modelling framework is on the labor-leisure choice brought about by the payroll tax change, as there is no involuntary unemployment in USREP.

DO NOT CITE, COPY OR DISTRIBUTE

Since our modelling approach does not fully represent labor market distortions, it could lead to a bias in estimation of efficiency gains in scenarios that cut payroll taxes.

5. 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.

5.1. Distributional effects on income groups

We analyze the impact of carbon pricing on different income groups. Figure 1 shows the impact on welfare[9] (measured in terms of equivalent variation[10]) in 2015 for twenty different income groups (ventiles)— Group V1 contains the households with the lowest incomes and Group V20 those with the highest[11]. This figure enables us to analyze whether the 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 can be drawn from comparing the two isolated recycling schemes (*House-Bonus* and *Payroll*) is that the *House-Bonus* scenario is progressive, whereas the *Payroll* recycling tends to be proportional or even slightly regressive. As can be expected, the positive effects for the low-income households can be even higher when the rebates only cover the lower income households (*Bonus-D5* and *Bonus-Poor*), showing that lower income groups benefit from the rebate and the effect of the reduction in payroll taxes. 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 even progressive.

The second main conclusion is that to include a per-household carbon rebate (the *House-Bonus* scenario) results in positive welfare impacts for the majority of household ventiles (except the higher income groups), while in the *Payroll* scenario the lowest income groups have small negative welfare

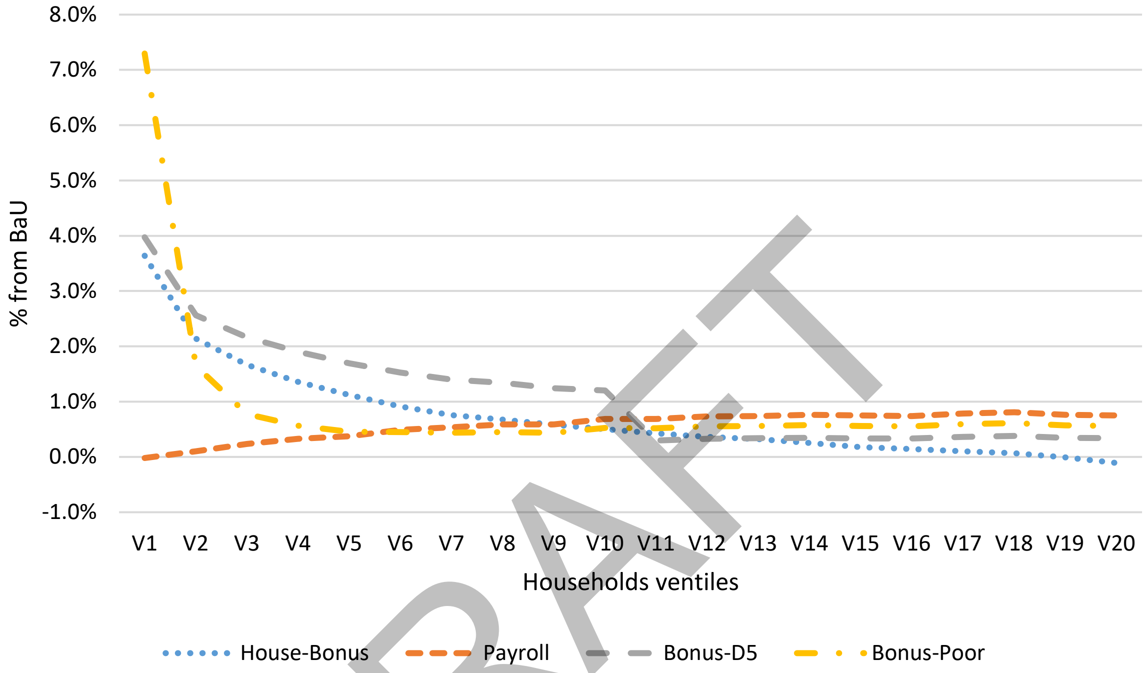
[9] To calibrate the difference between the national and the aggregated micro data, we have used a residual household which represents the expenditure and income not collected by the microdata. Appendix A shows the welfare impacts for the residual household in each scenario.

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

[11] Appendix B shows the distributional welfare impacts by income decile for the main regions/states included in the USREP, showing that national distributional impacts also remain robust at the regional level.

impacts and the higher income brackets positive. The positive welfare impacts of the carbon rebates (*House-Bonus, Bonus-D5* and *Bonus-Poor*) reflect the importance of these transfers for low-income households. Even in the *House-Bonus* scenario, where the same amount of rebate is transferred to each household regardless of type and income level, the positive impacts are much larger for low-income households than for the wealthier income brackets.

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



For the lowest income households, rebates provide a major boost in their disposable income, and they can offset any negative impacts of the carbon price itself, especially in the *Bonus-Poor* scenario, where the poor households received an increased carbon rebate (i.e., an equivalent of $2,800). As a result, the lowest income households have the greatest welfare benefit from the carbon tax with rebates, seeing up from around 4% welfare improvement from the policy in *House-Bonus* and *Bonus-D5*, to 7% in scenario *Bonus-Poor*. On the other side, when the rebate is for all households (the *House-Bonus* scenario), the wealthiest households do not offset the negative impacts of the carbon price with this rebate. However, the scenarios that include lower payroll taxes (*Bonus-D5, Bonus-Poor and Payroll)* involve welfare gains for all the income groups, even the high income brackets, showing the benefits for those households from lower payroll taxes.

One of the main strengths of CGE models is that they capture different channels of welfare impacts. For carbon pricing, the main impact channels are expenditure and income. In terms of the expenditure channel, 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),

DO NOT CITE, COPY OR DISTRIBUTE

disproportionately impacting households that spend larger than average shares of their income on those commodities. 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 the income channel, 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. Moreover, the revenue recycling scenarios have a direct impact on the income side, since they modify the income factors—for example, the carbon rebate or the reduction of the payroll taxes that affect labor prices (see table 2).

