Distributional Implications of Carbon Taxation: Lessons from British Columbia

A Senior Honors Thesis for the Department of Economics

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Contents

Abstract

Carbon taxation is widely favored by economists as the most efficient policy to mitigate the economic damage of anthropogenic climate change. Actual implementation of the policy, however, has been limited, due in part to political opposition rooted in a commonly held belief that the tax is regressive. In this paper, I conduct a distributional analysis of British Columbia's \$30/ton CO_2 eq carbon tax to test this claim of regressivity. I simulate the imposition of the carbon tax with a Leontief input-output model of the British Columbia provincial economy and incorporate general equilibrium effects to factor prices using macroeconomic estimates from a computable general equilibrium model. I then apply the estimated increases in consumer prices to household-level microdata on income and expenditure to calculate the total incidence to each household as a result of the tax and compare five different policy designs to analyze their distributional impact: 1) no rebate of revenues, 2) a flat per-household rebate, 3) a rebate based on household capital income, to model a corporate tax cut 4) a rebate based on household earned income, to model an income tax cut and 5) a rebate based on transfer income, to model an enhancement of welfare programs. I also analyze the dispersion of incidence within income groups under each rebate policy and test different potential sources of heterogeneity. I find that, in the absence of revenue considerations, the tax has no statistically-significant trend in incidence with regard to income. However, once the use of the revenues is considered, the manner in which the revenues are returned determines the distributional impact of the policy. I find that the transfer-based rebate is the more progressive with respect to income than the flat rebate, suggesting it is the optimal policy for satisfying vertical equity considerations, while the wage and capital rebate policies are regressive. I also find that the flat rebate produces the lowest level of heterogeneity in incidence, suggesting it is the optimal policy for horizontal equity. I also consider some potential political advantages or disadvantages of each rebate scheme based on their respective distributional impacts.

1 Introduction

Carbon taxes are widely favored by economists as the most economically efficient policy for reducing greenhouse gas emissions to mitigate anthropogenic climate change. Carbon taxation is based on a simple principle: pay for what you pollute. Greenhouse gas emissions are a textbook example of a negative externality, whereby consumption of goods and services produced through carbon-intensive production processes entails costs that are not reflected in the price paid by consumers (Metcalf, 2019). As a result, carbon emissions enjoy an effective social subsidy that is paid for in the form of environmental and economic damages due to climate change. This subsidy hampers efforts to transition to a lower-carbon energy mix; because fossil fuel energy sources can externalize the full cost of production, they enjoy an advantage over renewable sources in terms of price competitiveness.

A carbon tax operates under the principles of Pigouvian taxation, seeking to induce changes in the allocation of resources for consumption and production by internalizing the social cost of carbon emissions in market prices. A Pigouvian tax is welfare-enhancing, as it forces producers and consumers to base their decisions on the full cost of production and consumption. The result is a more efficient allocation of resources, enhancing overall social welfare (Baumol, 1972).

Applying this theory to greenhouse gases is fairly straightforward: carbon emissions create damages to society as a consequence of anthropogenic climate change, including higher sea levels, desertification, species extinction, stronger storms, and a wide range other negative effects. A carbon tax has four primary aims, which all seek to limit these damages: 1) to incentivize a greater proportion of low- and zero-carbon fuel sources in the overall energy mix, 2) to encourage greater investment in carbon-abatement technology in production processes, 3) to induce innovation in carbon abatement technology, and 4) to dis-incentivize the consumption of carbon-intensive goods. These goals can also be achieved through other policies, such as regulation (standard-setting, etc.) or subsidies. However, a carbon tax is believed to be the most cost-effective policy, because, as a price instrument, it encourages carbon abatement along the abatement curve.[1]

However, despite broad and longstanding agreement among economists on the merits of a carbon tax, such measures have only been sparsely implemented around the world and have proven to be politically fraught (World Bank, 2019). Opponents of carbon taxation have often argued that a carbon tax is a regressive tax and is disproportionately borne by lower-earners who consume a higher proportion of their income (Grainger and Kolstad, 2009). Policymakers are increasingly aware of this criticism, and new proposals for a carbon tax, such as the "carbon dividends" plan for the United States proposed by former Secretaries of State George P. Schultz and James A. Baker III (Schultz and Halstead, 2018), argue that this issue can be overcome by offsetting the revenue in the form of tax cuts/credits or direct cash rebates, a policy sometimes called "revenue neutrality."

The purpose of this paper is to test the claim of regressivity under different tax and rebate policy designs by analyzing the distributional effects of the revenue-neutral carbon tax implemented in British Columbia, Canada in 2008, which remains in effect today. While the regressivity issue is only one obstacle to the implementation of a carbon tax, it is perhaps the easiest to address via policy design. An understanding of how different rebate policies impact the distributional implications of the tax can offer important lessons for policymaking.

The rest of the paper is outlined as follows. Section 2 provides an overview of the existing literature on carbon taxation and its economic impacts, as well as a description of the British Columbia carbon tax and analysis on the

[1]The abatement curve, represented, for example, by the McKinsey curve, refers to the set of all possible carbon-abatement actions – ranging from upgrading to LED light bulbs to major retrofits of fossil fuel energy plants – in order of their cost per unit of emissions reduced (McKinsey & Company, 2009). By incentivizing abatement along the curve, a carbon tax encourages the "easiest" investments to be made first and the most costly ones to be made last.

growth, emissions, and distributional effects in the province. Section 3 describes my method for estimating the effect of the tax on consumer prices and calculating per-household incidence. In section 4, I analyze the distributional impact of the tax under five revenue scenarios: a decomposed result with no use of revenues, a flat per-household rebate, a rebate linked to capital income to simulate a corporate tax cut, a rebate linked to wage income to simulate an income tax cut, and one linked to transfer income to simulate use of the revenues to expand existing transfer programs. Section 5 concludes with lessons for policymaking from the distributional analysis and describes areas for further study.

2 Literature Review

This section outlines the case for carbon taxation in greater detail and discusses some of the challenges for implementation. It also provides a more detailed overview of British Columbia's carbon tax policy.

2.1 The Case for Carbon Taxation

2.1.1 Overview of Climate Science

The case for imposing a tax on carbon emissions is based on the idea that the accumulation of carbon-containing greenhouse gases in the atmosphere contributes to an imbalance in the earth's carbon cycle, leading to a long-term upward trend in global temperatures. This planetary warming has social and economic costs that are not reflected in the market prices of carbon-based fuels and derivative production.

The Greenhouse Effect The greenhouse effect is the process that allows for life on earth to take place by keeping global temperatures within stable, tolerable bounds. As sunlight hits the earth in the form of ultraviolet radiation, some of it is reflected back into space, while about 70% is absorbed by the earth's surface (Hsiang and Kopp, 2018). In order to maintain a stable temperature on the earth's surface, that energy that is absorbed must be balanced by the earth's own emission of infrared radiation – heat (Hsiang and Kopp, 2018). In the absence of any atmosphere, that heat energy from sunlight, which is vital to sustaining life, would quickly dissipate back into space and the earth would be uninhabitable. Carbon-containing gases in the atmosphere, primarily carbon dioxide, methane, and water vapor, are transparent to ultraviolet radiation from the sun, but absorb infrared radiation emitted by the earth. In other words, they make it easy for heat to enter the earth, but difficult for it to leave.

This "greenhouse effect" is precisely what makes the earth habitable. In the absence of greenhouse gases, the earth's mean surface temperature would be approximately -18 degrees Celsius, far too cold to sustain life (Hsiang and Kopp, 2018). But as with many things, moderation is key. The strength of the greenhouse effect depends on the concentration of GHGs in the atmosphere; too little and the earth will be too cold, but too much and it will be too hot.

The Carbon Cycle The atmospheric concentration of GHGs is naturally regulated at an equilibrium through a process known as the carbon cycle. When carbon-containing substances are burned or decompose, they release carbon-based gases into the atmosphere. That carbon is then absorbed by natural carbon "sinks," mainly plants and oceanic plankton, which use them for photosynthesis and then burn or decompose, repeating the cycle. The net atmospheric GHG levels remain mostly stable, with some seasonal variation.

However, the natural carbon cycle does not include all of the carbon-based material on earth, much of which is buried deep underground where it does not burn and therefore does not release emissions. These "fossil fuels" – mostly crude oil, coal, and natural methane gas deposits – are effectively "locked away" underground and are not part of the carbon cycle.

Pre-industrial economies were thus, for the most part, carbon-neutral, because they depended on the process of photosynthesis in plants (Wrigley, 2013). The main sources of fuel before the industrial revolution – wood, plant material, animal products, and their derivatives like charcoal and animal oil – are already part of the carbon cycle and do not contribute net emissions to the atmosphere. When a unit of wood is burned, for example, the emissions that are released into the atmosphere are absorbed by other trees, which use the carbon to grow new wood. No net carbon is added to the system.

The issue with these fuels, however, is that their energy density is relatively low. Whereas wood has an energy density of 16 MJ/kg, coal contains 24 MJ/kg, crude oil contains 44, and liquefied natural gas contains 55 (Hore-Lacy, 2011). The lack of an energy-dense fuel source that could be economically exploited was a key impediment to economic development in the pre-industrial era (Wrigley, 2013).

Beginning in the industrial revolution, however, humanity acquired the technology to economically extract subterranean deposits of combustible fuels (beginning with coal, later oil, and more recently natural gas) and began burning them to produce energy. Access to new energy-dense fuels was a crucial factor, that allowed for the development of an industrial economy, which in turn enabled mass consumption (Wrigley, 2013). This new innovation has undeniably yielded unprecedented benefits for human prosperity by removing one of the biggest constraints on economic development. Indeed, it is impossible to imagine how modern life might have become possible without these new energy sources.

However, the discovery of fossil fuels also began a long, sustained process of upsetting the earth's natural carbon cycle. Unlike with pre-industrial fuel sources like wood or animal oils, burning fossil fuels creates net positive greenhouse gas emissions, because the carbon from those fuels was previously "locked away" underground. Burning fossil fuels amounts to an exogenous injection of new carbon into the system, which in turn raises the atmospheric concentration of greenhouse gases. A higher GHG concentration causes the atmosphere to trap heat more effectively. The result is a gradual warming of the earth's overall climate (Keeling, 1997).

The warming process also entails a risk of positive feedback, whereby the process of planetary warming may itself alter the carbon cycle, accelerating the warming process. Rising average global temperatures may hinder the growth of trees and vegetation, which would itself accelerate warming by causing less carbon to be absorbed (Keeling, 1997). This kind of positive feedback is often referred to as "runaway" climate change and is among the top preoccupations in risk management pertaining to climate change.

2.2 The Social Cost of Carbon

The ecological and climatic impacts of a gradual warming of the earth's average temperature are numerous and diverse. Some potential risks are straightforward, such as the extinction of certain species as their habitats or food supplies become no longer viable; desertification of crop lands, leading to interruptions in regional food supplies; more intense seasonal storms, such as hurricanes and monsoons; and, of course, rising sea levels, which threaten to flood coastal areas, possibly inundating them beyond our capability to protect them. Others are less intuitive, such as the risk of greater spread of infectious (particularly tropical) diseases (Kompas, Pham, and Che, 2018). Estimates of how these effects will impact the economy and general prosperity vary considerably

Emissions of carbon-containing greenhouse gases from industrial processes and consumption are a textbook example of an un-priced externality, imposing costs upon society that are not reflected in the price of individual consumption. These costs, referred to as the "social cost of carbon," are the basis for taxing carbon emissions. In theory, pricing carbon at its marginal social cost would keep the damages from emissions at tolerable levels to maximize overall social welfare.

This social cost can be estimated using integrated assessment models (IAMs), which combine economic and climatological simulations to calculate the effect of climate change on the economy under various assumptions and scenarios (Auffhammer, 2018). The estimates vary considerably depending the underlying models and assumptions, especially the discount rate.

Calculating the social cost of carbon is imprecise, and researchers disagree considerably about what assumptions, what models, and what discount rate to apply to the IAMs, which in turn determine the estimated social cost. Nordhaus (2017), for example, estimates the the social cost of carbon to be around US\$31/tCO_2 eq for the current period, rising annually. This estimate is on the lower end of the spectrum, based on relatively optimistic assumptions of the economic damage function. On the upper end, the Stern Review conducted in 2006 by Sir Nicholas Stern for the

British government using much less optimistic assumptions estimates the social cost for the current period to be as high as four times that figure (Stern, 2006).

Regardless of the debate over the exact social cost, however, the theoretical basis for taxing carbon remains the same. Furthermore, because any carbon price will be set through a political process, rather than economic debate, carbon taxes are unlikely to set at the exact social cost anyways. In practice, given the difficulty of estimating the exact social cost of carbon, carbon taxes may be set with the intention of meeting a specific revenue target over a given period of time, or they may be set to achieve a target reduction in emissions (Metcalf, 2019). Nonetheless, the economic justification remains the fact that carbon emissions have unpriced social costs and reducing emissions is in the public interest.

