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Cash transfers for pro-poor carbon taxes in Latin America and the Caribbean

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Carbon taxes are advocated as efficient fiscal and environmental policy tools, but they have proven difficult to implement. One reason is that carbon taxes can aggravate poverty by increasing prices of basic goods and services such as food, heating and commuting. Meanwhile, cash transfer programmes have been established as some of the most efficient poverty-reducing policies used in developing countries. We quantify how governments could mitigate negative social consequences of carbon taxes by expanding the beneficiary base or the amounts disbursed with existing cash transfer programmes. We focus on Latin America and the Caribbean, a region that has pioneered cash transfer programmes, aspires to contribute to climate mitigation and faces inequality. We find that 30% of carbon revenues could suffice to compensate poor and vulnerable households on average, leaving 70% to fund other political priorities. We also quantify trade-offs for governments choosing who and how much to compensate.

Countries in Latin America and the Caribbean (LAC) face common challenges in the pathway to sustainable development. Many of them have moved beyond low-income status and aspire to join the Organisation for Economic Co-operation and Development (OECD). All have committed to climate mitigation through the Paris Agreement. Nevertheless, the provision of essential services remains a priority in the region[1–3]. Six percent of Latin Americans lack access to water, 18% lack sanitation and 5% lack a reliable electricity connection[4–6]. In addition, fiscal consolidation to reduce debt is a prime concern[7], leaving little room for governments to manoeuvre.

Carbon taxes could help fund development priorities and achieve mitigation targets. A carbon tax consistent with the Paris Agreement goals could generate more than US$100 billion revenue per year in the region, enough to close the water, sanitation or electricity access gap[4]. Taxing greenhouse gases would also incentivize consumers and firms to reduce fossil fuel and beef consumption, thereby improving health outcomes and reducing emissions of global and local pollutants[8–11].

However, carbon taxes are often difficult to implement, as illustrated by the yellow-vest movement in France, the *gasolinazo* in Mexico and the rejection of a carbon tax in Washington[12,13]. One stated reason is their potential adverse near-term social impacts, especially on poor and vulnerable housheolds[14–18]. But the experience of energy subsidy removal suggests that compensating negatively affected households with complementary policies can help reforms succeed[19–25].

We assess how existing cash transfer programmes can be used to mitigate the negative impact of carbon taxes on poor and vulnerable households. Cash transfer programmes are one of the most efficient ways for delivering social assistance: they reduce poverty, improve school attendance and health outcomes, encourage savings and investment, foster business creation, increase labour-force participation for adults and reduce child work[26]. Mexico pioneered their implementation with the *Progresa* programme in the mid-1990s. Similar programmes are now present in most countries in LAC and reach more than 140 million people, including 48 million beneficiaries of *Bolsa Familia* in Brazil, the largest such programme in the world[27,28]. But cash transfers have limitations[29]. In the region, they reach only half of the households living in poverty (they suffer from weak coverage), and 40% of the disbursements benefit households that are not poor at all (they are imperfectly targeted)[28].

Modelling the impacts of a carbon tax on consumers

Consumers are affected in two ways when governments tax carbon emissions: directly through cost increases of fossil fuels and electricity and indirectly through increasing production costs affecting prices of all other goods and services[14,18,30]. We quantify the impact of carbon pricing on consumers in 16 LAC countries (Table 1) in two main steps: assessing how a carbon tax would increase the price of goods and services and evaluating their influence on overall household expenditure.

First, we use input–output analysis to assess the impacts from increasing the price of fossil fuels on the basis of their greenhouse gas (GHG) content, directly as costs to households and indirectly through value chains (Methods). Specifically, we assess the costs of imposing a tax on both CO_2 emissions and non-CO_2 GHG emissions (methane, nitrous oxide and fluorinated gases) according to their respective global-warming potential. We model a $30 per ton CO_2-equivalent (tCO_2e) carbon tax, a conservative estimate of the price signal consistent with the Paris Agreement temperature targets according to a recent World Bank report[8]. But our model is linear, and our results can easily be scaled down or up to other carbon tax levels.