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. As have been done in Böhringer et al. (2019), we 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:

$$\frac{du}{u} = \frac{d(m/p)}{m/p} = \frac{\frac{m+dm}{p+dp} - \frac{m}{p}}{m/p} = \frac{\frac{m}{p+dp} - \frac{m}{p}}{m/p} + \frac{\frac{dm}{p+dp}}{m/p}$$

$$= \underbrace{\left(\frac{1}{1+\hat{p}} - 1\right)}_{\text{Expenditure effect}} + \underbrace{\frac{\hat{m}}{1+\hat{p}}}_{\text{Income effect}} \quad \text{[E.1]}$$

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

Figure 2 decomposes the welfare impact for 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 channels differ depending on the scenario and the income group. Under all scenarios, the carbon price has negative expenditure welfare impacts that tend to be slightly regressive across income groups. The reasoning can be traced back to the expenditure patterns of the U.S. households. Carbon prices mainly increase the price of energy-related goods such as heating, electricity, fuel or transport (Table 2). Although, low-income households spend a larger proportion of their income on heating and electricity (about 5.5% of total consumption for the first quintile, while the highest income quintile devotes only about 2% of total consumption), higher income households tend to spend more on transport, and as a result, expenditure welfare impacts are slightly regressive since the difference are not enough to conduct large regressive impacts.

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

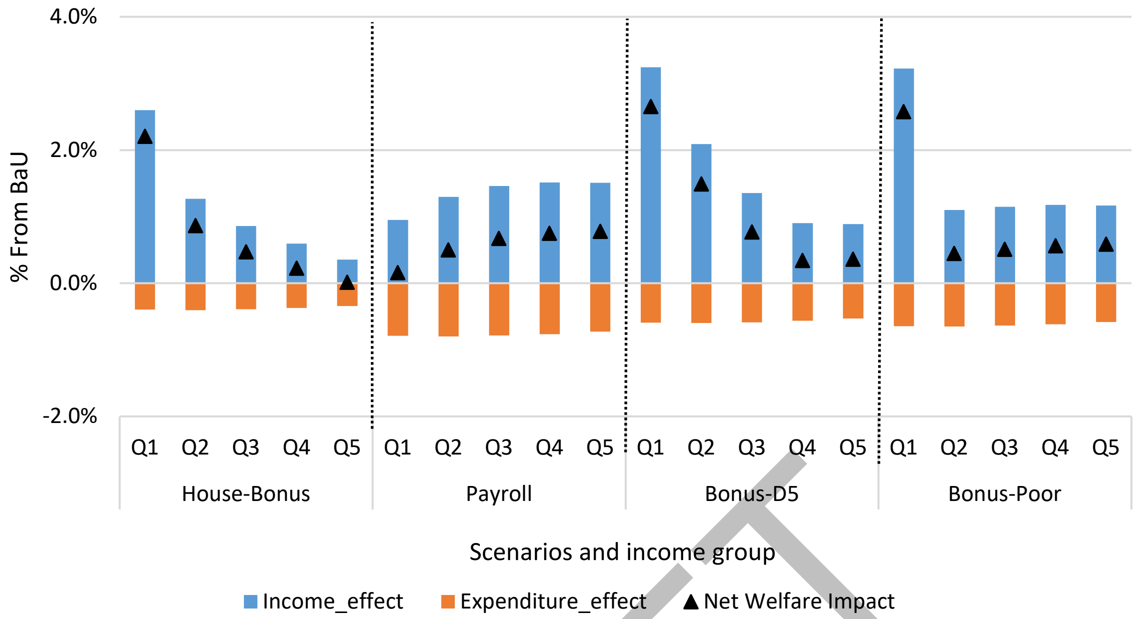


Table 2: Nominal Factor prices and Energy consumption prices

	House-Bonus	Payroll	Bonus-D5	Bonus-Poor
Nominal Factor prices (capital and Labor) and Transfer payments[12] (in % from BaU)				
Capital	*-0.90*	*-0.18*	*-0.51*	*-0.33*
Labor	*-0.25*	*1.77*	*1.01*	*1.40*
Transfers	*2.95*	*-0.90*	*0.45*	*-0.36*
Energy consumption prices (in % from BaU)				
	House-Bonus	*Payroll*	*Bonus-D5*	*Bonus-Poor*
Electricity	*5.93*	*6.64*	*6.53*	*6.61*
Fuel	*11.38*	*12.10*	*11.83*	*11.98*
Heating	*12.07*	*12.78*	*12.67*	*12.73*
Transport	*4.21*	*3.70*	*3.86*	*3.73*

The negative expenditure welfare impacts are offset for most quintiles by the positive income welfare impacts in each scenario. For the scenarios that include direct rebates (*Household_ Bonus*, *Bonus-D5* and *Bonus-Poor*), the income effects of the rebate are positive and greater for the lowest 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., the income channel is led by the income sources impacts). Greater impacts on

[12] Transfers from government to households are made up of both non-carbon related transfers (such as social security or public retirement pensions) and the allocation of carbon revenues. The final transfer payments are therefore calculated according to both categories

income sources more relevant to low-income households would tend to lead to greater impacts on the poorest households.

In terms of income composition, transfer payments are progressive, whereas labor income is more important for the middle and higher income groups. Whereas capital is regressive in the USA. Hence, the progressive effect of *House-Bonus* is dominated by the higher transfer payments, whereas the positive labor prices[13] on the *Payroll* scenario drive the regressive impact on the income side. In the combined scenarios (*Bonus-D5 and Bonus-Poor)*, the higher labor prices also allow to increase the income welfare impacts and almost offset the expenditure welfare losses for the higher income groups. However, the progressive effects on low income households are mainly driven by the higher transfer payments[14].