2.3 Challenges for Implementation

Despite a strong efficiency basis, carbon taxation remains only a small part of the world's response to climate change. As of 2019, carbon taxes cover only 20 percent of global greenhouse gas emissions, and where those taxes have been implemented, they are often too low to have a meaningful effect on emissions (World Bank, 2019). Only about five percent of global emissions are taxed at a price consistent with estimates of the social cost of carbon (World Bank, 2019). Dolphin, Pollitt, and Newbery (2016) estimate that the average weighted global price on carbon is about US\$0.74/tCO_2eq, far short of even the lower-end estimates of the social cost of carbon, which put the cost around US\$31 (Nordhaus, 2017). Meanwhile, world subsidies for the burning of fossil fuels total to about US\$493 billion per year (International Energy Agency, 2015).

2.3.1 Political Opposition

The main obstacle to the widespread implementation of carbon taxation in developed countries is politics. The first significant attempt to implement a carbon tax in the United States was as far back as 1992, when then-Senator Al Gore proposed one. His plan was met with immediate resistance even from within the Clinton administration which he soon joined as Vice President (Schneider, 1993) and the policy never materialized. Since then, carbon taxation has suffered a string of political setbacks even as the U.S. population has grown increasingly aware of the threat posed by climate change.

A more recent effort to implement a nationwide carbon price via a cap-and-trade system in the proposed Waxman-Markey bill in 2009 was passed in the House of Representatives, but was never taken up by the Senate, even as the Democratic Party held large majorities in both houses of Congress. The bill faced concerns that it would stifle economic growth during the height of the Great Recession and failed to get the support of crucial Democratic legislators from states with large fossil fuel sectors (Roberts, 2010). More recently, in 2016, voters in Washington state rejected a statewide ballot measure for a modest \$15/tCO_2eq carbon tax 59-40%, despite wide acceptance of climate science (70%) and support for policy solutions to reduce greenhouse gas emissions (78%) among voters in the state (Marlon et al., 2020b), as well as a personal push by the governor, Jay Inslee, who has made climate change a top priority in his administration. In 2019, Republican state legislators in Oregon staged a walk-out to deny quorum for the consideration of a cap-and-trade bill (Williams, 2019).

There is no shortage of reasons for political pushback against carbon taxation. For one, there is a small, but vocal contingent among the political right in the United States who are skeptical of or outright deny the scientific basis for anthropogenic climate change (Marlon et al., 2020a). And lobbying by the fossil fuel industry to prevent carbon pricing legislation and downplay the threat of climate change has played a role, although many energy companies, including oil companies like Shell and ExxonMobil, are increasingly supportive of carbon pricing as a way to manage regulatory risk (Evers-Hillstrom and Arke, 2019). But the main issue is that voters themselves are reluctant to pay higher prices for energy.

A carbon tax makes energy more expensive, which in turn raises the production cost of all goods and services produced with energy from carbon-emitting sources. Firms will attempt to pass this cost on to consumers, employees, and owners of capital in the form of higher prices, reduced wages or employment, and lost corporate profits. Furthermore, climate change is an intergenerational problem, where consumption by those alive today imposes costs on people who will be alive many years from now (Wunsch, Schmitt, and Baker, 2013). For an entirely self-interested, rational utility maximizer, it may in fact be in their interest to consume as much as possible, regardless of emissions, because they will not be alive to bear the costs. Convincing them to make sacrifices for future generations can be a tough political sell.

Another consistent concern with regard to carbon taxation is the distributional impact of incidence. Carbon taxes are commonly believed to be regressive taxes, because the incidence falls heavily upon consumer prices. Increased consumer prices disproportionately impact lower-earners, because these individuals tend to consume a higher proportion of their income (Murray and Rivers, 2015). This distributional concern leads to a common criticism of carbon taxation: that it is unfair and elitist (Redwood, 2019). My thesis explores and challenges the validity of this claim.

2.4 British Columbia's Carbon Tax

2.4.1 Overview

In July 2008, British Columbia implemented North America's first standalone carbon tax applied equally to all combustion sources of fossil fuels burned in the province (Harrison, 2013). By all indicators, the tax has been a success. Since its implementation, emissions in the province have been falling relative to the rest of Canada, with an estimated 9% overall reduction in greenhouse gas emissions (Elgie and McClay, 2013) driven by an 11-17% reduction in per capita gasoline demand (Rivers and Schaufele, 2012), and major reductions in natural gas demand (15% residential, 67% commercial) (Gulati and Gholami, 2015). The tax also had no significant negative impact on economic growth as critics had feared it would (Metcalf, 2019), and some of the reductions in income and corporate taxes that accompanied it may have even had a pro-growth effect (Murray and Rivers, 2015).

Several aspects of British Columbia's carbon tax make it ideal for a case study. First, BC's tax was implemented as a standalone carbon pricing policy, making it easier to isolate the economic and distributional effects. Many jurisdictions that tax carbon do so as part of a combination of policies like permit trading schemes and emissions standards that make it difficult to determine the effect of the carbon tax alone. Secondly, the BC tax was successfully implemented by a center-right government with no significant ties to the environmental movement and with the support of the province's business community (Murray and Rivers, 2015). Third, while the policy was initially unpopular, the tax now enjoys stable positive support among British Columbia voters, suggesting the BC experience may hold lessons for policymakers hoping to implement carbon pricing elsewhere, which thus far has proven to be a tough political sell (Murray and Rivers, 2015).

Like many carbon tax proposals, the decision by the BC government to tax carbon provoked significant public opposition. The "Axe the Tax" campaign, led by provincial legislators from rural communities in the north of the province, argued that the tax was unfair, because rural dwellers have higher heating costs owing to the colder climate and because they have fewer transit options to substitute gasoline consumption (Harrison and Peet, 2012). The prospect of higher gasoline prices further inflamed opposition beyond rural dwellers (Harrison, 2013).

To address these political issues, the government decided to combine its carbon tax proposal with a package of fiscal stimulus intended to make the tax "revenue-neutral." Revenue neutrality – sometimes referred to as revenue recycling – implies that for every dollar raised in revenue from the carbon tax, one dollar worth of revenue will be cut elsewhere in the tax code, whether by reducing other less efficient taxes or by simply returning the revenue as a cash rebate, sometimes referred to as a "dividend." Either way, the result is that the government has not raised any net revenue from the tax.

It should be noted that revenue neutrality is a political consideration, not an economic one, and does not affect the efficiency of the carbon tax itself, though some measures like cuts to distortionary taxes could potentially improve the efficiency of the tax code overall, resulting in a "double dividend" (Goulder, 2013). New proposals for carbon taxes increasingly insist upon revenue-neutrality as a way to make them politically palatable, like the Climate Leadership Council's proposed "carbon dividends" plan for a flat per capita cash rebate of revenues from a $40 carbon tax, whose authors point to British Columbia as an example of successful implementation (Schultz and Halstead, 2018). In practice, BC's carbon tax was not totally revenue neutral; the total budgetary offsets slightly exceed revenue raised from the tax, making it a small net stimulus (Metcalf, 2019).

British Columbia's carbon tax went into effect in 2008. The price was introduced at $10/ton, rising annually by $5 until it reached $30 in 2012, where it was frozen for seven years until it was raised to $40 in 2019 and is set to rise again to $50 in 2021 (Rhodes and Jaccard, 2013). The gradual implementation of the carbon tax was added to secure buy-in from the community, giving firms time to make long-term investments in carbon abatement before being hit by the tax (Murray and Rivers, 2015).

One important caveat to the British Columbia example is that the province uses very few fossil fuels in the production of electricity. About 95% of electricity produced in BC is done with renewable sources, predominantly hydropower, which are not subject to the carbon tax because they do not produce emissions. In jurisdictions with a greater proportion of fossil fuels in their electricity production mix, a carbon tax would result in significantly larger increases in the price of electricity. Evidence from British Columbia does not, therefore, provide a good example of the impact of a carbon tax on electricity prices. However, in other areas, such as heating and transportation, British Columbia provides a comparable example to other jurisdictions.

2.4.2 Growth and Distributional Impacts

As with many carbon tax proposals, criticism of the tax rested on two assertions: 1) that the tax would negatively impact economic growth and employment, and 2) that the tax is elitist and would be disproportionately borne by poor, rural, and working-class individuals to the benefit of wealthier urban and suburban people.

Growth and Employment There is little evidence to suggest that the carbon tax had a significant negative or positive impact on overall economic growth in the province. As Metcalf (2015) notes, this is not surprising, given that the carbon tax as a percent of total provincial revenues (5-6%) is very small.

The BC government's own review of the policy used a numerical modeling study to find a small negative impact on GDP growth in the province (British Columbia Ministry of Finance, 2013). However, this conclusion is not supported by subsequent studies using different methods. Metcalf (2019) compares relative growth rates before and after the tax was implemented with difference-in-difference regressions, finding no statistically-significant effect on the province's economic growth. His findings also suggest that the revenue-recycling measures may have helped offset any deleterious growth impact of the tax. Beck et al. (2015), who use a CGE model of the provincial economy to estimate effects of the tax, find that overall household welfare was reduced by about 0.08%. They also find that the revenue-recycling measures helped reduce this impact by 0.05% from 0.13%.

With regard to the effects on employment, the literature suggests that the effect of the carbon tax is industry-specific. Yamazaki (2017) uses a partial equilibrium demand model of the labor market, with labor demand as a function of the carbon tax, to estimate effects on employment and wages. He finds that emissions-intensive and trade-exposed sectors, such as basic chemical manufacturing, were negatively affected by the carbon tax. However, he finds that other sectors actually benefited from increased supply of labor as a result of the tax and that the net effect to labor supply was modestly positive. However, these jobs coincided with a decline in wages, suggesting the carbon tax led to the creation of more, lower-wage jobs.

Distributional Impact The idea that carbon taxes are "unfair" on distributional grounds is perhaps the most common criticism of the policy. This argument appears logical at first glance; lower-income individuals tend to consume a higher proportion of their income, so a tax that raises the cost of consumption will be borne disproportionately by lower-earners. However, it does not account for 1) general equilibrium effects on wages and capital earnings and 2) the revenue-recycling measures. In general, a tax is considered progressive if the total economic incidence is higher for households that are better-off, usually measured as income or consumption, and regressive if the opposite is true (Rosen and Gayer, 2014). A robust measure of progressivity or regressivity must account for all aspects of economic incidence, not just the cost of consumption.

Lee and Sanger (2008) use a static model assuming full pass-through of the tax to find that, while the carbon tax is progressive in the first year, as it rises over the subsequent years it becomes moderately regressive in its impact. They argue that, although the carbon tax rises with income, higher-earners pay less carbon tax as a proportion of their income, even though their carbon footprint is much larger. They also find that the revenue-recycling measures could help to deliver a progressive result, but the measures included in the BC policy package actually produce a regressive result, because the benefits of the income and corporate tax reductions fall disproportionately to the top income quintile.

However, their model does not account for general equilibrium effects to wages and capital, which tend to be progressively distributed and may even outweigh the regressive effects on the consumption side (Rausch et al., 2010).

Beck et al. (2015) use a computable general equilibrium model to analyze the distributional effects of the tax. Rather than assuming full pass-through of the tax, their CGE model distributes the tax burden at each step of the production structure based on the relative elasticities of supply and demand. With this method, they are able to account not just for consumption effects, but also the effects on factor prices. Their findings are twofold. First, even in the absence of revenue-recycling, the carbon tax itself is progressively distributed across income deciles. The progressive impact is driven by changes in factor prices, which disproportionately impact higher-earning households. Because, higher-earners derive a higher proportion of their income from wages and capital income, the decline in factor prices due to the tax affects them more than lower-earners. Lower-earning households, meanwhile, derive a greater proportion of their income from government transfers, which are relatively enhanced, because they are indexed to inflation. While the consumption-side impacts are indeed regressive, the distributional impact is driven overwhelmingly by households' source of income, not the destination of their expenditures. Secondly, they find that the revenue-recycling measures included in the tax package enhance the progressivity of the tax. The lump-sum "climate action dividend" in the first year of the tax is the main source of progressivity, while the wage income boost from the personal income tax cut is shared by all households. In fact, they find that lower-earning households tend to be net beneficiaries, not payers, from the tax shift.

3 Method

The goal of this paper is to determine how the burdens and benefits of different carbon tax policies are distributed across income groups using empirical evidence from British Columbia. To do so, I construct an input-output model of the British Columbia economy to analyze the incidence of the \$30/tCO_2eq carbon tax in the province. Combining estimates in consumer changes with household-level microdata on consumption and income, I calculate an estimate of total tax incidence for each household and analyze the distribution of those incidences under several different revenue rebate policies. The outline of my method is as follows.