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Table 1 | Impact of a US$30 per t$CO_2$e tax on the cost of consumption items, as a percentage of the current price, per item and country

	Median	Argentina	Bolivia	Brazil	Chile	Colombia	Costa Rica	Ecuador	El Salvador	Guatemala	Honduras	Mexico	Nicaragua	Panama	Paraguay	Peru	Uruguay
Natural gas	27.3	154.9	111.5	70.6	21.9	73.6	19.4	58.4	20.1	20.1	19.4	50.6	21	19.5	90	32.7	19.1
Petroleum, gasoline and diesel	13.7	15.6	16.3	13.9	11.3	11.9	11.4	14.3	11.5	15	13.5	15.3	14.1	11.8	18.7	9.5	10.7
Electricity	8.6	18.4	25.8	2	8.6	4.2	2.2	11.9	5.1	8.7	10.7	15.5	9	7.2	0.5	10.8	5
Public transport	3.6	3.5	9.1	2.8	2.8	2.8	2.8	4.1	3.6	11.3	5.3	3.6	5.4	9.2	4.4	3.5	2.1
Food	3.1	5.3	13.1	4.7	2.1	3.8	1.8	2.9	1.6	2.4	3.3	2.2	3.8	1.4	7.8	2.1	6
Construction, including materials	1.4	1.6	4.7	0.9	1	1	0.7	1.7	0.9	1.5	1.5	1.8	2.3	1.8	0.7	1.2	0.6
Water	1.2	1.2	2.1	0.4	0.4	0.2	1.1	6.7	1.8	1.8	4.3	1.7	2.2	0.5	0.9	0.6	0.4
Manufacturing, electronics and machinery	1.1	1.4	6.7	0.6	1.5	0.5	0.4	1.5	1.1	2	1.1	0.9	4.5	1.4	0.6	0.8	0.8
Other expenditures	0.6	0.6	3.1	0.4	0.5	0.5	0.2	0.7	0.4	0.8	1.1	0.6	1.8	0.5	0.6	0.6	0.4

The second step is to assess, from consumer income and expenditure surveys (Supplementary Methods), the fraction of spending that households devote to each consumption item, specifically for the wealthiest and poorest quintiles. From household expenditure data and the price increases in household goods and services, we assess the total (direct and indirect) impact of the carbon tax on households, before any redistribution.

Our approach provides an upper-bound estimate of the short-term impact of carbon taxes on households, before firms adjust production processes and consumers adapt to new prices. With a more sophisticated representation where firms and households from different income levels adjust to a carbon tax over time, the estimate of the total cost to households of a constant carbon tax would presumably lower over time, and its incidence could change[14]. However, a meta-analysis of the literature suggests that modelling this dynamic response of firms and consumers plays a limited role in determining the distributional impact of price hikes[31]. Our parsimonious and transparent approach is in line with studies from the International Monetary Fund that aim at giving an indication of how governments can improve the social acceptability of energy price hikes[18,32].

Options to recycle carbon revenues into cash transfers

Carbon taxes may adversely affect poor and vulnerable households, undermining social development objectives and potentially reducing support for reforms[15,17,24,33–37]. The academic literature has established that adequately redistributing carbon revenues can help compensate vulnerable households[15,30,38,39] and may enhance public support for carbon taxes[15,34,36].

There are two main options to redistribute revenues. One is to reduce existing taxes, which may come with the additional benefit of improving economic efficiency, especially in countries where the informal sector and tax evasion are substantial issues[15,40–43]. The other is to increase spending, using either in-kind transfers (such as vouchers for food or energy services or subsidized public transport) or cash transfers.

Here, we focus on how cash transfers can be used to redistribute carbon revenues. It is not clear whether poor people in developing countries pay enough taxes to make cutting taxes an effective compensation mechanism, but the data we use do not allow the investigation of this question. Moreover, the experience from subsidy removal suggests that governments that reinforce social transfers as part of a reform package are more likely to succeed in increasing prices[16,19–21,23,25].

We analyse four ways of redistributing carbon revenues into cash transfers (Methods). The first is to create a new universal carbon rebate. This simple policy, often mentioned in the academic literature and in policy proposals[19,44,45], redistributes carbon revenues to all households on a per capita basis. Iran and India have implemented such a scheme to compensate the impacts of subsidy removal[15].

Alternatively, the government may leverage existing conditional and unconditional cash transfer programmes, incrementally improving the established enrolment and delivery mechanisms[46]. Under our second simulation, the current-enrolees rebate, we assess the impact of rebating carbon revenues evenly to all households currently enrolled in cash transfer programmes.

Another option is to expand the beneficiary base. Rather than assuming that governments can implement carbon rebates perfectly targeted to the households most affected by carbon taxes, we investigate incremental improvements from the existing situation. For example, most of the cash transfers in the region are conditional cash transfers, with one popular condition being school attendance[27,28]. Carbon rebates could use existing registries of beneficiaries without applying some of the conditionalities. As an example, our third simulation models an expanded-enrolees rebate that would share carbon revenues with a list of beneficiaries that includes 25% more households than those currently receiving transfers in all quintiles (for example, 50% enrolment increases to 62.5%).

Because existing cash transfers do not perfectly target poor households, registries of beneficiaries are an imperfect base for designing compensation mechanisms. In the fourth policy simulation, we quantify the impact of skewing the list of beneficiaries in favour of poor households (poverty-targeted rebate). In this scheme, carbon revenues are shared evenly among a list of enrolees that starts from the beneficiaries of current cash transfer programmes, excluding 50% of top-quintile households and including the same number of bottom-quintile households.