5.2. *Welfare effects on different household classifications.*

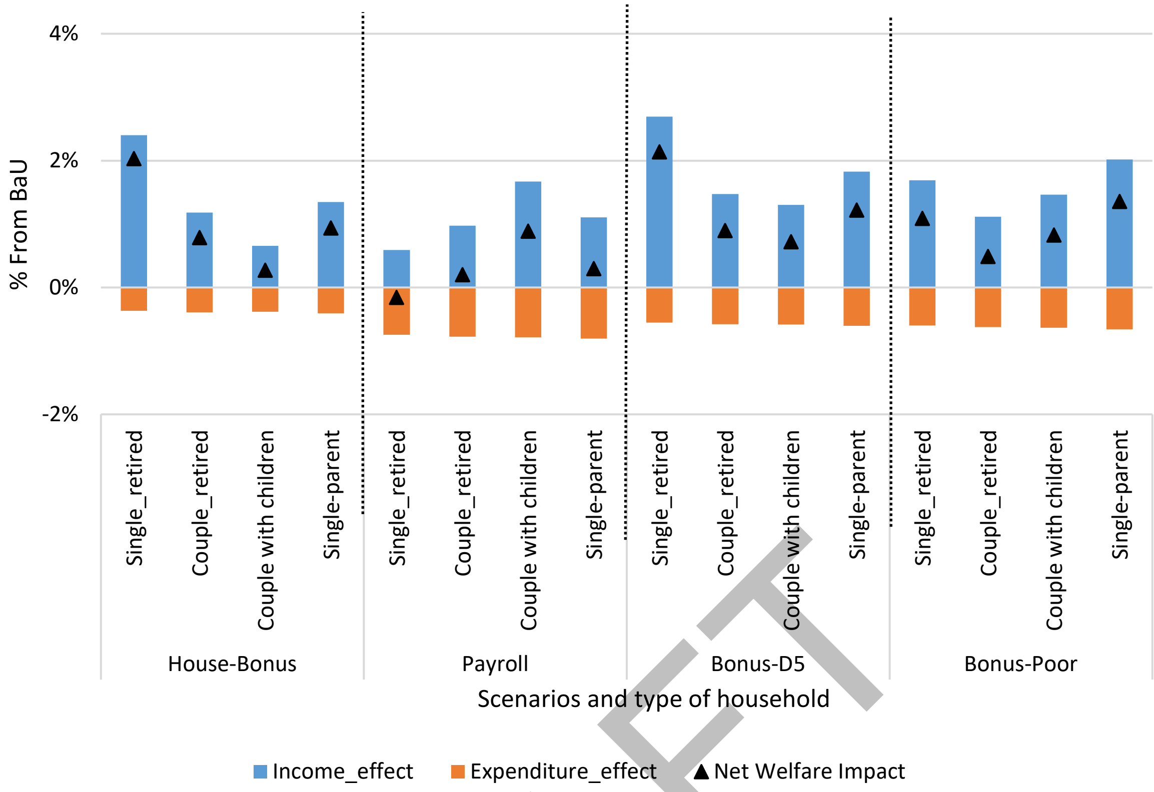
When considering the distributional impacts of a policy, impacts across income groups is not the only relevant measure because welfare impacts for different household classifications also matter. Figure 3 shows the impacts on welfare for the following four household types: couples with children, single-parents households, retired couples and retirees living alone.

There is a close correlation between the impact per household type and the household income. Households that are made up of single-retirees and single-parents tend to belong to lower income brackets, which explains why the rebates (scenarios *House-Bonus, Bonus-D5 and Bonus-Poor*) increase their welfare. The positive welfare impacts on the single-parent households under the *Bonus-Poor* scenario come from the fact that these categories of households are more related to poverty. On the other side, 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 because labor is one of the main income sources for them. The higher labor prices in the combined recycling schemes (*Bonus-D5* and *Bonus-Poor*) also increase the income welfare gains of this household category compared to the *House-Bonus* scenario.

[13] Wages (or the labor price) are determined by supply and demand in the USREP model. The labor supply offered by households is demanded by the sectors, which bear the payroll tax.

[14] In the combined scenarios the transfers payments will be different depending on which households receive direct transfers. This explains why in the *Bonus-Poor* case the average transfer payment is lower than in BaU, since only poor households benefit from higher transfers, which is not sufficient for average transfer payments to be higher.

Figure 3. Expenditure, income and net welfare impacts by household type (% HEV in income).



5.3. Inequality analysis.

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

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 shows the results for each inequality measure under each revenue recycling scenario. Under the scenarios *House-Bonus, Bonus-D5 and Bonus-Poor*, all inequality measures improve. As expected, lower income households have greater welfare benefits when the direct 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 of the CO_2 revenues through the direct rebates may benefit inequality, regardless of the inequality measure analyzed. The positive inequality impacts of the direct rebates are even higher when only the low- and middle-income groups are benefit from it (*Bonus-D5*). It comes from the fact that only a part of the revenue is necessary to compensate the low income households and to improve inequality. However, when compensatory programs only focus on very poor households (*Bonus-poor*), then inequality measures, while improving, underperform in comparison to the scenarios with wider-ranging direct rebates (*House-Bonus* and *Bonus-D5*). Such programs only focus on very poor households and therefore do not improve the income distribution for the middle income groups, resulting in lower inequality gains compared to the other direct rebates scenarios (*House-Bonus* and *Bonus-D5*).