First, I use the supply and use tables from the System of National Accounts to create an industry-by-industry matrix relating the values of inter-industry transactions for intermediate commodities. Then, I construct a second matrix describing the inputs for the production of final consumer goods, expressed as a portion of the total output. These two matrices allow me to "track" a change in the price of any input to its effect on consumer prices prior to any general equilibrium effects to factor prices.

Next, I estimate how much the price of any good is affected by the carbon tax by taking sectoral energy emissions data, multiplying it by the carbon price, and dividing it by the total output of that sector. I then apply that sectoral tax rate to each of the constituent industries in the national accounts to simulate a price increase. Using the transactions matrices, I am able to simulate a full pass-through of the tax to consumer prices. The result is a column vector describing the price change for each consumption category.

Third, I simulate general equilibrium effects to factor prices from the tax using the estimated macroeconomic effects from a computable general equilibrium model. Based on these estimates and holding nominal wages as the numéraire, I shift a portion of the tax burden from consumption prices to lost capital income to reflect the effect of the tax on factor prices. The result is a slightly reduced increase in consumption prices and an additional tax burden to each household based on their real capital income and real wages.

Fourth, I calculate the total tax burden for each household as the sum of their increased cost of consumption plus their lost capital income. The tax burden is denominated in dollars and does not include utility considerations. In order to make comparisons between income groups, I analyze incidence as a proportion of household income.

Finally, I simulate the revenue recycling under a variety of rebate scenarios and analyze how different revenue recycling policies affect the progressivity of the tax. The remainder of this section describes each step in greater detail.

3.1 Tax Incidence: Theory

A carbon tax is a tax that is levied on the burning of fossil fuels. The statutory remittance of the carbon tax typically occurs as far upstream in the production process as possible (Metcalf and Weisbach, 2009). Firms themselves are not capable of bearing taxes, because they are not themselves economic actors, but rather vehicles of economic activity by which capital and labor are combined to produce goods and services. The value of any tax that is levied upon a firm must therefore be passed on to capital, labor, or production in the form of reduced corporate profits, reduced wages/employment, and/or increased consumer prices respectively.

The incidence of a tax refers to how its economic effect is distributed among consumer prices, wages, and capital returns. Under Arrow-Debreu general equilibrium (with accompanying assumptions of perfect competition, convex preferences, and demand independence) (Arrow and Debreu, 1954), the distribution of incidence of a tax on any good/service is based on its respective relative price elasticities of supply and demand. If supply is elastic while demand is inelastic, the burden will borne in a larger proportion by reduction of consumer surplus and vice-versa. If supply and demand are equally elastic, the tax will be borne in equal proportion by both.

The economy-wide incidence effects of a tax can be estimated with a computable general equilibrium (CGE) model, which relates the production of all goods to the production of all other goods, along with labor and capital. Creating such a model is outside the scope of this paper, but the macroeconomic estimates from an already existing CGE model can be used to adjust the results of a simpler input-output incidence model to reflect general equilibrium effects.

3.2 Data

3.2.1 System of National Accounts

The System of National Accounts (SNA) is an economy-wide dataset that tracks production and inter-industry transactions among all sectors of the British Columbia provincial economy. It relates the value of production of all outputs by all industries in the economy to their use as inputs in the production of other outputs, as well as the gross value added to each industry and any final demand for each output (Statistics Canada, 2015).

The data is decomposed into a "Supply" table, which records the value of production of all goods by each industry, and a "Use" table, which records the value of those goods as inputs for production in each industry. The data are denominated in dollars (Canadian). Each datum is interpreted as the quantity of that good that can be purchased at that price.

The National Accounts operate on the principle that "what goes in must come out," such that inputs plus gross value added equal outputs plus final demand, with no loss in value from inefficiency.

The SNA data are collected annually according to the United Nations' international statistics standard for national accounts (United Nations Statistical Commission, 2008).

3.2.2 Survey of Household Spending

The Survey of Household Spending (SHS) collects detailed information about households' income sources and consumption of specific goods, as well as a number of demographic characteristics (Statistics Canada, 2017). It is similar to the Consumer Expenditure Survey in the United States. Data are collected annually in the 10 provinces via questionnaire by interviewing a sample of representative households. A more detailed expenditure diary is collected from selected households for a more detailed accounting of consumption of specific goods (Statistics Canada, 2018). For this study, I use only the interview data, which has a greater sample size while still reporting sufficiently specific consumption categories for an incidence analysis.

Each household that is surveyed acts as a "representative household" for a larger number of households with similar characteristics. Each one is assigned a sampling weight based on the number of households with very similar characteristics in the total population that it represents (Statistics Canada, 2018). For example, a household with a sampling weight of 1000 is treated for the purpose of analysis as 1000 households with those same characteristics. The sum of the sampling weights equals the total population in the model.

As with all surveys, the SHS is subject to sampling error. Particularly for the interview section, the data are subject to recall error. Some sampling bias may also be present. The data are also subject to some non-sampling error due to methods taken to protect the anonymity of respondents. For one, the data are top-coded to suppress households with very high values in certain categories (primarily income), which could allow them to be identified. As such, those data face an artificial upper-bound that may affect some outliers. The values are also subject to a small degree of random noise to further anonymize responses.

The interview and diary datasets are not compatible with each other and should be used together. While the diary data is more detailed and may be slightly more accurate, the exhaustive data collection method means that there are far fewer observational units. For this study, I choose to use the interview data exclusively, as my method does not require the level of detail on expenditures presented in the diary data, but does benefit from the greater number of observational units in the interview set. This is standard practice among researchers for similar analyses.

3.2.3 BC Emissions Inventory

The British Columbia emissions inventory records the annual release of greenhouse gases, disaggregated by energy sectors, industrial processes, agricultural sectors, waste sectors, and land use sectors. Only the emissions from the energy sectors are of interest to this study, as the carbon tax is levied on the burning of fuels, not on emissions from other greenhouse gas-emitting processes. Data on the emissions of different gases are reported both in CO_2 equivalents and in their own units. The data are collected in accordance with the United Nations Framework Convention on Climate Change (UNFCCC), which sets out reporting categories and methodologies for emissions estimates (British Columbia Ministry of Environment and Climate Change Strategy, 2019).

3.3 Impact of the Carbon Tax on Consumer Prices

In order to estimate the impact of the carbon price, I develop an input-output model of the British Columbian economy, based on the principles developed by Leontief (1986) and adapted for carbon tax analysis by Fullerton (1995) and extended in Metcalf (1999).

The model makes the following key assumptions: 1) goods are produced and sold in a perfectly competitive environment, so that all factor price increases are passed onto the consumer, 2) all domestic goods are assumed to have Armington properties and are sufficiently different from foreign goods that the price of domestic goods can change in response to changes in factor prices (Armington, 1969), and 3) input substitution is not possible as factor prices change. These are a standard set of assumptions for this type of model, which simplify the analysis (Metcalf, 1999).

3.3.1 Forming the Transactions Matrix

I begin with data from the 2015 System of National Accounts (SNA) Supply and Use tables for British Columbia, which report the inputs and outputs of each industry by each industry, as well as the final demand for those outputs and the gross value added in each sector.

The data are divided into a Supply matrix $M_{I\times C}$, which reports the goods C produced by industries I, and a Use matrix $U_{C\times I}$, which reports the usage of goods C in the production of industries I. I form a new industry-by-industry transaction matrix $S_{I\times I}$ by dividing each entry of $M_{I\times C}$ by its column sum and multiplying:

$$S_{I\times I} = M_{I\times C} \times U_{C\times I}$$

I then add another row and column for value-added and final demand respectively. In an economy with N industries, the result is a transaction matrix with the elements

$$S_{N\times N} = \begin{bmatrix} x_{11}p_1 & x_{12}p_1 & \dots & x_{1n}p1 & d_1p_1 \\ x_{21}p_2 & x_{22}p_2 & \dots & x_{2n}p2 & d_2p_2 \\ \dots & \dots & \dots & \dots & \dots \\ x_{n1}p_n & x_{n2}p_n & \dots & x_{nn}p_n & d_np_n \\ v_1 & v_2 & \dots & v_n & \end{bmatrix} \tag{1}$$

where x_{ij} represents the quantity of output from industry j demanded for production by industry i, p_i represents the price of outputs i, v_i represents value-added (wages and corporate profits) of the ith industry, and d_i represents final demand of output i. The prices are normalized to one such that x and d represent the quantity that can be bought for C$1.

The S-matrix is an Input-Output table, whereby the columns represent the input equations and the rows represent the outputs. The columns and rows for each industry must sum to the same value, such that inputs equal outputs plus value-added or final demand.[2] Adding across each row denotes the sum of demands for outputs i, and adding down each column denotes the sum of the value of outputs j.

[2]Each column sums to the total value of goods produced by each industry. Each row sums to the total value demanded from the outputs of each industry. Their sums must equal each other to satisfy the condition that inputs equal outputs.

3.3.2 Calculating Input Coefficients

Letting x_j equal the sum of demands in row j, I define a_{ij} as the input coefficient, representing the input of the ith good as a fraction of total output in industry j.

$$a_{ij} = \frac{x_{ij}}{x_j} \tag{2}$$

Where

$$x_j = \sum_{i=1}^{N} x_{ji} + d_j$$

The input coefficients are represented in matrix $A_{N\times N}$.

Since the sum of inputs equals outputs, the system of equations can be rewritten as:

$$\begin{aligned}
x_{11}p_1 + x_{21}p_2 + ... + x_{n1}p_n + v_1 &= x_1 p_1 \\
x_{12}p_1 + x_{22}p_2 + ... + x_{n2}p_n + v_2 &= x_2 p_2 \\
&... \\
x_{1n}p_1 + x_{2n}p_2 + ... + x_{nn}p_n + v_n &= x_n p_n
\end{aligned} \tag{3}$$

To find the input coefficients, each equation is divided by its respective total output and rearranged such that:

$$\begin{array}{ccccc}
(1-a_{11})p_1 & -a_{21}p_2 & -... & -a_{n1}p_n & = v_1/x_1 \\
-a_{12}p_1 & +(1-a_{22})p_2 & -... & -a_{n2}p_n & = v_2/x_2 \\
... & ... & ... & ... & ... \\
-a_{1n}p_1 & -a_{2n}p_2 & -... & +(1-a_{nn})p_n & = v_n/x_n
\end{array} \tag{4}$$

These equations can be represented with matrix algebra as:

$$(I - A')P = V \tag{5}$$

where

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} P = \begin{bmatrix} p_1 \\ p_2 \\ \dots \\ p_n \end{bmatrix} V = \begin{bmatrix} v_1/x_1 \\ n_2/x_2 \\ \dots \\ v_n/x_n \end{bmatrix}$$

and where $I_{N\times N}$ is the corresponding identity matrix. The equation is then rearranged to derive the price vector. Under the unit price convention, these prices are all normalized to 1 by construction.

$$P = (1 - A')^{-1}V \tag{6}$$

3.3.3 Estimating Tax Rates

The tax rate faced by each industry is equal to the required revenue (R_i) from that industry as a proportion of total output.

$$t_i = \frac{R_i}{\sum_{j=1}^{N} x_{ij}} \tag{7}$$

The carbon tax in British Columbia as of 2015 was \$30 per ton of CO_2 eq. According to the provincial budget and fiscal plan for the corresponding year the tax raised approximately \$1.24 billion in revenue (British Columbia Ministry of Finance, 2015). Specific data on the tax rates faced by each industry in the input-output accounts or the revenues raised from them do not exist, so it is necessary to estimate the per-industry tax rate based on data on sectoral emissions. I use data from the 2015 British Columbia Provincial Greenhouse Gas Emissions Inventory, which provides total emissions (kt $\mathrm{CO_2}$ eq) that year from 14 relevant sectors. The carbon tax in 2015 is \$30 per ton CO2 eq. For each sector with emissions m_i tons $\mathrm{CO_2}$ eq, the required revenue is calculated as

$$R_i = m_i \times \$30 \tag{8}$$

I then scale the revenue estimates so that the total revenues raised from all sectors equal the revenue reported in the provincial budget.[3]

To estimate this industry-by-industry distribution of the tax, I use data on the recorded emissions of 11 broad sectors. I exclusively group the industries in the System of National Accounts based on the best match with the sectors in the emissions data.[4] I then compute the required revenue (ρ_σ) for each sector by multiplying the reported emissions from those sectors times the carbon price, scaled to match the total revenues (\$1.24 bil) reported in the BC Budget

[3] See appendix A for breakdown of revenues

[4] For a breakdown of the sectoral categorization of each industry, see the appendix B

(British Columbia Ministry of Finance, 2015). I then calculate a tax rate for each sector (t_σ).