Metrics to compare the redistribution schemes

We assess our carbon redistribution options using three metrics. First, we compute their incidence on households' expenses at the quintile level, when all carbon revenues are redistributed. If poorer quintiles end up paying more, relative to their income, than richer quintiles, the scheme is deemed regressive. If poorer quintiles end up paying relatively less, or receiving relatively more, than richer households, the scheme is progressive.

Second, we compute the fraction of individuals within each quintile that are net contributors or beneficiaries from each simulated reform (also redistributing all carbon revenues). Indeed, our current-enrolee and expanded-enrolee schemes distribute the same

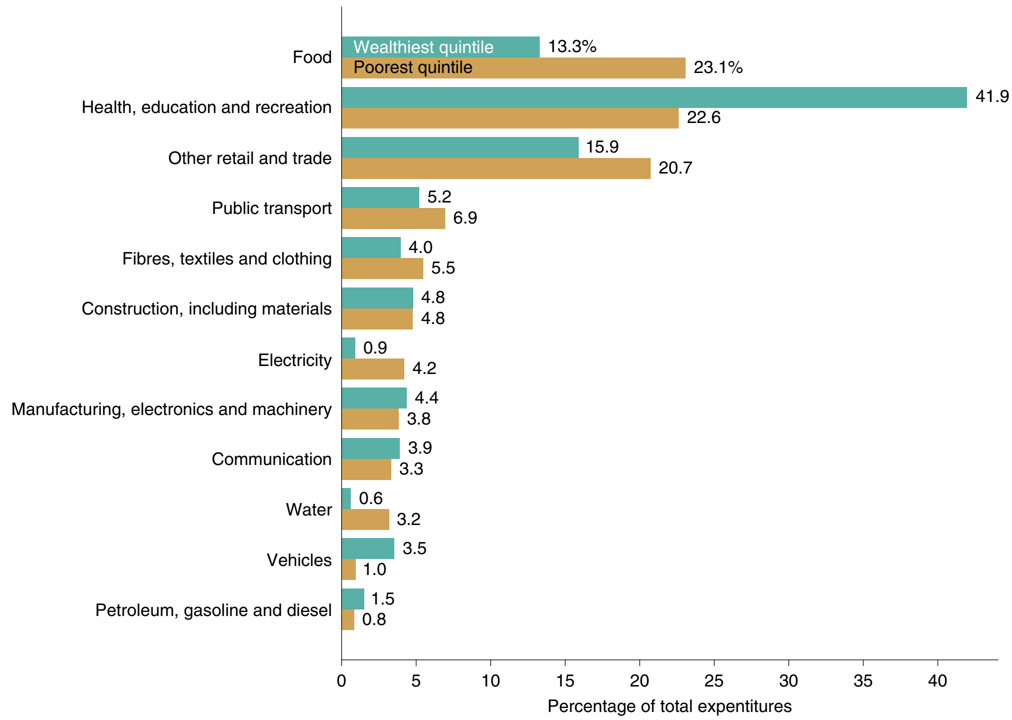

Fig. 1 | Household expenditures per consumption item, as a fraction of total household expenditure, for the poorest and wealthiest quintiles in Brazil.

total value to each quintile by design. At the household level, however, increasing the number of beneficiaries matters. Rebating carbon revenues from an unchanged beneficiary base leaves out the consumers who are currently not benefiting from any cash transfer programme, resulting in many poor consumers having to cover the full cost of the carbon tax. However, expanding the number of beneficiaries reduces the resources available per beneficiary.

Third, we compute the fraction of revenues required to compensate the two bottom quintiles for their carbon costs, using the four different recycling schemes. If the purpose of the governments is to make poor and vulnerable household groups break even while maximizing the fraction of carbon revenues used to fund other development programmes or pay back national debt, they may not need to recycle all the proceeds of carbon taxes into improving existing cash transfers.

Food prices tend to make carbon taxes regressive

Table 1 shows the simulated impact of a \$30 per tCO_2e carbon tax on the price of goods and services in the 16 countries of our sample. The greatest price increases would happen for natural gas and petroleum products (median increases of 27% and 14%, respectively). Fossil fuels are indeed the commodities with the highest carbon content per dollar. Electricity is the third most impacted item (+9%), particularly in countries such as Bolivia, Argentina and Mexico, which generate electricity with a larger share of fossil fuels. Public transport would be the fourth most impacted item (+4%), followed by food (+3%). The same carbon price yields different relative price increases across countries because the prices of energy and commodities vary across countries, reflecting different cost structures, taxes and subsidies[9].