Table 4. Inequality impacts by country and measure

	BaU	***House-Bonus***	***Payroll***	***Bonus-D5***	***Bonus-Poor***
Top 1%	8.92%	8.85%	8.86%	8.85%	8.86%
Top 10%	32.53%	32.34%	32.48%	32.35%	32.42%
Ratio 80/20	9.24	9.02	9.24	8.99	9.05
Palma Ratio	2.13	2.09	2.13	2.09	2.11
GINI	43.09%	42.79%	43.06%	42.78%	42.91%

5.4. Possible trade-offs between equity and efficiency.

CGE models linked with household microdata is a useful approach for evaluating the trade-offs between equity and efficiency. CGE models enable us to analyze low-carbon policies from the 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 these trade-offs under the alternative revenue recycling scenarios. Following Böhringer et al. (2012), we present welfare changes as changes in the equally distributed equivalent income (Y_{ede}) as defined by Atkinson (1970):

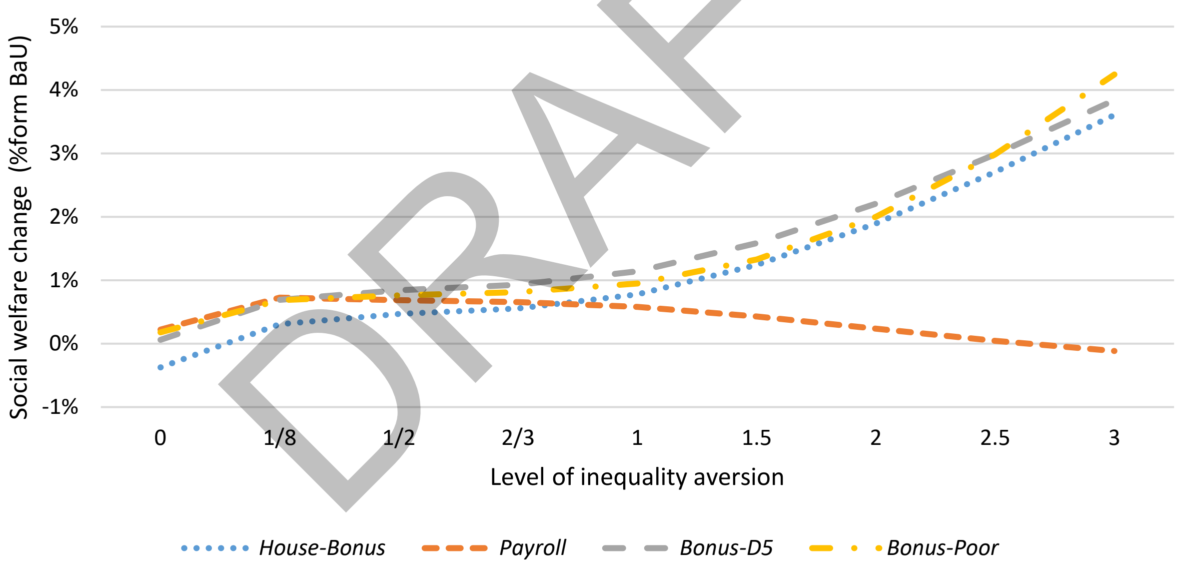
$$Y_{ede} = \left[\frac{1}{N}\sum_{h} Y_h^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}, if\ \varepsilon \neq 1 \qquad [E.2]$$

$$Y_{ede} = \prod_h Y_h^{\frac{1}{N}}, if\ \varepsilon = 1 \qquad [E.3]$$

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

Figure 4 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 (i.e., the Benthamite perspective) and a society is only considered better if there is an improvement in efficiency. On the other side, when the inequality aversion increase – the society becomes more concerned about the well-being of poorer households relative to richer households[15]. Figure 4 shows the impacts on social welfare under the three financing scenarios for alternative degrees of inequality aversion ranging from "0" to "3".[16]

Figure 4: Atkinson Social Welfare change by scenario and country (% from BaU).



The results in Figure 4 show that 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. However, the welfare impacts are positive and higher when lower payroll taxes are introduced, and therefore the *Payroll* scenario ranks first in terms of efficiency,

[15] The overall impact shows the total welfare impact considering all the households in the model. However, as we have not information on the income and socioeconomic characteristics of the residual households, they are not included when inequality aversion is greater than 0.
[16] Creedy and Sleeman (2006) use ε = 0.2 and ε= 1.2. The survey by Pirttilä and Uusitalo (2010) suggests an upper bound of 3.

followed by the other scenarios that also include lower payroll taxes (*Bonus-Poor* and *Bonus-D5*). These results show the double dividend gains in term of efficiency from cutting distortionary taxes. Thus, although from a policy perspective policymakers may choose between different revenue recycling designs without significant efficiency concerns, the results show a clear ranking in terms of efficiency in favor of reducing distortionary taxes, such as payroll taxes.

However, as inequality-aversion becomes more important, the direct rebates schemes perform much better than when a payroll tax reduction stands alone (scenario *Payroll*). As discussed, the lowest income households are more prone to have welfare benefits when direct rebates are introduced. These findings are in line with our previous distributional and inequality analysis, which shows the progressive effect of the scenarios that include carbon rebates (*House-Bonus, Bonus-D5 or Bonus-Poor)* compared with the proportional impacts of the *Payroll* schemes. Moreover, these results confirm the trade-offs between equity and efficiency of isolated revenue recycling schemes (showing that reducing distortionary taxes can improve the efficiency of the economy, but at the same time resulting in regressive distributional impacts) and the scenarios that only introduce direct rebates (that improve the distributional impacts but perform the worst in terms of efficiency). Our results also show that these potential trade-offs between equity and efficiency can be addressed by combining recycling regimes that compensate low-income households while also reducing distortionary taxes, as they have greater efficiency gains and progressive impacts.

These results show the relevance of including distributional issues in the analysis. Although the choice of revenue recycling scheme may have little effect on 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. In addition, these findings show that policy-makers can introduce combined measures that alleviate losses for low income households, reduce inequality, and also improve efficiency of the economy.