For each sector σ with constituent industries n of output x_n such that

$$X_\sigma = \sum_{\sigma=1}^{11} x_{n,\sigma} \tag{9}$$

The required revenue ρ_σ is exogenous to the calculation, so

$$t_\sigma = \frac{\rho_\sigma}{X_\sigma} \tag{10}$$

Rearranged

$$X_\sigma \times t_\sigma = \rho_\sigma$$

$$t_\sigma(x_{1,\sigma} + x_{2,\sigma} + ... + x_{n,\sigma}) = \rho_\sigma$$

So, by the distributive property, the tax rate for any output x of industry n in sector σ is the sectoral tax rate t_σ.

3.3.4 Applying the Tax Rates

The tax rates calculated in equation (10) can be applied to equation (6) to estimate the effect of the carbon tax on the prices of the outputs of each industry. Each intermediate input has its own tax rate t_n, so equation (3) can be expressed as:

$$\begin{aligned} x_{11}p_1(1+t_1) + x_{21}p_2(1+t_2) + ... + x_{n1}p_n(1+t_n) + v_1 &= x_1p_1 \\ x_{12}p_1(1+t_1) + x_{22}p_2(1+t_2) + ... + x_{n2}p_n(1+t_n) + v_2 &= x_2p_2 \\ &... \\ x_{1n}p_1(1+t_1) + x_{2n}p_2(1+t_2) + ... + x_{nn}p_n(1+t_n) + v_n &= x_np_n \end{aligned} \tag{11}$$

Equation (11) can be written in matrix using the same steps used to derive equation (6), such that:

$$P^* = (1 - A'T)^{-1}V \tag{12}$$

where

$$T_{N\times N} = \begin{bmatrix} 1+t_1 & 1+t_1 & ... & 1+t_1 \\ 1+t_2 & 1+t_2 & ... & 1+t_2 \\ ... & ... & ... & ... \\ 1+t_n & 1+t_n & ... & 1+t_n \end{bmatrix}$$

The result is a price vector $P_{N\times1}$, which gives the new price p_n^* of each industry's output. The effect of tax on the price is $p_n^* - 1$.

3.3.5 Transformation to Consumer Prices

The new prices calclulated with equation (12) are intermediate outputs that are not consumed by households. These price changes must be transformed to consumer prices for distributional analysis.

To transform these prices, I use the transformation matrix $Zed_{N\times M}$ from the input-output accounts, which reports the use of outputs from N industries in the production of M consumer goods. Dividing each element by its column sum[5] gives the matrix $Z_{N\times M}$ with elements z_{nm}, which reports what share of the output for good m is derived from intermediate industry n. The columns of Z each sum to 1.

I then use the Z-table to to calculate the $M \times 1$ vector of consumer prices P_c for $M = 100$ consumption categories, whereby

$$P_c = Z'P^* \tag{13}$$

The effect of the change in price of any intermediate good n on the consumer good m is directly proportional to how much of input n is used in the production of m. In the resulting column vector P_c, the effect of the tax on the price of any good is $p_{c,m} - 1$ (where $p_{c,m}$ is the new price for good (row) m, an element of the vector P_c).

3.4 General Equilibrium Effects

The method thus far has assumed that the carbon tax will be fully passed forward to consumers in the form of higher prices. However, in a general equilibrium setting, part of the tax will be passed onto wages paid to workers and capital returns to shareholders, which will in turn reduce the wage and investment income of households (Horowitz et al., 2017).

To estimate the per household general equilibrium factor effects, I use macroeconomic impact estimates from Okagawa and Ban (2008), who use a computed general equilibrium model to estimate the effects on consumer prices, wages, and capital returns as a result of a carbon tax.

The real impact of changes to wages, capital returns, and the price level are all measured relative to each other, so one of these must be normalized to zero and held as the numéraire (Goulder and Hafstead, 2017). The effects of the

[5]Each column sums to the total output of consumer good m

other two are then measured relative to that numéraire. For this method, I choose to hold wages constant, though, in principle, it does not matter which is used.

I begin by calculating the difference between the percent change in real wage (w/p) and in real capital returns (r/p). Because nominal wages are held as the numéraire and the change in price level is the same for both, the difference in percent change to wages and capital returns is the net effect to capital income. I then calculate Φ, which is the amount total tax revenues collected from capital returns.

$$\Phi = \theta * K \tag{14}$$

where

$$\theta = \frac{\bar{w}}{\bar{p}} - \frac{\bar{k}}{\bar{p}}$$

and where $\bar{w}$ is the percent change in average wages, $\bar{k}$ is the percent change in average capital returns, and $\bar{p}$ is the percent change in the consumer price level as calculated in the CGE model. K is the sum of the capital income for all households. By construction, θ is the percent change in nominal capital income $\bar{k}$. Since nominal wages are held as the numéraire and price changes are the same for both terms, then by construction

$$\theta = \bar{k} = \%\Delta K$$

The required revenue R is still the same as before, but part of that revenue now takes the form of lost capital returns rather than higher consumption prices. The amount of revenue raised from higher consumption prices is now equal to $R_c = R - \Phi$. As a result, the changes in consumer prices calculated in (13) must be slightly reduced such that this condition holds. The new change in price $\hat{p}_m$ (the "new new" price) is the original price change scaled down according by the proportion of revenue shifted to capital returns. Each element of P_c is reduced, such that:

$$\hat{p}_m = (p_m - 1) * \frac{R - \Phi}{R} + 1 \tag{15}$$

In effect, the new consumer prices are scaled down to reflect that a portion of the tax burden takes the form of lost capital returns. This returns an adjusted P_c vector[6] that can be used to calculate the tax incidences of individual households.

[6]For list of consumer price changes, see appendix C

3.5 Calculating Individual Household Tax Incidence

I begin with data from the 2015 Survey of Household Spending (SHS) for British Columbia, which records the income (including decomposition into wages, capital returns, transfers, and "other" sources) and consumption for a sample of 1426 weighted representative households, along with other characteristics. Each representative household has a corresponding sampling weight W. To ensure concordance between datasets, the weighted income and consumption data in the SHS are scaled to match the aggregates in the SNA.

Each household consumes a combination of natural gas (g), gasoline (f), electricity (e), transportation (r), and a basket of all "other" goods (o). For the purposes of this section, I will refer to g, f, e, and r as the "specified" goods and all goods in basket o as the "other" goods.

Upon the imposition of the carbon tax, the price of each specified good increases by $t_m = p_m^* - 1$. The price of the other goods basket is determined as a residual from the remaining revenue based on the total consumption of that basket C_o. $\hat{R}$ denotes the total revenue from tax effects on the "other" goods and $R_c = R - \Phi$ denotes the total revenue from the tax effect on the prices of all consumer goods (the total consumption-side revenue)

$$P_o = 1 + \frac{\hat{R}}{C_o - \hat{R}} \tag{16}$$

where

$$\hat{R} = R_c - \sum_{h=1}^{1426}((g\frac{t_g}{t_g+1} + f\frac{t_f}{t_f+1} + e\frac{t_e}{t_e+1} + r\frac{r_g}{r_g+1}) * W_h)$$

For each representative household h I then calculate total tax incidence from consumption costs ψ_c, such that

$$\psi_{c,h} = g\frac{t_g}{t_g+1} + f\frac{t_f}{t_f+1} + e\frac{t_e}{t_e+1} + r\frac{r_g}{r_g+1} + o\frac{t_o}{t_o+1} \tag{17}$$

where

$$\Psi_c = \sum_{h=1}^{1426}(\psi_{c,h} * W_h) = R_c$$

The variable $\psi_{c,h}$ denotes the total consumption-side tax incidence for each unweighted representative household h, while Ψ_c is the total consumption-side incidence for all weighted households combined. To get the full final incidence for each unweighted representative household, the tax burden from lost capital returns ($\psi_{k,h}$) must also be tacked on:

$$\psi_{k,h} = k_h * \theta \tag{18}$$

where the total combined incidence on the capital side

$$\Psi_k = \sum_{h=1}^{1426} (\psi_{k,h} * W_h) = \Phi$$

So,

$$\psi_h = \psi_{c,h} + \psi_{k,h} \tag{19}$$

ψ_h is a dollar value of tax incidence faced by each unweighted representative household h. As a final check on the method, the following condition should be satisfied:

$$\Psi = \Psi_c + \Psi_k = R$$

If this condition is met, then the total revenues raised from the tax equal the total burden to households, indicating that all the tax revenues are accounted for in household incidence. It should be noted that this methodology has not considered the use of the revenues raised from the tax. The revenue use will be considered as part of the analysis.

4 Results and Analysis

In the distributional analysis, I analyze the different incidence scenarios from three perspectives: 1) the inter-decile distribution of mean incidence for each income decile, 2) the number of households in each decile who are net beneficiaries from the tax (i.e. they receive more in rebates than they pay in tax), and 3) the heterogeneity of incidence within each income decile. The first two provide a measure the vertical equity of the tax (whether wealthier people pay more tax), while the third provides a measure of horizontal equity (whether there are significant disparities in income for households in the same income group).

Vertical equity is a standard consideration in distributional analyses. In general, a tax can be considered progressive when its economic incidence rises with the propensity to bear it. In the context of this paper, I consider a tax to be progressive if its incidence as a proportion of household income is positively correlated with total household income and regressive if that correlation is negative. This is the standard definition used for incidence analyses (Rosen and Gayer, 2014).

Horizontal equity is less typically analyzed, but in the case of a carbon tax, it may help explain why some groups might oppose a carbon tax even if the impact is vertically progressive. Looking at vertical equity alone only tells part of the distributional story. If households with certain characteristics (ex: the unemployed) are particularly hard-hit by the tax, they might oppose the policy, even if their income group is, on average, better off because of the tax, because they are not the average for their income group. These findings would have implications for policy design if, for example, securing buy-in from certain groups is necessary for building a pro-carbon tax political coalition.

When dividing the households into deciles, I drop those households in the bottom of half of the first decile from the analysis. The reason for this adjustment is that collecting accurate data on households at the very bottom of the income distribution (for example, the homeless) tends to be difficult. Thus, Pechman (1985) advises dropping them from the analysis entirely.

Furthermore, using annual household income for the incidence analysis as a proxy for well-being poses some limitations. In particular, Poterba (1989) argues that annual household income may not truly reflect well-being if it not a good measure of lifetime income, as it may not be for some households. For example, a household headed by a young adult who is not yet established in their career, but has good long-term earnings prospects, may have a low household income even though they are not really "poor." Similarly, a household headed by a retiree or a temporarily unemployed person may have low income, but sufficient savings to sustain consumption greater than income. Thus, he advises using household expenditure, rather than income, as a proxy for well-being. I account for this lifetime income issue in the heterogeneity analysis with a dummy variable for head of household aged 40-65, with the assumption that people in their peak earning years will likely have annual income that is reflective of their lifetime income potential.

4.1 Scenario 1: No Use of Revenues

In this scenario, I estimate the incidence of the carbon tax in the absence of any use of the revenue, either for a rebate or for government spending. The use of revenues is ignored. This scenario not realistic, but the results demonstrate the decomposed incidence of the tax, which is later adjusted based on how the revenue is returned.

4.1.1 Inter-Decile Distribution

Figure 1 depicts the distribution of incidences within each income decile. Overall, there appears to be a slight upward trend in proportional incidence as income rises, but I cannot statistically reject that there is no overall income trend in the incidence. This finding suggests that, while the tax may be slightly progressive, it is at the very least proportional with regard to income.

However, when decomposing the effect in estimates 2 and 3 in table 1, I do find significant trends on the income and consumption sides of the tax incidence. The "source-side" effects refer to the tax incidence that is borne in the form of lost income from decreased factor prices (lower wages and capital returns). It is the variable $\psi_{k,h}$ from equation 18, as a percentage of income. The "use-side" effects, meanwhile, refer to the tax incidence that is borne in the form

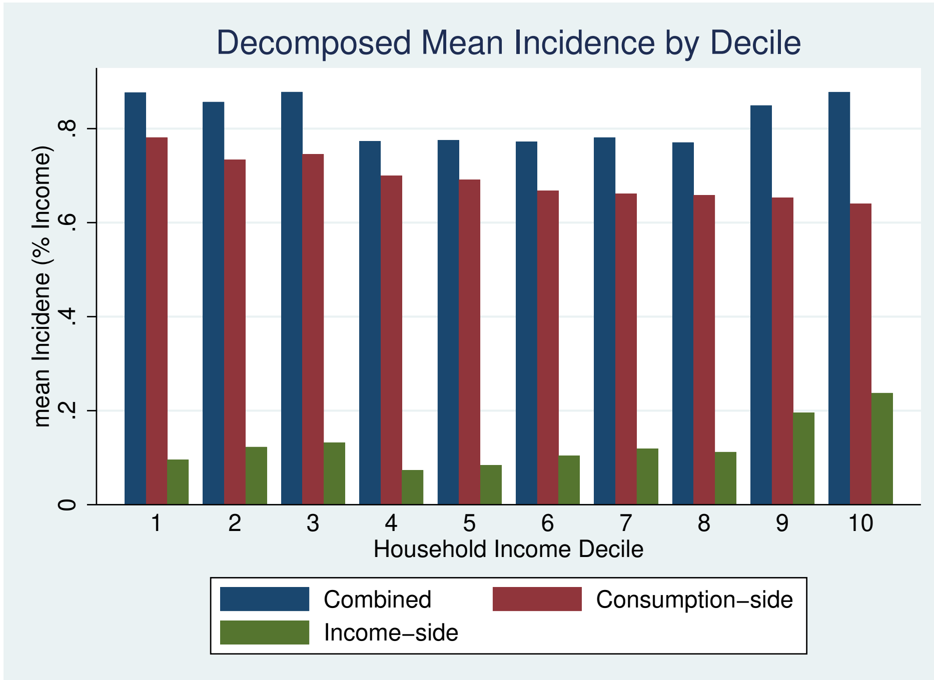

Figure 1: Mean per-household incidence for each income decile with no rebate of revenues. Blue denotes total incidence (combined income and consumption effects), while red denotes the share of incidence attributable to higher consumption prices (the use-side) and green denotes the share attributable to reduced factor prices (source-side).

of higher prices of consumption. It is the variable $\psi_{c,h}$ from equation 17, as a percentage of income. The result is that the decomposed tax is regressive on the use side and progressive on the source side.