Figure 1 shows the percentage of spending that Brazilian households devote to each consumption item listed in Table 1, specifically for the wealthiest and poorest quintiles. Trends in Brazil are representative of the situation across the 16 countries of our sample (the Supplementary Information provides quantifications for each country). Notably, the bottom quintile spends nearly a quarter of its expenditures on food, while the wealthiest quintile spends 13%. The richest quintile spends relatively more on vehicles and fuels than the poorest quintile, 5.0% versus 1.8% in Brazil, as richer households are more likely to own a car.

On average, the indirect impacts of carbon taxes on food, public transportation and electricity turn out to cost households more than the direct impacts on fossil fuels. Across all countries and quintiles, the cost of non-CO_2 GHG emissions from food and the cost of CO_2 emissions from public transport and electricity represent respectively 42%, 10% and 5% of the total cost of the carbon tax. The preponderant role of food price hikes comes from the fact that while food prices are not dramatically affected by a carbon tax (Table 1), food represents an important share of consumer expenses in the region (Fig. 1 and Supplementary Information).

The case of Brazil, pictured in Fig. 2, shows the importance of the prices of food, public transport and liquid fuels. Electricity and natural gas are negligible here as Brazil relies mostly on hydroelectricity, and natural gas is not commonly used for heating there (see Supplementary Information for other country results). The direct impact on fossil fuels matters relatively more for richer households because they are more likely than poorer households to own private vehicles.

In most Latin American countries (Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Guatemala, Honduras, Mexico, Nicaragua, Panama, Peru, Paraguay and Uruguay), the combined direct and indirect cost of a carbon tax is regressive, driven by the larger share of food, public transport and electricity in the poorest households' budgets. In Bolivia, the cost to the poorest quintile is more than 10% of their total expenditures due to poor households' high spending on food (52%) and high emissions of non-CO_2 GHGs from food production. In Ecuador and El Salvador, the tax is progressive but still costs the poorest quintile 2.5% and 1.2% of total expenditures, respectively.

The cost of non-CO_2 emissions constitutes a significant share of the total cost of the carbon tax on consumers and a significant driver of its regressive impact. Taxing only carbon emissions from

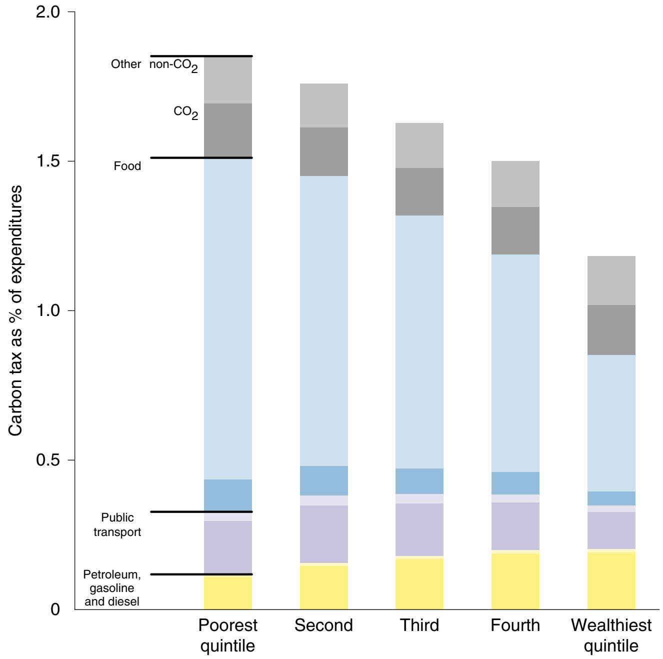

Fig. 2 | Impacts of a \$30 per tCO_2e tax in Brazil, per consumption item and per expenditure quintile.

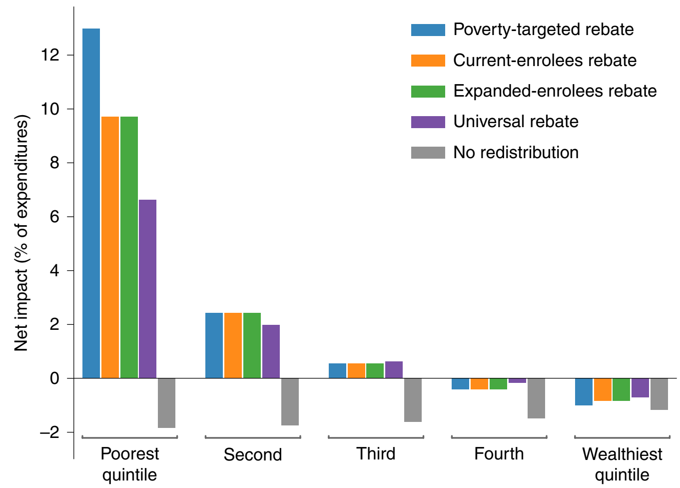

Fig. 3 | Net impact of a \$30 per CO_2e tax coupled with alternatives for fully redistributing carbon revenues in Brazil.

fossil fuel without compensation would be progressive in most countries, in line with previous results[14] (Supplementary Data). This difference matters for real-life implementation: many carbon tax proposals focus on taxing the carbon content of fossil fuel energy as a first step, as doing so can be easier than taxing non-CO_2 emissions from agriculture.