6. Conclusions

Environmental justice and inequality are particularly important for the environmental policy agenda. Our study highlights the role that revenue recycling design plays in the distributional impacts of environmental policies. By analyzing distributional impacts of different revenue recycling schemes for the USA, we provide insights that potential concerns about the regressivity of carbon pricing can be offset by using different revenue recycling schemes. We find that household rebates have progressive welfare impacts, whereas policies focused on improving efficiency of the economy (such as payroll tax reductions) have slightly regressive welfare impacts. However, the scenarios that cut distortionary taxes perform better from an efficiency perspective than the full carbon rebates, which shows a trade-off between equity and efficiency of the isolated revenue recycling schemes. These potential trade-offs can be addressed by combining recycling regimes that compensate low-income households while also reduce distortionary taxes because they have positive synergies that translate into greater efficiency gains and progressive impacts. However, as with any modeling, the exact numerical values should be treated with a great degree of caution, given that many aspects of the labor market and other details are simplified or beneath the level of model aggregation.

We also explore distributional impacts beyond the income groups by looking at different types of households (single, married, with children, retired, etc.). Different revenue recycling schemes have different impacts on these categories of households, which also needs to be factored into decisions about the carbon policy design. The distributional impacts from different revenue recycling schemes drive the impacts of the policy on overall inequality metrics. Across all metrics, recycling schemes that include direct rebates improve inequality more than when all revenues are used to reduce payroll taxes. Further, as the level of inequality aversion increases, rebate recycling schemes perform much better than those that only include payroll taxes reduction in terms of social welfare impacts. The combined measures have positive inequality impacts because only part of the revenue is necessary to compensate low income households and the remaining revenues can be used to reduce other distortionary taxes and achieve efficiency gains.

Ultimately, the integration of a CGE model with the details of household microdata creates a powerful tool that provides important insights into differences among households. Another area of application for these combined models is projecting how energy consumption may vary by household type. An area for future research is a detailed look at relationships between inequality, energy use, emissions and efficiency. Our study shows an applicability of such approach and provides a discussion of strategies that policy makers can use to mitigate distributional impacts to ensure a just transition to a low-carbon economy with positive synergies on economic efficiency.

Acknowledgements

Xaquin Garcia-Muros acknowledges financial support from the European Union's H2020-MSCA-IF-2017 Actions No 796650 (CHANCE project).

DO NOT CITE, COPY OR DISTRIBUTE

References

Alvarez, M. (2019). Distributional effects of environmental taxation: An approximation with a meta-regression analysis. *Economic Analysis and Policy*, Elsevier, vol. 62(C), pages 382-401.

Anger, N., Böhringer, C. and Löschel, A. (2010). Paying the piper and calling the tune?: A meta-regression analysis of the double-dividend hypothesis. *Ecological Economics*, Elsevier, vol. 69(7), pages 1495-1502, May.

Armington, P.S. (1969). A Theory of Demand for Producers Distinguished by Place of Production. *IMF Staff Papers*, 16 (1), 159–78.

Atkinson, A.B. (1970). On the measurement of inequality. *J. Econ. Theory* 2, 244–263

Atkinson, A. B., T. Piketty and E. Saez (2011). Top Incomes in the Long Run of History. *Journal of Economic Literature* 49 (1), pp. 3-71.

Babiker, M. H., Metcalf, G.E. and Reilly, J. M. (2003). Tax distortions and global climate policy. J. Environ. Econ. Manag. 46, 269–287.

Ballard, C. (2000). How many hours are in a simulated day? The effect of time endowment on the results of tax-policy simulation models. Working Paper, Michigan State University. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.198.3954&rep=rep1&type=pdf

Berry, A. (2018). Compensating households from carbon tax regressivity and fuel poverty: A microsimulation study. hal-01691088.

Böhringer, C., Carbone, J.C., and Rutherford, T. F. (2012). Unilateral Climate Policy Design: Efficiency and Equity Implications of Alternative Instruments to Reduce Carbon Leakage. *Energy Economics* 34, 208-217.

Böhringer, C., Garcia-Muros, X., and González-Eguino, M. (2019). Greener and Fairer: A Progressive Environmental Tax Reform for Spain. *Economics of Energy & Environmental Policy* (doi: 10.5547/2160-5890.8.2.cboh)

Bureau of Labor Statistics (2006). 2006 consumer expenditure interview survey public use microdata documentation. Available online at: http://www.bls.gov/cex/2006/csxintvw.pdf.

Bureau of Economic Analysis (2007). Annual I-O PCE bridge matrix. Available at http://www.bea.gov/industry/xls/PCEBridge_2002-2007.xls.

Burtraw, D., Sweeney, R., and Walls, M. (2009). The incidence of US climate policy: Alternative uses of revenues from a cap-and-trade auction. *RFF Discussion Paper* 09-17-REV.

Carbone, J., Morgenstern, R.D., Williams III, R.C. and Burtraw, D. (2013). Deficit reduction and carbon taxes: Budgetary, economic, and distributional impacts. *Resources for the Future*

Caron, J., Cohen, S.M., Brown, M. and Reilly, J. M. (2018): Exploring the impacts of a national U.S. CO2 tax and revenue recycling options with a coupled electricity-economy model. *Climate Change Economics*, 9(1): 1840004 (doi: 10.1142/S2010007818400043).

Carraro, C., Galeotti, M., and Gallo, M. (1996). Environmental taxation and unemployment: some evidence on the double dividend hypothesis in Europe. *J Public Econ* 62, 141-181.

Census Bureau (2020). Poverty Thresholds by Size of Family and Number of Related Children. Available at https://www.census.gov/data/tables/time-series/demo/income-poverty/historical-poverty-thresholds.html

Creedy, J. and Sleeman, C. (2006). The Distributional Effects of Indirect Taxes: Models and Applications from New Zealand. *Edward Elgar Publishing*.