To statistically confirm this result, I run three simple regressions of total incidence, use side incidence, and source side incidence respectively on household income deciles D.

$$\psi_h = \alpha + \beta_1 D_h + \varepsilon$$

$$\psi_{c,h} = \alpha + \beta_1 D_h + \varepsilon$$

$$\psi_{k,h} = \alpha + \beta_1 D_h + \varepsilon$$

Regression estimates in table 1 show no statistically-significant income trend in total tax incidence before the revenues are rebated. However, when analyzing the decomposed use- and source-sides of incidence, some trends do emerge. There is a statistically-significant progressive trend in incidence (positive β_1) for source-side impacts alone, whereas there is a statistically-significant regressive trend for use-side impacts. In other words, the effects to income from the tax are progressive, while the effects to consumption are regressive. This result accords with the findings in

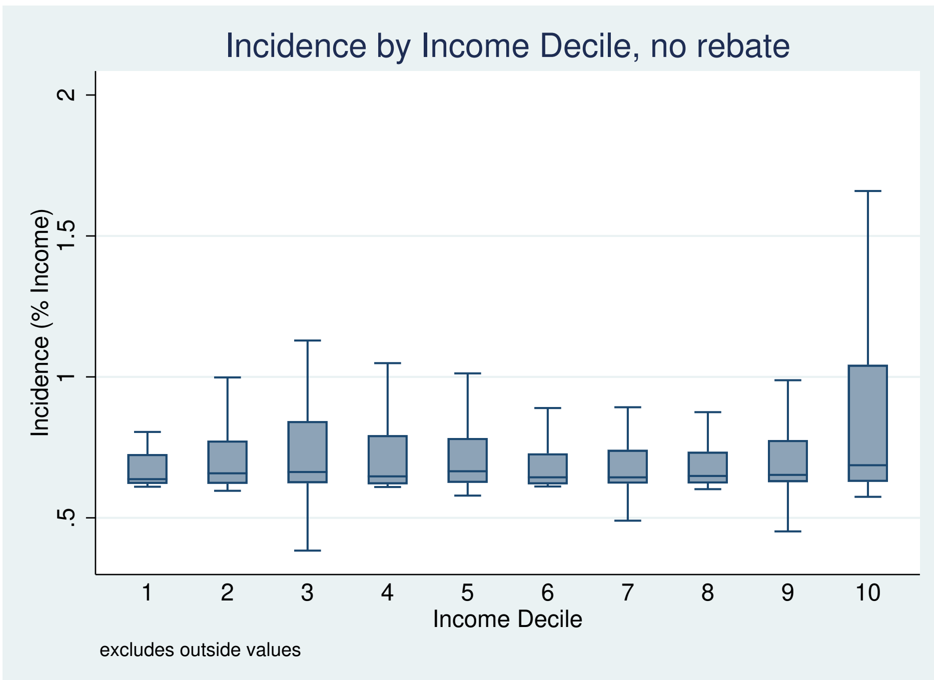

Figure 2: Distribution of percentage incidences ignoring use of revenue. The box shows the distribution from the first to third quartile, with the bar in the box representing the median. The protruding "whiskers" denote the highest and lowest non-outlier observations outside of the first to third quartile range. A more compressed plot denotes a more homogeneous distribution of incidence.

Goulder et al. (2019) in their simulation of a carbon tax in the United States, who also find progressive source-side and regressive use-side effects.

Table 1: Decomposed Incidence (No Rebate)

	(1)	(2)	(3)
	Total Incidence	Use-Side Incidence	Source-Side Incidence
Income Decile	-0.00136	-0.0137***	0.0123***
	(-0.31)	(-4.48)	(3.90)
Constant	0.827***	0.768***	0.0597**
	(29.10)	(38.82)	(2.92)
Observations	1362	1362	1362

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.1.2 Intra-Decile Heterogeneity

Analyzing the trend in incidence between deciles offers an indication of the implications of the tax for vertical equity. Indeed, vertical equity is the most commonly measured outcome in distributional analysis. However, horizontal equity – the distribution of the tax among households in the same income group – may also be of interest to policymakers. Horizonal inequities, such as disparities in impact between urban and rural dwellers, may contribute to political cleavages in a way that is overlooked in a vertical distributional analysis.

Heterogeneity within income deciles, as quantified by the standard deviation of incidence, offers an indication of the horizontal distributional implication of the tax (Cronin, Fullerton, and Sexton, 2019). In order to make comparisons between deciles, I divide the standard deviation by the median income for each decile. In general, less intra-decile heterogeneity (smaller standard deviation) suggests the policy is more horizontally equitable, because it indicates that the tax impacts everyone in the same vertical (income) group more or less the same.

As is apparent from the plot in figure 2, there is considerable heterogeneity within deciles of proportional tax incidence. In the figure 3, I quantify this heterogeneity as the standard deviation divided by the median income of each decile to contextualize the measure across deciles.

The result is a downward-sloping trend, with greater heterogeneity among the lowest deciles. The bottom three deciles in particular exhibit a relatively high degree of heterogeneity in incidence. Decomposing the incidence to income- and consumption-side effects shows a notable trend: whereas consumption-side heterogeneity is larger in the first four deciles, in the upper six deciles the income-side heterogeneity outweighs it. The difference between the two decreases as income rises and then begins increasing again after the middle deciles.

Of course, this scenario is only half of the story, as the revenue from any carbon tax would be used in some way,

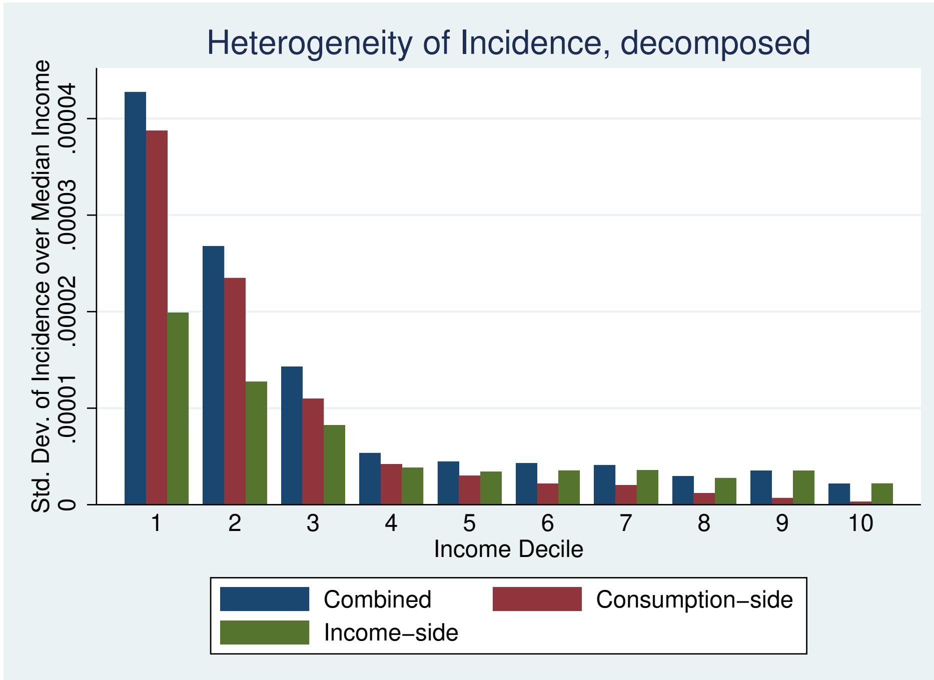

Figure 3: Standard deviation of incidence among household income deciles divided by median household income per decile. Heterogeneity shows a downward-sloping trend, with the greatest heterogeneity in the bottom three deciles and fairly even among the rest.

whether recycled as in British Columbia or spent on green public spending projects as in other jurisdictions. Nonetheless, this decomposed impact offers a good foundation to analyze how the revenue use can change the distributional impact of the tax.

4.2 Scenario 2: Equal Per-Household Rebate

In this scenario, I estimate the incidence of the carbon tax with an equal per-household rebate of the revenues. The rebate is calculated as the sum of the revenues divided by the sum of the sampling weights, which represent the total number of households in the model.

4.2.1 Inter-Decile Distribution

Figure 4 depicts the distribution of mean household incidences in each decile. Overall, I find a positive, statistically-significant relationship between household income deciles and percentage incidence, which is consistent with a progressive tax. The tax burden as a percent of household income increases at a decreasing rate as income rises.

Furthermore, under this scenario with the rebate, the majority (approximately 62%) of households are financially better-off or no worse-off than they were before the tax was imposed. That is to say that their net burden as a percent

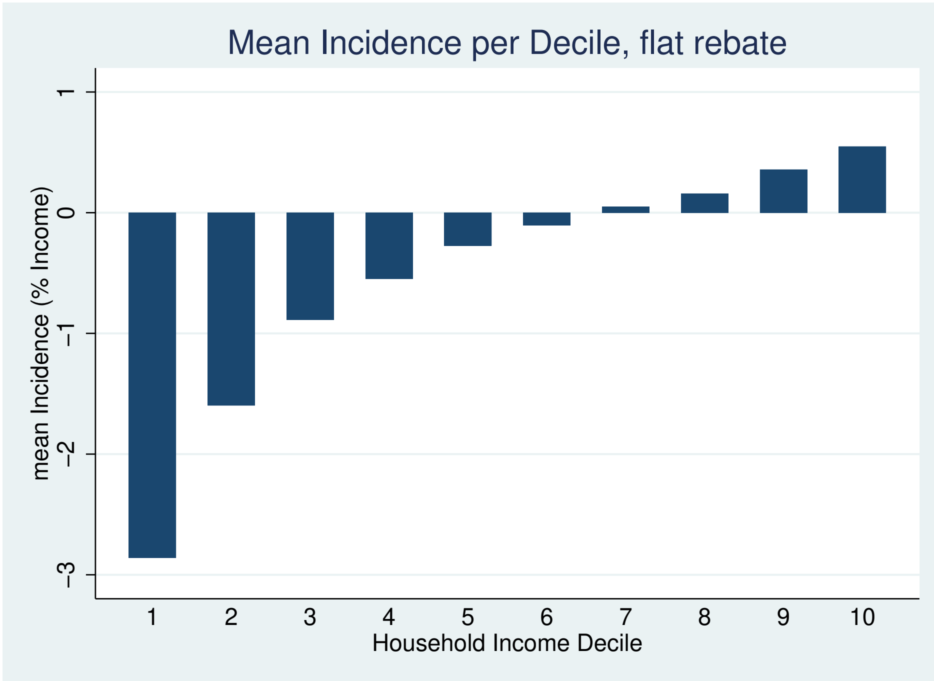

Figure 4: Mean per-household incidence for each income decile under a flat per-household rebate. Negative incidence denotes net financial gain from tax and rebate scheme.