Cash transfers can make reforms progressive

Figure 3 shows the result of our policy simulations for Brazil. Under the universal rebate, the three bottom quintiles would be net beneficiaries, while the top two quintiles would be net contributors. In all 16 countries of the sample, recycling carbon revenues into a universal rebate would ensure that bottom quintiles benefit from the reform. Across countries, the median impact on the poorest quintile is 4.7% of total expenses, 0.6% on the third quintile and −0.9% on the richest quintile (Supplementary Information).

In Brazil, the current-enrolee rebate has a more progressive impact than the universal rebate. In all countries except Honduras and Paraguay, the two bottom quintiles would benefit from a current-enrolee rebate. Except in Honduras and Paraguay, existing cash transfers programmes are more likely to reach poorer households than richer households. Rebating carbon revenues only to current enrolees thus tends to make bottom quintiles better off than rebating to all households. (In Argentina and Bolivia, current enrolment is flat, and the impacts of the two schemes are similar.) Across all countries in our sample, the median impact on the poorest quintile of the current-enrolees rebate is 8.8% of expenditures versus 4.7% for the universal rebate.

In Argentina, Chile, Panama and Paraguay, our surveys do not discriminate cash transfers from other government transfers. For these four countries, we analysed a rebate to beneficiaries of all transfers from the government. We found that non-cash government transfers tend to benefit richer households more than poorer households (this is true across the 16 countries). Indeed, those transfers include contributory pensions, unemployment benefits and health insurance that, by design, benefit richer households with formal jobs more than poorer households with informal or no jobs[47]. In all countries, rebating carbon revenues to beneficiaries of all government transfers would benefit bottom quintiles less than using a universal rebate or a rebate to enrolees of current cash transfer programmes.

The expanded-enrolees rebate performs similarly to the current-enrolees rebate, both in Brazil (Fig. 3) and across countries, when looking at the average effect by quintile. Indeed, the two schemes distribute the same total value to each quintile by design. At the household level, however, the two schemes have different effects. In Brazil, 61% of individuals in the bottom quintile would be net beneficiaries of a carbon tax combined with the current-enrolees rebate (Fig. 4, orange line). This corresponds to all current beneficiaries from cash transfers (Fig. 5). At the other end of the income distribution, 33% of Brazilians in the highest quintile are recipients of cash transfers, but only half of them (18% of the quintile) would be net beneficiaries of the current-enrolees scheme. Indeed, richer households tend to spend more money (in absolute terms) on the carbon tax than poorer households, while the rebate gives the same amount to all beneficiaries by design. Poorer recipients thus tend to receive more than what they pay in carbon taxes. The expanded-enrolees scheme performs better in this metric: in Brazil, almost 80% of the bottom quintile would be net beneficiaries (green line). Across countries, the expanded-enrolees rebate results in 61% (median) of bottom-quintile households being net beneficiaries.

Finally, Fig. 3 shows that in Brazil, the poverty-targeted rebate would, as expected, have a more progressive impact than both the current-enrolees and the expanded-enrolees schemes, when measured at the quintile level. The poverty-targeted scheme results in more households from the bottom quintile benefiting than the other schemes in nine countries (Argentina, Bolivia, Brazil, Chile, Honduras, Nicaragua, Panama Paraguay and Uruguay; Figs. 3 and 4 and Supplementary Information). In the other seven countries (Colombia, Costa Rica, Ecuador, Guatemala, Mexico, Peru and El Salvador), expanding enrolment performs better for households in the bottom quintile. The difference is due to current enrolment patterns. In countries where enrolment decreases strongly with income (such as Colombia), expanding coverage across the board is more effective, while in countries where enrolment in current cash transfer programmes is flat over expenditure groups (for example, Bolivia) or even increases with income (for example, Honduras), improving the targeting tends to be more effective.