DO NOT CITE, COPY OR DISTRIBUTE

De Bruin, K., Monaghan, E. and Yakut, A.M. (2019) The economic and distributional impacts of an increased carbon tax with different revenue recycling schemes. *Research Series 95*, Economic and Social Research Institute.

Dinan, T., and Rogers, D. (2002). Distributional Effects of Carbon Allowance Trading: How Government Decisions Determine Winners and Losers. *National Tax Journal*. 55, no. 2: 199–221

Dinan, T. (2015). Offsetting a Carbon Tax's Burden on Low-Income Households. In I. Parry, A. Morris and R. Williams III (eds.), Implementing a US carbon tax, Abingdon: Routledge, 120-140.

Environmental Protection Agency (EPA) (2011). Plan for Environmental Justice 2014. Office of Environmental Justice U.S. Environmental Protection Agency.

Environmental Protection Agency (EPA) (2020). Environmental Justice Progress Report.

Gago, A. Labandeira, X., Labeaga, JM., and López-Otero, X., (2020). Transport taxes and decarbonization in Spain: Distributional impacts and compensation. *Hacienda Pública Española/Review of Public Economics*.

Glomm, G., Kawaguchi, D. and Sepulveda, F. (2008) Green taxes and double dividends in a dynamic economy. *Journal of Policy Modeling*, 30 (1), pp. 19-32

Goulder, L. (1995). Environmental taxation and the double dividend: A reader's guide. *International Tax and Public Finance* 2, 157.

Federal Reserve (2007). 2007 Survey of Consumer Finances (SCF). Survey methodology available at: https://www.federalreserve.gov/econres/scf_workingpapers.htm

Freire-González, J. (2018) Environmental taxation and the double dividend hypothesis in CGE modelling literature: A critical review. *Journal of Policy Modeling*. Volume 40, Issue 1. Pages 194-223.

IMPLAN (2008). State-Level U.S. Data for 2006. MIG Inc., Huntersville, NC. (http://support.implan.com).

Jorgenson, D.W., Goettle, R.J., Ho, M.S., and Wilcoxen, P.J. (2013) Double dividend: Environmental taxes and fiscal reform in the United States. *MIT Press*, Cambridge, MA

Kaufman, N. and E. Krause E. (2016). Putting a Price on Carbon: Ensuring Equity. World Resources Institute.

Klenert, D., Mattauch, L., Combet, E., Edenhofer, O., Hepburn, C., Rafaty, R. and Stern, N. (2018), Making carbon pricing work for citizens. *Nature Climate Change*, 8: 669-677.

Labandeira, X., and Linares, P. (2013) Impuestos energético--ambientales en España. *Economics for Energy*, Vigo.

Lustig, N., (2019). The "Missing Rich" in Household Surveys: Causes and Correction Approaches. Commitment to Equity (CEQ) Working Paper Series 75, Tulane University, Department of Economics.

Majocchi, A., (1996). Green fiscal reform and employment: a survey. *Environ. and Resour*. Econ. 8, 375–397.

Metcalf, G.E. (1999). A distributional analysis of green tax reforms. *National Tax Journal*, 655–81.

Metcalf, G.E., Mathur, A. and Hassett, K.A. (2010). Distributional impacts in a comprehensive climate policy package. *NBER Working Paper*, p. w16101.

Mathur, A. and Morris, A. (2012). Distributional Effects of a Carbon Tax in Broader U.S. Fiscal Reform, *Energy Policy*, 66, 326-334.

Morris, A. C. and Mathur, A. (2014). A carbon tax in broader U.S. fiscal reform: Design and distributional issues. *Center for Climate and Energy Solutions*.

Parry, I.W.H., and Williams, R.C. (2010). What are the costs of meeting distributional objectives for climate policy? *The BE Journal of Economic Analysis and Policy*, 10(2), Article 9, i–ii,1–33.

Pearson, M., and Smith, S. (1991). The European Carbon Tax: An Assessment of the European Commission's Proposals. Institute for Fiscal Studies, London.

Pirttilä, J. and Uusitalo, R. (2010). A 'Leaky Bucket' in the Real World: Estimating Inequality Aversion using Survey Data. *Economica* 77(305): 60–76.

Pomerleau, K. and Asen, E. (2019). Carbon tax and revenue recycling: revenue, economic, and distributional implications. *Fiscal Fact*, 674, Tax Foundation.

Poterba, J.M. (1991). Is the Gasoline Tax Regressive? *National Bureau of Economic Research*

Rausch, S., Metcalf, G. E., and Reilly, J. M. (2011). Distributional Impacts of Carbon Pricing: A General Equilibrium Approach with Micro-Data for Households. *Energy Economics*, 33: S20-S33.

Rausch, S. and J. Reilly (2015): Carbon taxes, deficits, and energy policy interactions. *National Tax Journal*, 68(1): 157–178 (http://globalchange.mit.edu/publication/16180)

Rutherford, T.F., and Tarr, D. (2008). Poverty effects of Russia's WTO accession: modeling "real" households with endogenous productivity effects. *Journal of International Economics* 131–150.

UN (2015). Transforming our World: the 2030 Agenda for Sustainable Development. United Nations Department of Economic and Social Affairs.

Vivid Economics (2012), Carbon taxation and fiscal consolidation: The potential of carbon pricing to reduce Europe's fiscal deficits. *ECF and GBE*.

Yuan, M., Rausch, S., Caron, J., Paltsev S., and Reilly, J. M. (2019): The MIT U.S. Regional Energy Policy (USREP) Model: The Base Model and Revisions. Joint Program Technical Note TN #18, August, 24 p. (http://globalchange.mit.edu/publication/17331).

Yuan, M., A. Barron, N. Selin, P. Picciano, L. Metz, J. Reilly and H. Jacoby (2021): Meeting potential new U.S. climate goals. Joint Program Report Series Report 351, April, 24 p. (http://globalchange.mit.edu/publication/17596).