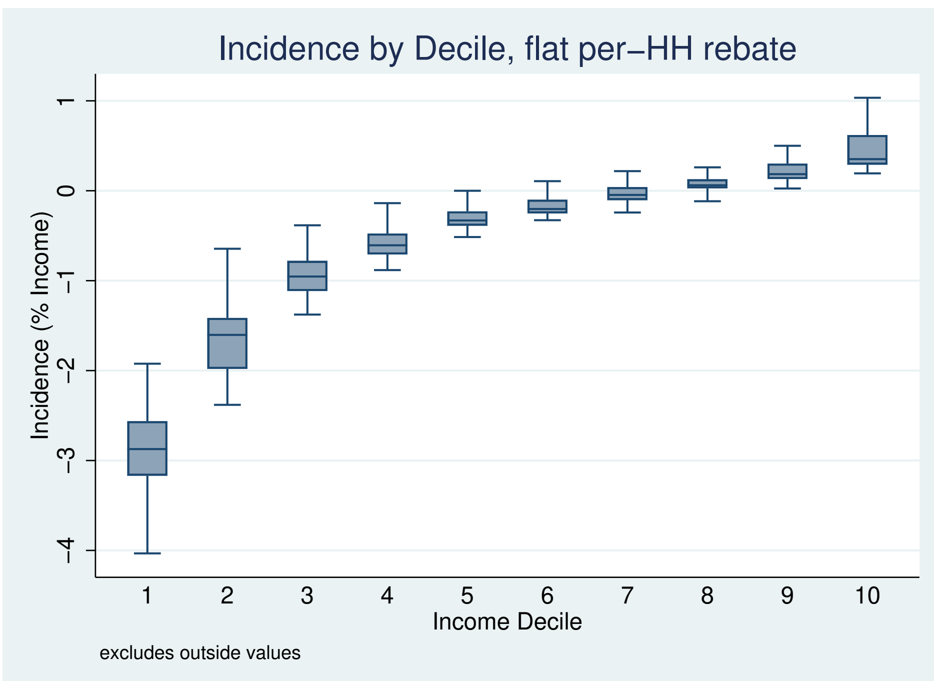

Figure 5: Distribution of percentage incidences within deciles given a $644.77 rebate. Each point represents a weighted representative household. Approx. 62% of households pay net zero or negative tax.

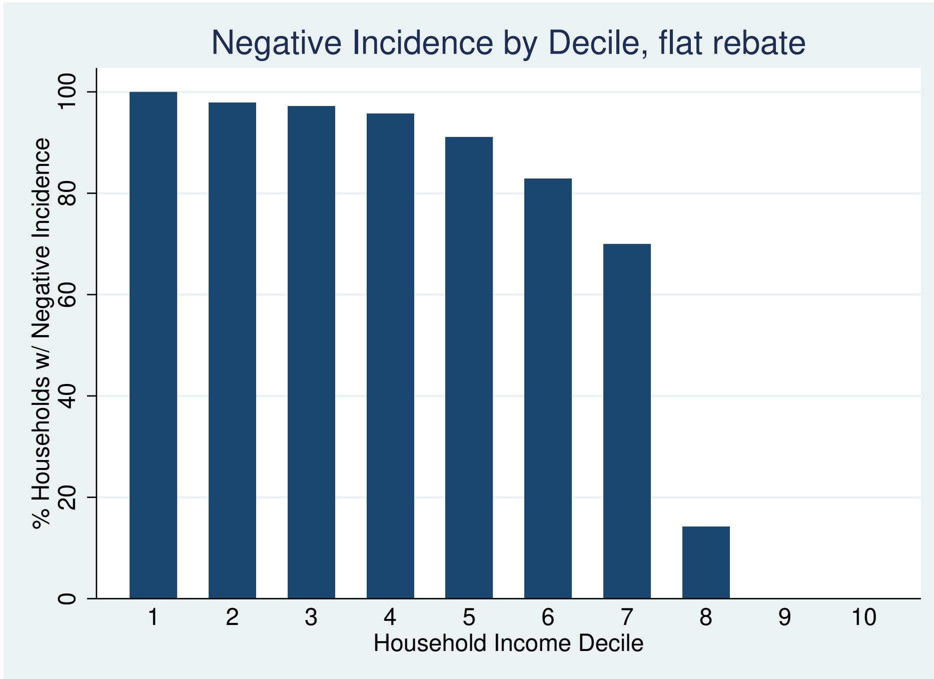

Figure 6: Percentage of households in each decile with net negative tax incidence. Almost all households in the bottom half of the income distribution are net winners from the tax.

of income was zero or negative. This adds an additional element of progressivity to the overall tax code by easing not just the carbon tax burden, but the overall tax burden faced by lower-earning households. Figure 6 shows that nearly every household in the first five deciles are net winners from the tax. The households that are net payers of the carbon tax tend to be among the top 30% percent of earners.

Regression analysis also shows that the tax is progressive even when controlling for capital income as a proportion of total income. Whereas in the pre-revenue scenario, capital income distribution was the main driver of progressivity, in this case the policy is progressive even when ignoring the impact of the capital income distribution.

Regression analysis in table 2 shows that the progressive trend is statistically-significant with respect to income, even when decomposing the source- and use-side effects of the tax. Whereas previously the tax was only progressive on the income side, with the flat rebate the tax is progressive on both sides.

4.2.2 Intra-Decile Heterogeneity

To quantify heterogeneity of impact among each decile, I present the standard deviation of the incidence divided by the median household income for that decile, shown in figure 7. The standard deviation is a typical measure of dispersion. Dividing it by the median household income allows for comparisons between income groups. The result is very similar

Table 2: Flat Rebate

	(1)	(2)	(3)
	Mean Incidence	Mean Incidence	Mean Incidence
Income Decile	0.277***	0.276***	0.264***
	(55.65)	(55.08)	(67.68)
Source-side		-0.0685	
		(-1.56)	
Use-side			0.980***
			(29.42)
Constant	-1.979***	-1.927***	-2.038***
	(-61.65)	(-41.36)	(-80.93)
N	1362	1362	1362

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

the result before the rebate, with a downward-sloping trend in heterogeneity. The largest level of heterogeneity occurs at the first three deciles, leveling out toward the middle of the income distribution.

To more closely analyze sources of heterogeneity within deciles, I regress household incidence as a percentage of income against 12 new variables that express certain household demographic characteristics. In addition to a numerical measure of household size, I include 11 dummy variables. Each dummy variable equals 1 if the following are true, respectively: the head of household is in their peak earning years (aged 40-65); there are elderly individuals in the household; there are multiple full-time earners in the household; the head of household is unemployed; the head of household has at least a bachelor's degree; the head of household works full-time; there are children in the household; the household owns their home; the household owns at least one vehicle; the household owns a recreational vehicle; and the household is dependent on government transfers as their primary source of income. These are all variables which would be expected to be correlated with household income, energy use, or both. I then run a second regression to include income decile fixed effects to focus attention on variation within the deciles. The results of these regressions are presented in table 3.

In addition to household income, nine characteristics are conclusively correlated with incidence: household size, the presence of multiple full-time earners, the presence of elderly people, whether the head of household is unemployed, whether the head of household works full-time, the presence of minors, home ownership, vehicle ownership, and dependence on transfers.

The positive coefficient for household size is an intuitive result. Households with more members will have more people consuming energy-intensive goods which are subject to the tax, even if there are some household-level economies of scale (Nelson, 1988), and if multiple household members have income, the total household loss in in-

Table 3: Correlates of Incidence, Flat Rebate

	(1) Incidence	(2) Incidence
HH Size	0.277***	0.00884
	(10.04)	(0.56)
Aged 40-65	0.0945*	0.0381
	(2.42)	(1.79)
Multiple Earners	0.0585	-0.0971**
	(1.00)	(-2.95)
Elderly	0.297***	0.0795**
	(5.51)	(2.67)
Unemployed	0.0793	0.142***
	(1.44)	(4.74)
College	0.192***	0.0666**
	(5.03)	(3.15)
Work Full Time	0.227***	-0.00322
	(4.47)	(-0.11)
Has Children	-0.272***	-0.0214
	(-4.27)	(-0.61)
Owns Home	0.423***	0.143***
	(9.50)	(5.78)
Owns Vehicle	0.337***	0.0560
	(5.22)	(1.58)
Owns Rec Vehicle	0.107*	0.00653
	(2.28)	(0.26)
Depends on Transfers	-1.182***	-0.170***
	(-19.67)	(-4.45)
Dec2		1.229***
		(22.34)
Dec3		1.908***
		(33.52)
Dec4		2.235***
		(37.78)
Dec5		2.486***
		(40.26)
Dec6		2.662***
		(42.59)
Dec7		2.788***
		(44.59)
Dec8		2.954***
		(46.79)
Dec9		3.115***
		(47.63)
Dec10		3.313***
		(50.91)
Constant	-1.733***	-3.024***
	(-20.64)	(-49.67)
Observations	1362	1362

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

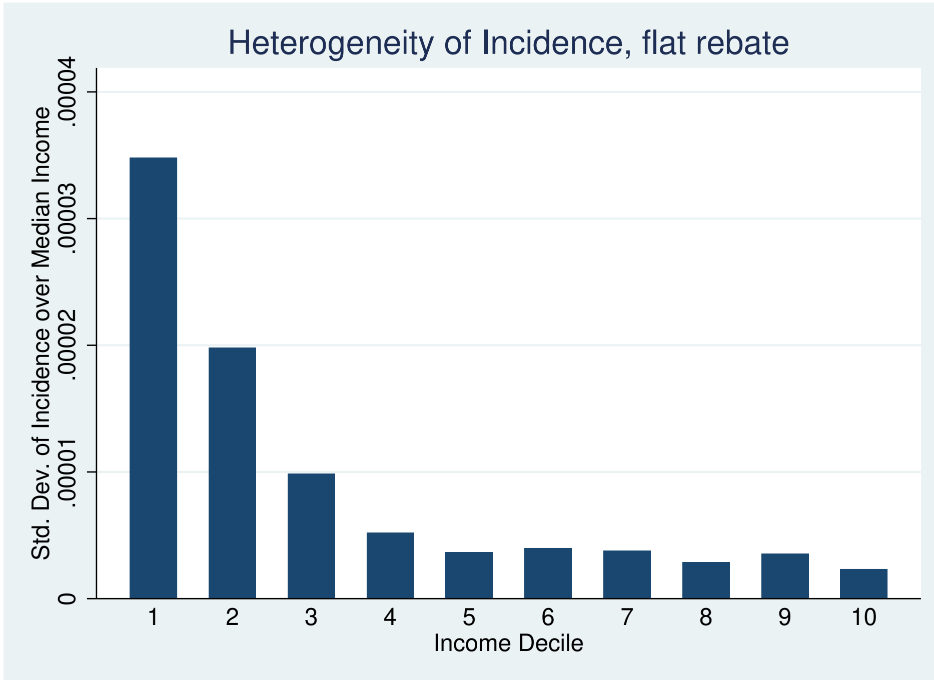

Figure 7: Standard deviation of incidence divided by median income per decile . Heterogeneity of impact is greater at the lower end of the income spectrum.

come from the tax will also be higher. The rebate is a flat check given on a per-household, not per-capita, basis, so the net rebate per-member is smaller for households with more members. Thus, households with more members will, on average, have a larger net tax burden than smaller ones. However, the addition of income decile fixed effects eliminates household size as a significant correlate.

The presence of multiple-earners has a negative coefficient, meaning that households with more than one full-time earner will, on average, have a smaller net tax burden. Since incidence is measured as a percentage of household income, households with multiple full-time earners will likely have significantly higher household income, so the denominator of the dependent variable will be larger. Thus, they will pay less tax as a percentage of income.

The positive coefficient for presence of elderly likely operates on a similar, but opposite mechanism. Elderly people are less likely to have income, but still consume goods subject to the tax. Households with elderly members will thus tend to consume more and so pay more tax relative to their income. It is possible that the variable is picking up lifetime income effects. Their higher incidence may reflect that their lifetime income is higher than their current consumption, because they are no longer in their working years.

For unemployed, the regression coefficient is positive, suggesting households with an unemployed head tend to pay more tax on average under this scheme. These households are likely to have much lower income, so the denominator for proportional incidence is smaller. However, a positive regression coefficient for unemployed does not necessarily imply a regressive impact, as an unemployed individual may only be temporarily out of work. Under Friedman (1957)'s permanent income hypothesis, a temporarily unemployed person will not significantly reduce their consumption while between jobs, because their lifetime income is much higher.

Households headed by a full-time employee, meanwhile, also tend to pay more tax on average, likely because of the source-side effects to their income from the carbon tax. However, this variable is not statistically significant (and actually becomes negative) when income decile fixed effects are added.

The presence of children, meanwhile, is correlated with a lower than average tax burden. Adding income decile fixed effects, however, eliminates this variable as a statistically significant correlate.

Households that own their home, rather than renting, also tend to pay more tax, because they are more likely to have to pay for utilities like electricity and heating as well as maintenance for their home. Renters might have some of these expenses covered by their landlord. Similarly, those that own a vehicle for personal transportation tend to pay more tax, because gasoline becomes more expensive, although this variable is eliminated with fixed effects.

Dependence on transfers, meanwhile, is correlated with lower than average tax burden. And although the coefficient becomes much smaller (in absolute value) with the addition of fixed effects, it remains a statistically-significant correlate. Households that depend on transfers as their largest income source are likely to have a smaller than average source-side burden from the carbon tax, because real transfer income is unaffected by the carbon tax.

Although the age of the head of household dummy variable loses significance with the addition of income fixed effects, the college education dummy remains significant. Education is potential proxy for lifetime income effects. The positive coefficient suggests that people with higher lifetime income potential pay more tax – a progressive result.