A fraction of carbon revenues suffices

Table 2 reports the percentage of carbon revenue required to compensate the two bottom quintiles for their carbon costs, using the

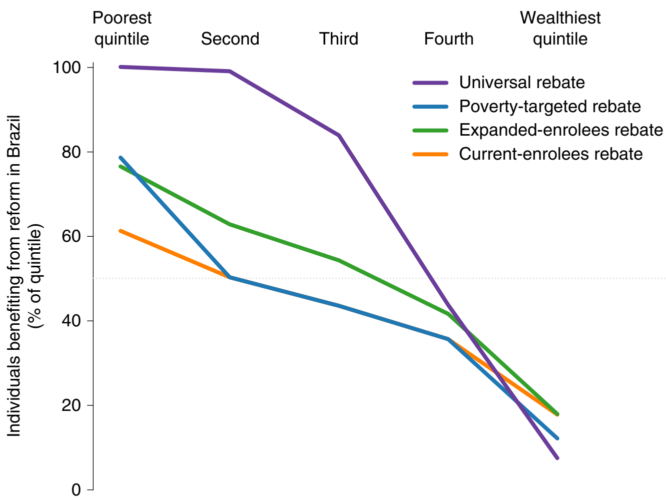

Fig. 4 | Fraction of households in each quintile experiencing a net benefit from the combined carbon tax and rebate schemes in Brazil.

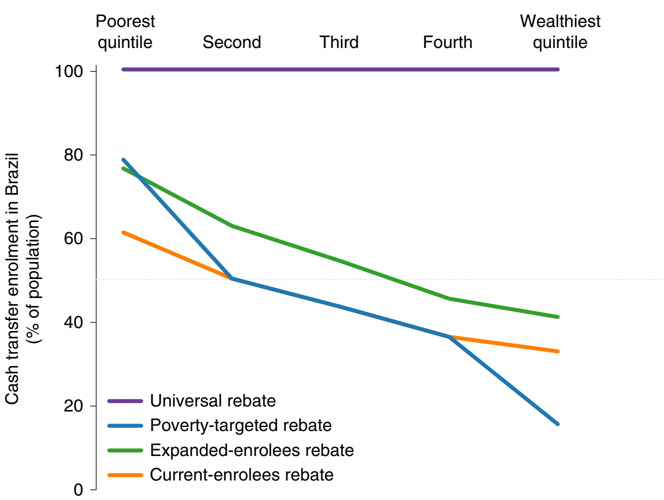

Fig. 5 | Coverage of simulated carbon rebate programmes in Brazil.

four different recycling schemes. In Brazil, for example, the poorest 40% pays 14% of the total carbon tax. A perfect redistribution mechanism starting from the bottom of the income distribution would need to spend 14% of total revenue from a carbon tax to compensate these two quintiles (first line of Table 2). However, an ideal redistribution scheme would require detailed knowledge of each household's expenditure schemes. Other systems based on existing cash transfer programme registries or universal redistribution could be easier to implement but would be more expensive (Table 2).

To compensate the two bottom quintiles for the carbon tax by issuing a carbon rebate to all current enrolees of social protection schemes, the Brazilian government would need to spend two times the amount required in a perfectly targeted scheme—that is, 28% of total carbon tax revenues. If the government first reduced targeting imperfections in existing social protection schemes (that is, reduced coverage of rich households by 50% and improved coverage of poor households), then the fraction of tax revenue needed would drop to 24%. The government could also simply redistribute 34% of carbon revenues into a universal rebate evenly shared among all households.

Discussion

In summary, we find that recycling revenues from a \$30 per tCO_2e tax back to households in cash disbursements would have a progressive income effect; that is, it would reduce inequality: households in poorer quintiles would see their real income increase by 5–9% on average, while households in richer quintiles would be net contributors. Governments do not need to redistribute all carbon revenues to compensate poor and vulnerable groups. In half the countries we analysed, governments would need to recycle less than 30% of carbon revenues into carbon rebates backed by existing cash transfer programmes to make the poorest two quintiles break even, leaving more than 70% of carbon tax receipts to fund other priorities.

If the objective is to maximize the number of poor and vulnerable households who benefit from the reform, recycling carbon revenues in a universal rebate is the preferred option. Over 90% of households in the bottom three quintiles would benefit. But creating a universal rebate from scratch could be challenging. If governments need to start from existing programmes, improving their coverage is an effective option. Ideally, the expansions of existing cash transfer programmes could target poor households. But governments could face technical difficulties identifying and reaching poor households[28] or political difficulties enacting reforms that do not benefit middle-class and well-off voters[29]. Our simulations of an expanded-enrolee rebate show that the inclusion of richer households would not necessarily jeopardize the effectiveness of the scheme.

As a caveat, in addition to compensating poor and vulnerable households, making sure that a majority of consumers benefit from the reform might be necessary to ensure political feasibility[17,29]. Supplementary Table 2 shows that among the redistribution schemes we modelled, only the universal rebate can consistently transform at least 60% of consumers into winners. Further research could investigate what fraction of carbon revenues would need to be recycled into a well-selected combination of cash transfers, in-kind transfers and tax rebates to ensure that both poor households and most households across income groups benefit from reforms.