DO NOT CITE, COPY OR DISTRIBUTE

Appendix A: Welfare impacts for the residual household in each scenario

As we point out in Section 3.2, we have used a residual household approach to calibrate the difference between the IO-data and the microdata. In this approach, we do not alter the household data collected by the survey, ensuring that our distributional analysis reflects the original expenditure and income structure of the different households collected in the survey (in this case - the CEX survey). However, this approach can diffuse some impacts. Another workaround might be to scale the total expenditures and income of households in the microsimulation data to match total household expenditures and incomes in the macro data (see Böhringer et al. 2019). However, this approach has its own limitations, as the pattern of household expenditure and the structure of income sources must be modified to fit the macro-structure, and therefore this alternative approach alters the household micro-data collected by the survey that are representative for the society. Given that our analysis focuses primarily on distributional impacts, the Residual Household approach better ensures that the incidence conclusions remain robust to the micro-data collected. However, this methodological debate requires further analysis.

Table A.1. shows the main difference between the micro-data and the macro-data used in our approach. Although some of the commodities differs between the macro and the micro data, the incidence and distributional impacts found in this paper are valid for the U.S. households, because they show the impact on the households covered by the CEX survey, which, according with the Bureau of Labor Statistics, is representative of the US population. In addition, the CEX has been used extensively in other distributional research developed for the U.S. economy (see, e.g., Carbone et al., 2013; Glomm et al., 2008; Jorgenson et al., 2013; Rausch and Reilly, 2015).

Table A.1. Difference between the microdata and the macro data used

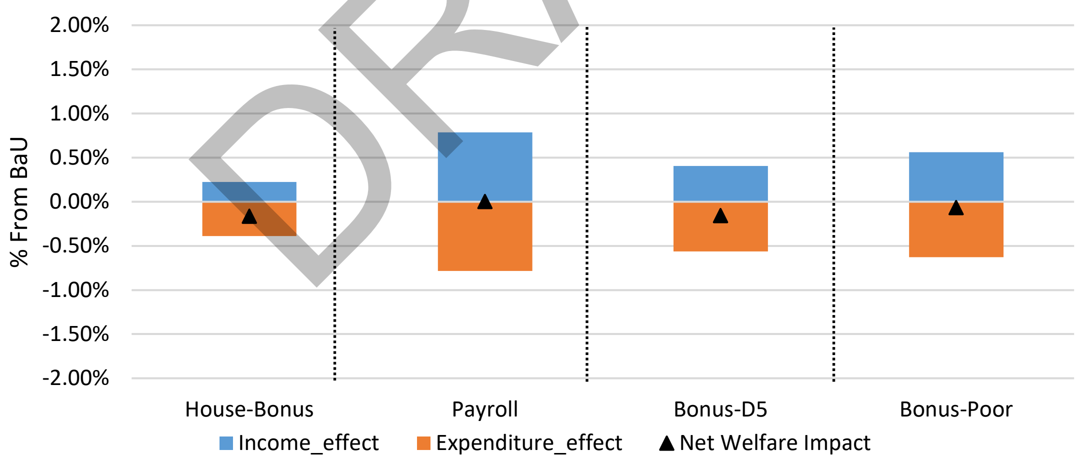
Expenditure difference			
	Macro Data	Micro data	% covered by micro data
AGR	50.9	50.8	100%
GAS	59.6	41.7	70%
ELE	152.0	104.8	69%
OIL	390.2	116.2	30%
TRN	165.6	81.0	49%
SRV	7047.5	3738.9	53%
EIS	353.5	128.2	36%
OTH	1216.9	596.6	49%
Income difference			
	Macro Data	Micro data	% covered by micro data

DO NOT CITE, COPY OR DISTRIBUTE

Capital	4760.78	1919.95	40.3%
Labor	7412.23	4432.23	59.8%
Transfer	1550.15	423.15	27.3%

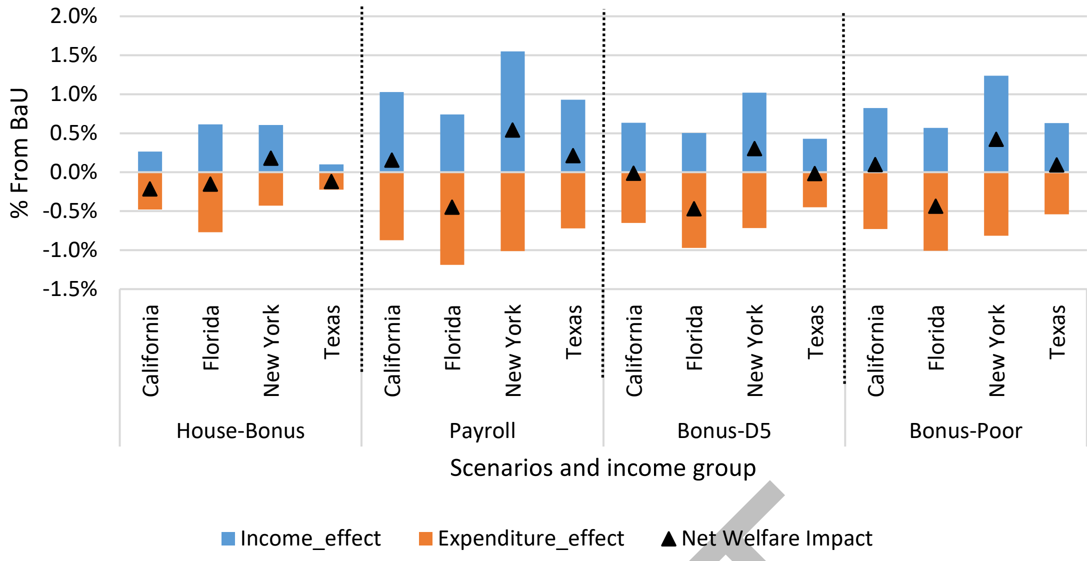
Figure A.1. shows the average welfare impacts for the residual households in each scenario[17], whereas Figure A.2. shows the welfare impacts for the residual household included in the main regions/states included in USREP: California, Florida, New York and Texas. The results show that the welfare impacts of the residual household from the income and expenditure channel are consistent with the welfare impacts of the different income groups for each recycling scheme (see Figure 2). As also shown in Figure 2, welfare impacts from the income or expenditure channels differ depending on the scenario. In all scenarios, carbon price has negative expenditure welfare impacts, which are offset by positive income welfare impacts. These results also show that the residual household is closer to the welfare impacts of higher income brackets, as the welfare impacts of income are larger the higher the payroll tax reduction (i.e., the *Payroll* scenario, which is followed by the *Bonus-Poor* scenario), demonstrating that surveys such as CEX suffer from underrepresentation of the upper tail of the distribution (Atkinson, 2011 or Lustig, 2015).