Overall, the flat rebate scheme produces mixed progressivity within income groups. The coefficients for college education, homeownership, and dependence on transfers are a progressive result, whereby those who are better off pay more and the opposite. However, the effects of elderly, unemployed, full time work, and multiple earners is slightly regressive. Furthermore, the decile fixed effects confirm the inter-decile distributional result, with households in higher deciles generally paying more tax.

4.3 Scenario 3: Capital-Based Rebate

One aspect of the British Columbia rebate package (and one that is sometimes floated as a revenue-recycling option) is to offset part of the revenues as a reduction in corporate taxes. In this scenario, I simulate a rebate of the revenues back to households according to their capital income as a rough estimate of the effect of a corporate tax cut on the progressivity of the policy. I assume for the purposes of this model that the tax cut is passed on entirely to owners of

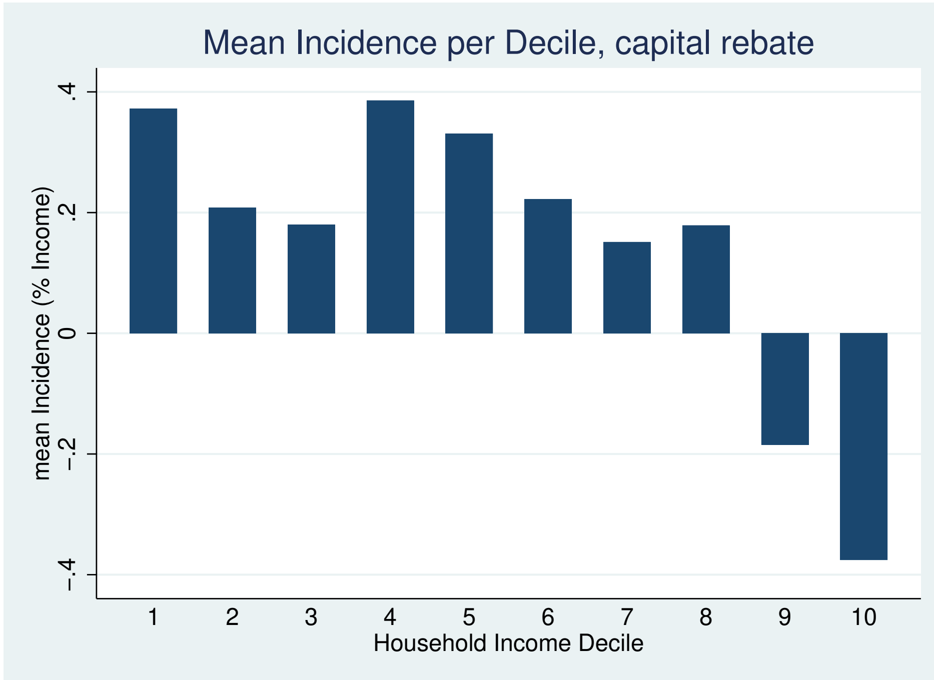

Figure 8: Mean per-household incidence for each income decile under a capital-based rebate. Negative incidence denotes net financial gain from tax and rebate scheme.

capital, though in reality there would likely be some general equilibrium effects to wages and prices as well.

Each representative household h with a capital income k and sampling weight W_h receives a rebate R_k such that:

$$R_{k,W,h} = \$1,240,000,000 \times \frac{k_h \times W}{\sum (k_h * W_h)} \tag{20}$$

$$R_{k,h} = R_{k,W,h} / W_h \tag{21}$$

The result is that the rebate is distributed based on what proportion of the total capital income goes to each household. For example, a household that collects 1% of the capital income in the economy would receive 1% of the total rebate.

4.3.1 Inter-Decile Distribution

Figure 8 shows the results of the simulation.

The result of this capital-based rebate is moderately regressive. Households in lower income deciles tend to pay more net tax than upper earners. Furthermore, while lower-earning households tend to be net tax payers, households in the top two deciles come out on average financially better off than they were before the tax. This regressive result is confirmed by regression analysis, with which I find a statistically-significant negative trend in incidence, with the

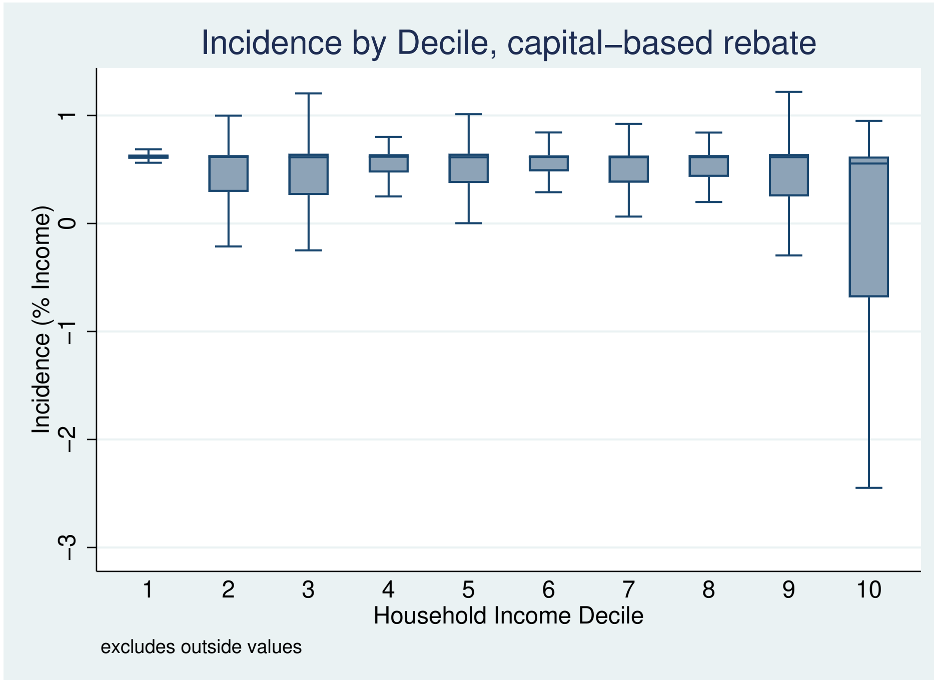

Figure 9: Per-household incidence by decile under a capital-based rebate. Net positive rebates accrue predominantly to households in the top two income deciles.

proportional tax burden falling as income rises.

Table 4: Capital Income-based Rebate

	(1) Incidence
Income Decile	-0.0665***
	(-4.80)
Constant	0.512***
	(5.72)
Observations	1362

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Furthermore, the number of "winners" from the tax (households with a net zero or negative tax incidence) is much lower than the previous scenario. Only 18% of households fit this category, compared to 62% in scenario 2. Figure 10 shows the distribution of net financial beneficiaries per decile. There is a clear upward trend in the results, showing that the net winners from the policy tend to be wealthier households. This result is not necessarily surprising, given that roughly 45% of the representative households have zero or negative capital income.

Overall, this rebate policy does not appear to enhance the progressivity of the carbon tax, but rather makes it worse,

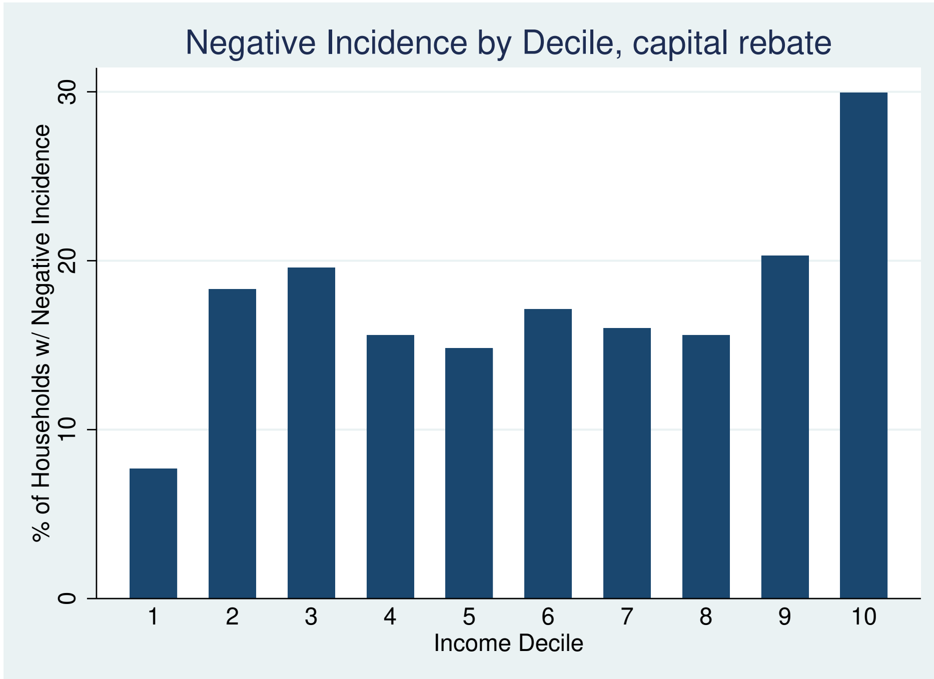

Figure 10: Percent of households with net negative incidence in each decile. The highest two deciles have the most net beneficiaries

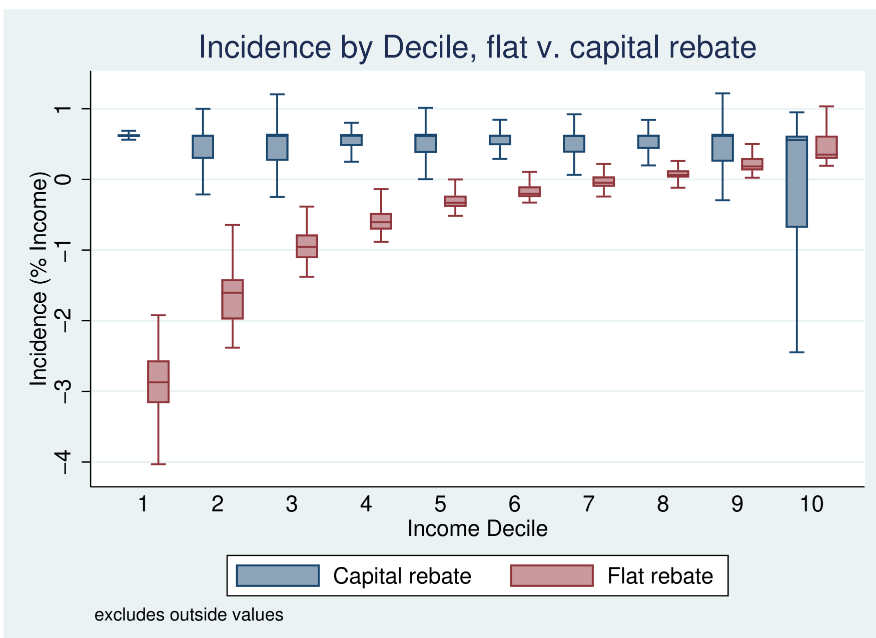

Figure 11: Per-household incidence by decile under a capital-based rebate vs. a flat per-household rebate.

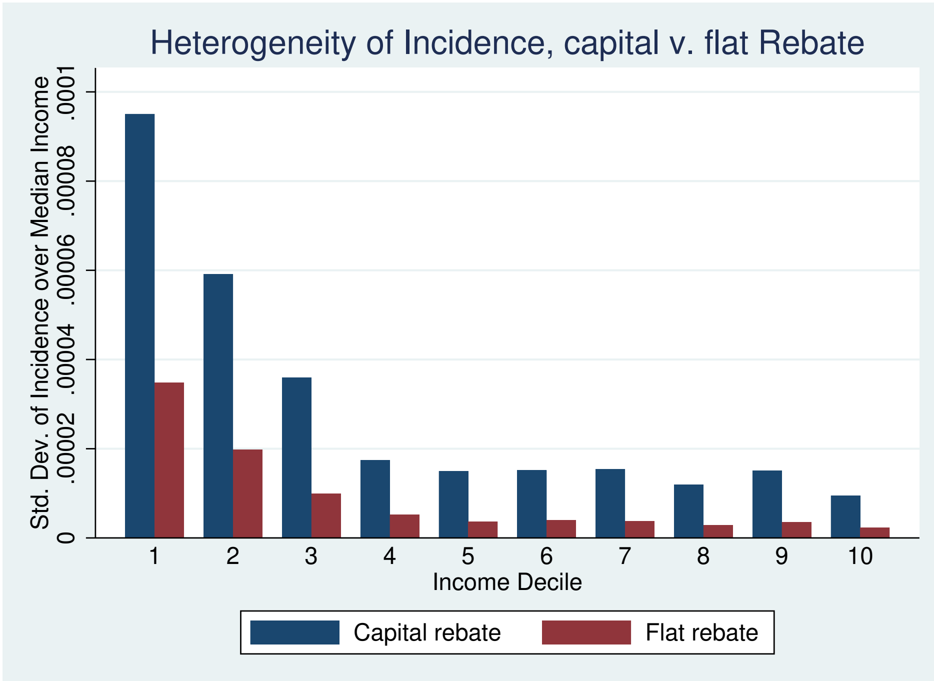

Figure 12: Heterogeneity of per-household incidence by decile under a capital-based rebate vs. a flat per-household rebate.

suggesting that a rebate scheme that benefits owners of capital should not be included in a carbon tax on distributional grounds.