Should governments compensate consumers for the impact of a carbon tax? Some authors consider that all taxes are takings of

Table 2 | Percentage of carbon revenue required to make the bottom 40% break even using different policy packages, per country

	Median	Argentina	Bolivia	Brazil	Chile	Colombia	Costa Rica	Ecuador	El Salvador	Guatemala	Honduras	Mexico	Nicaragua	Panama	Paraguay	Peru	Uruguay
Perfect compensation	16	20	19	14	16	15	14	17	17	15	11	16	15	13	20	18	18
Poverty-targeted rebate	25	40	40	24	30	22	21	25	22	24	36	24	27	23	64	22	36
Expanded-enrolees rebate	27	50	50	28	38	23	22	26	22	27	77	25	32	27	133	23	41
Current-enrolees rebate	27	50	50	28	38	23	22	26	22	27	76	25	32	27	129	23	38
Universal rebate	39	49	48	34	39	38	36	42	42	37	28	39	37	32	51	45	46

private property compensable by the government[48], while others consider compensation to provide perverse incentives and thus to be detrimental[49]. Beyond normative views, international experience suggests that any government project to implement carbon taxes without a plan to compensate, at least partially, affected households is unsustainable[16,17,19,23]. Our work provides insights on how cash transfer programmes can contribute to such a compensation while leaving most fiscal resources available to fund other priorities.

Methods

Input–output analysis. Input–output analysis has been frequently used to study distributional effects of energy subsidies and carbon pricing on different household groups[14,19,30,50–57]. In this study, input–output analysis was applied to model the impacts of the energy subsidy removal and/or energy price shocks on the five household quintiles via induced price changes in household expenditure items. This method captures both direct and indirect effects of energy price hikes on household expenditure, not only the price increase for energy products but also the price increase triggered by energy inputs to all final consumption items. In this study, input–output analysis is selected due to its simplicity and transparency compared with other economic system accounting methods such as the computational general equilibrium model[38,43,52,55,58]. The input–output model gives an upper-bound estimate of the short-term impact of energy price hikes on the price of other consumption goods before firms have had a chance to adjust production processes. The International Monetary Fund[32] noted that the short-term estimate provided by simple input–output analysis may also be closer to the perceived impact by the public, making it a good indicator for public policy focused on the social acceptability of energy price hikes.

Input–output analysis is a modelling approach that relies on national or regional input–output tables. A country's input–output tables show the flows of goods and services and thus the interdependencies between suppliers and consumers along the production chain across upstream and downstream industries within an economy[59]. The model consists of n linear equations depicting the production of an economy:

$$x_i = \sum_{j=1}^{n} z_{ij} + y_i \quad (1)$$

where n is the number of sectors in an economy, x_i is the total economic output of the ith sector, y_i is the final demand of sector i and z_{ij} is the monetary flow from the ith sector to the jth sector.

In matrix notation and for the economy as a whole, equation (1) can be written as:

$$x = Ax + y \quad (2)$$

Technical coefficient matrix $A = (a_{ij})$ is derived by dividing the intersectoral flows from sectors i to j (z_{ij}) by total input of sector j (x_j), in which $a_{ij} = z_{ij}/x_j$.

To solve for x, we get total output driven by final demand:

$$x = (I - A)^{-1} y \quad (3)$$

$(I - A)^{-1}$ is known as the Leontief inverse matrix, which shows the total production of each sector required to satisfy the final demand in the economy.

To estimate the direct and indirect effects of carbon pricing on income group q, we calculate the indirect and the direct effects separately. To calculate the indirect effect c_q^{indir}, we build a row vector of cost increase per unit of sectoral output e. Here, e is derived from the production cost increase in each economic sector due to the price of carbon emissions divided by the total sectoral output. The cost increase in each economic sector is estimated using the total carbon emissions multiplied by the price rate, p, for example, \$30 per tCO_2e:

$$c_q^{\mathrm{indir}} = e \times (I - A)^{-1} y_q \quad (4)$$

The direct effect c_q^{dir} of price shock on income group q is calculated using the household direct emissions of income group q multiplied by the carbon price rate p:

$$c_q^{\mathrm{dir}} = p \times y_q \quad (5)$$

Therefore, the total effect of carbon pricing on group q is calculated by:

$$c_q^{\mathrm{tot}} = c_q^{\mathrm{indir}} + c_q^{\mathrm{dir}} \quad (6)$$

Given an increase in energy prices, it would be more expensive for households to consume the same amount of energy as previously. We call direct impact of energy price hikes the additional share of a household's total expenditure required to consume the same amount of energy as before the price hike. This practice, common in the literature[60], provides a reasonable upper bound of the short-term impact of price hikes on households, before they have had time to adjust their consumption behaviour or take adaptive actions (such as investing in more energy-efficient cars or appliances).