Figure A.1: Average Welfare impacts for residual households in each scenario (% of HEV in income).



[17] To make sure that we include the impact of the rebate on residual households, and also in order not to overestimate the bonus transferred to the microhousehold data, we estimated the weight of the residual household as a function of the share of expenditure it represented in the economy. Therefore, in scenarios that include lump-sum transfers (*House-bonus, Bonus-D5* and *Bonus-Poor*), the lump-sum received by each household is according to the population weight of each household, including the residual household

Figure A.2: Welfare impacts for the residual household in each scenario for the main regions/states included in USREP.



Appendix B: Distributional impacts for selected U.S. states

Figures B.1-B.4 show the impact on welfare (measured in terms of equivalent variation) for ten different income groups (deciles)— Group D1 contains the households with the lowest incomes and Group D10 those with the highest, for four major U.S. states: California, Florida, New York and Texas. These regions cover around 33% of the total population and 36% of the US economy. Figures B.1- B.4. show that the distributional impacts for these regions are similar to those found at the national level. For these four states the *House-Bonus* scenario is progressive, whereas the *Payroll* recycling tends to be proportional or even slightly regressive. Also, as happened at the national level, the positive effects for the low-income households can be even higher when the rebates only cover the lower income households (*Bonus-D5* and *Bonus-Poor*), showing that lower income groups benefit from the rebate and the effect of the reduction in payroll taxes.

Figure B.1-B4. Welfare impacts per income group (deciles) for California, Florida, New York and Texas.

Figure B.1.California

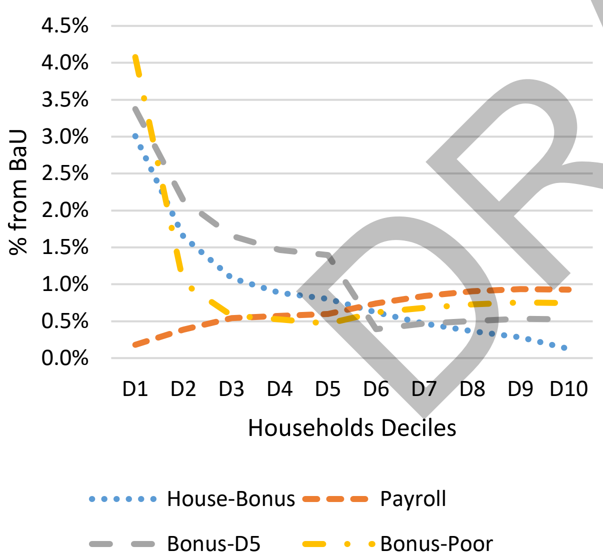
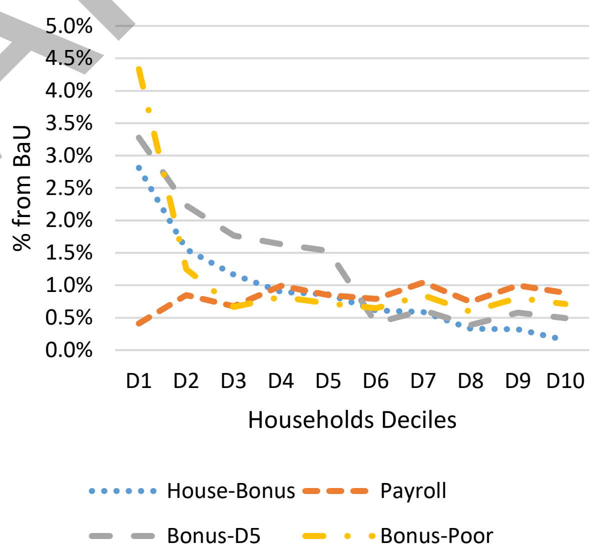


Figure B.2. Florida



DO NOT CITE, COPY OR DISTRIBUTE

Figure B.4. Texas

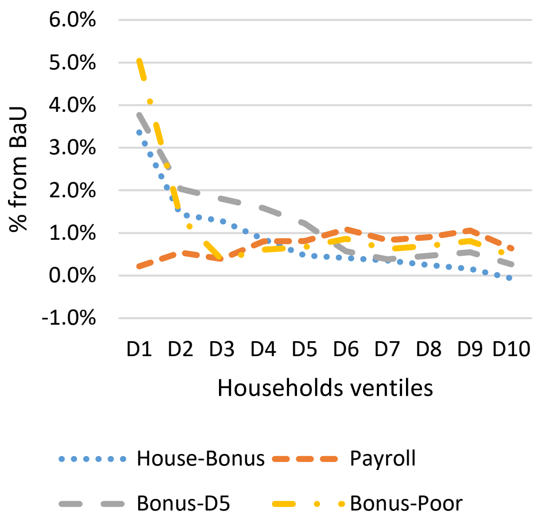


Figure B.3. New York