Carbon emissions occur in all stages of the economic value chain to produce goods and services that households consume, such as public transportation, food or electricity. We project by how much the price of goods and services consumed by households would increase if carbon is priced. For example, if in a given country producing \$1 worth of processed meat causes 1 $MtCO_2e$ (for example to transport the meat), then the cost of processing meat would increase by \$30 million on the basis of the carbon price of \$30 per tCO_2e emissions. Combining input–output tables and household surveys, we are thus able to analyse the indirect impact of energy price increases on household welfare. In doing so, we can also identify through which consumption categories households are most hurt when a carbon price is imposed. Here again our approach results in an upper bound of the short-term impact of carbon price shock on consumers via other consumption goods, before firms invest in energy-saving measures and/or households modify their consumption patterns.

Distributional impact analysis. Household surveys provide the most comprehensive description of household characteristics and behaviour available, including detailed summaries of consumption and income in each country. We use these data to evaluate the direct and indirect carbon emissions resulting from each household's unique consumption pattern and assign a cost to these emissions, assuming a carbon price of \$30 per tCO_2e emissions. Summing the carbon tax imposed on all households, we derive an estimate of the total revenue generated from the prospective tax on emissions from domestic consumption.

We consider the fitness of existing cash transfer systems as vehicles for redistributing the carbon tax revenue and alleviating the impact of carbon taxes on poor households (Supplementary Methods). We derive the enrolment and value of existing transfers on the basis of household receipts from either programme and evaluate the household-level impacts of scaling these systems out (increasing the number of beneficiaries) or up (increasing the amounts distributed to each beneficiary). In addition, we consider the impact of making social protection systems more targeted to the poorer recipients: we model a reduction of 50% of the coverage of social protection within the top two quintiles combined with an increase in the coverage of the same number of individuals in the two bottom quintiles of the population. Finally, we compare these alternatives to a scenario in which the carbon tax revenue funds a uniform lump sum cash transfer. We measure outcomes using two metrics: the net impact on the expenses of the five spending distribution quintiles in each country and the fraction of households in each quintile for which the sum of the carbon tax and change in social protection receipts generate a net cost.

Data sources. To calibrate the emission-extended input–output model, we applied the following data preparation steps. First, input–output tables were extracted from the Global Trade Analysis Project (GTAP) Power database version 9 (GTAP, 2016). For each country, the input–output table includes intermediate and final consumption matrices, value added and total output in 2011, reported for 68 economic sectors in monetary terms. Second, we divided the carbon emissions data from the GTAP Power database by the GTAP Power economic output (value added) per sector to calculate the emission intensity for all countries and sectors.

Third, to identify the household's consumption and spending trends, we harmonized the latest available household spending and income survey for each of the countries included in the analysis. We selected 16 countries to guarantee an inclusive representation of LAC in our analysis, limited only by the availability of data: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru and Uruguay (Supplementary Table 1).

We aggregated household data into homogeneous income and expense categories between countries. For income, we used labour incomes, rents, incomes from private transfers (local and remittances), incomes from public transfers (including conditional and unconditional public transfers) and other incomes.

In terms of the expenses, we classified the data in 14 categories: petroleum, gasoline and diesel; natural gas; electricity; coal; public transport; food and beverages; clothes and shoes; vehicles; communication; water; health, education and recreation; manufacturing, electronics and machinery; construction, including materials; and other. Individual income and expense data were aggregated at the household level. This process resulted in the construction of comparable databases containing the same number of consumption and expense categories for each analysed country.

These 14 categories were matched to the 68 sectors in the input–output tables. For each consumption item, consumption reported in surveys was scaled up or down so that total spending matched national spending as per the national accounts. We then used the ratio of final (scaled) to reported (prescaled) consumption for each household to scale the value of social transfer receipts by the same amount for consistency. We define welfare as the household's total annual expenditure reported in the household survey, expressed in US dollars (purchasing power parity). This expenditure represents the household's budget constraint.

Data availability

Households surveys for all countries but Guatemala and Honduras are readily available online (Supplementary Table 1). Input–output tables from the GTAP database are available for a fee from https://www.gtap.agecon.purdue.edu/

Code availability

The code used to simulate the impact of different carbon redistribution schemes is available at https://github.com/walshb1/LAC_carbon_taxes_vogtschilb_etal_natsust

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Author contributions

A.V.-S., B.W. and K.F. designed the research; A.V.-S, Y.L., K.F., L.D.C., D.Z. and M.R. prepared the data; A.V.-S., B.W. and K.F. conducted the analyses; A.V.-S., B.W., K.F., L.D.C., Y.L., D.Z., M.R. and K.H. wrote the paper.

Competing interests

The authors declare no competing interests.

Additional information

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