Of course, this analysis ignores general equilibrium effects, as well as longer-term effects from the accumulation of capital that may be relevant. These upper-earners will likely spend and invest some of their increased capital income, which could have windfall benefits to labor that are not estimated in this simple model, as advocates of "trickle-down" policies often argue.

4.3.2 Intra-Decile Heterogeneity

The heterogeneity of impact across deciles under the capital-based rebate is similar to the result from the flat rebate in its overall U-shaped trend, with greater heterogeneity at the upper and lower ends of the income distribution. However, as is evident in figure 12, there is considerably more heterogeneity of impact under this capital-based rebate scheme. A larger relative standard deviation in incidence for all income deciles suggests that the capital-based rebate scheme only worsens any horizontal equity issues with the distribution of the carbon tax. Not only is the tax made more regressive by this rebate scheme, but the disparities in impact between households in the same income group are larger than under a flat rebate. The capital-based rebate thus does not help enhance either the horizontal nor vertical equity of the tax.

For a closer analysis, I conduct the same regression analysis as in the previous scenario, looking at incidence under this capital scheme. The results are presented in table 5.

Under this capital rebate scheme, six characteristics are statistically-significant correlates of incidence: household size, presence of multiple earners, unemployment status, education status, homeownership, and dependence on transfers.

As discussed in the previous section, larger households pay more tax, because they have more consumers and potentially more earners, both of which contribute to a larger numerator in the dependent variable (which is tax burden over household income).

Whereas the presence of multiple full-time earners had a negative coefficient in the flat rebate scenario, under the capital rebate it has a positive correlation, suggesting that households with multiple full-time earners actually pay more tax. This result is likely due to the fact that the capital rebate is correlated with non-wage income. Households with more earners have more income from wages, leading to a higher source-side tax burden. However, their rebate is likely to be smaller, because they likely receive a greater proportion of their income from wages rather than capital.

Having an unemployed head of household, meanwhile, is correlated with a lower than average tax incidence. This result, again, is likely due to income composition; households with an unemployed head likely have low wage income relative to capital and transfer income. The rebate rewards households with a large proportion capital income in their total. Any transfer income, meanwhile, is unaffected by source-side incidence effects. As a result, these households will tend to have lower incidence on average. This is a progressive result.

Having a head of household with bachelor's degree is a statistically-significant correlate under this scenario, but the coefficient is negative. This result appears to be regressive with regard to lifetime income; those people with higher lifetime earnings potential will tend to pay less tax than those of lower potential.

Furthermore, whereas in the flat rebate scheme, homeownership was positively correlated with incidence, under the capital rebate scheme it is negatively correlated. This is most likely due to the way capital income is measured; a home is an appreciating capital asset, so an increase in the value of a household's home is considered capital income. Since the rebate is linked to capital income, these households will tend to have a lower net incidence of tax. This is a regressive result, as homeowners are considered "better off" than renters.

Finally, dependence on transfers is negatively correlated for the same reasons explained in the previous section. It should be noted that capital income is notoriously difficult to measure, especially in a survey like the Survey of Household Spending, which relies on on-the-spot recall by interviewees. As such, the results of this section should be interpreted with skepticism. A more nuanced study of capital income effects should use tax return data if possible.

With regard to the inter-decile fixed effects themselves, only membership of the last two deciles appear to have

Table 5: Correlates of Incidence, Capital Rebate

	(1) Incidence	(2) Incidence
HH Size	0.105	0.165**
	(1.87)	(2.82)
Aged 40-65	-0.199*	-0.155*
	(-2.50)	(-1.97)
Multiple Earners	0.166	0.369**
	(1.39)	(3.02)
Elderly	-0.160	-0.157
	(-1.45)	(-1.42)
Unemployed	-0.556***	-0.580***
	(-4.95)	(-5.21)
College	-0.400***	-0.306***
	(-5.16)	(-3.91)
Work Full Time	0.0572	0.0707
	(0.55)	(0.68)
Has Children	-0.0951	-0.128
	(-0.73)	(-0.99)
Owns Home	-0.329***	-0.223*
	(-3.62)	(-2.43)
Owns Vehicle	-0.124	-0.103
	(-0.94)	(-0.78)
Owns Rec Vehicle	0.0593	0.0994
	(0.62)	(1.05)
Depends on Transfers	0.626***	0.538***
	(5.10)	(3.82)
Dec2		-0.164
		(-0.80)
Dec3		-0.138
		(-0.66)
Dec4		0.0566
		(0.26)
Dec5		-0.0127
		(-0.06)
Dec6		-0.178
		(-0.77)
Dec7		-0.171
		(-0.74)
Dec8		-0.336
		(-1.44)
Dec9		-0.666**
		(-2.75)
Dec10		-0.894***
		(-3.71)
Constant	0.600***	0.558*
	(3.50)	(2.48)
Observations	1362	1362

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

a significant impact on incidence, with negative coefficients. This result further confirms the regressive distribution across income groups, with the top two deciles disproportionately benefitting from the scheme.

4.4 Scenario 4: Wage-Based Rebate

Another commonly suggested revenue policy, which was also part of the British Columbia carbon tax package, is to return the revenues as a wage income-based rebate, either as an income tax reduction or some kind of tax credit for earned income. In this scenario, I estimate the impact of a revenue rebate linked to wage income. To estimate the per-representative household rebate, I use the same equation as in scenario 3, but with wages rather than capital income, such that:

Each representative household h with a wage income y and sampling weight W_h receives a rebate R_y such that:

$$R_{y,W,h} = \$1,240,000,000 \times \frac{y_h \times W}{\sum (y_h * W_h)} \tag{22}$$

$$R_{y,h} = R_{y,W,h} / W_h \tag{23}$$

The result is that the rebate is distributed based on what proportion of the total wage income goes to each household. For example, a household that collects 1% of the wage income in the economy would receive 1% of the total rebate. This method assumes that the tax credit is the same for all households regardless of income. In practice, it would be possible to design a tax credit that is itself progressive.

4.4.1 Inter-Decile Distribution

Table 6: Incidence with Wage-based Rebate

	(1) Incidence % Income
Income Decile	-0.0742***
	(-10.50)
Constant	0.544***
	(11.93)
Observations	1362

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Under this scheme, I find a distribution of net incidence as reported in figure 14. The overall trend is regressive, with net incidence falling as income rises, suggesting that this rebate scheme tends to benefit higher earners. Regres-

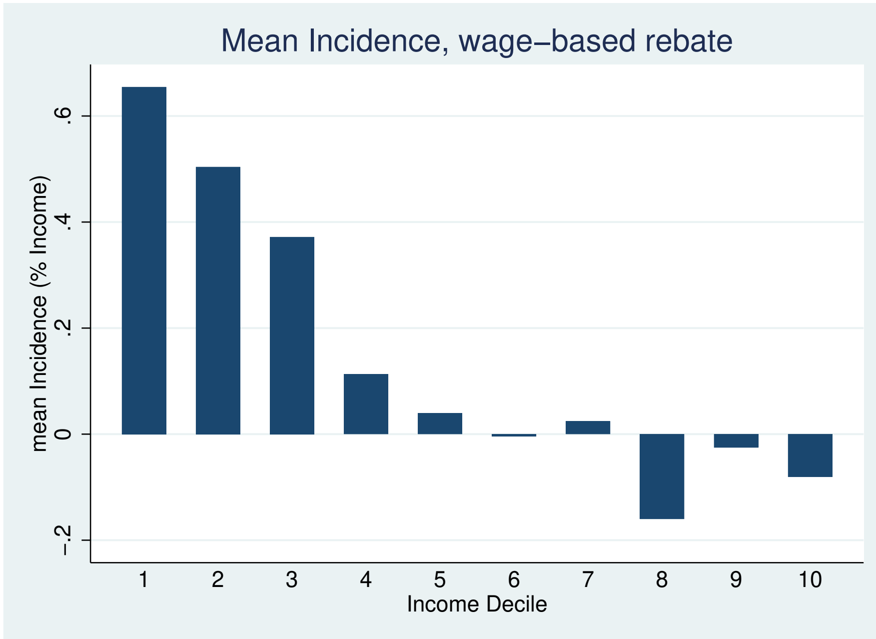

Figure 13: Mean per-household incidence by decile under a wage-based rebate.

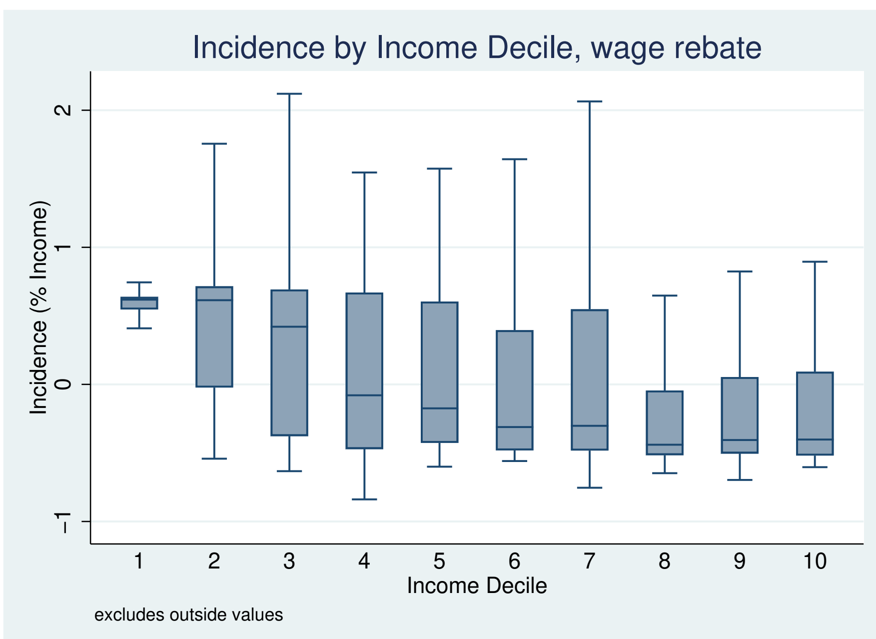

Figure 14: Per-household incidence by decile under a wage-based rebate. The line through each box represents the decile mean incidence, and each independent point represents an outlier.

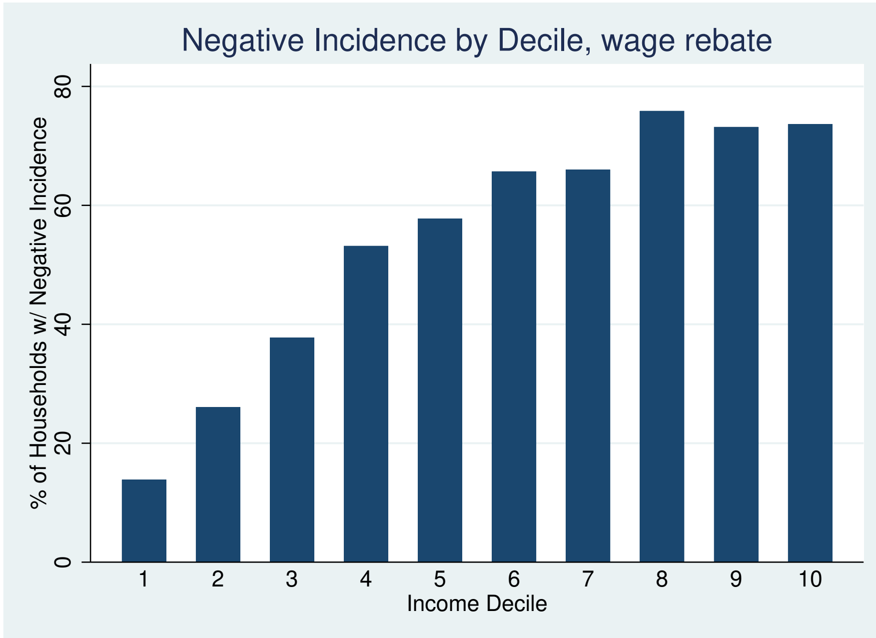

Figure 15: Distribution of net negative tax incidence by income decile. A greater percentage denotes more financial "winners" as a result of the tax.

sion analysis confirms a statistically-significant negative trend in incidence over income deciles. Comparing regression coefficients between tables 4.3.1 and 4.4.1 suggests that this wage-based rebate is, in fact, slightly more regressive than the capital-income based rebate.

However, the wage-based rebate scheme delivers a net negative incidence to far more households than under the capital income-based policy. As a result of the wage rebate, 57% of representative households are better off (net negative incidence) than under the capital rebate scheme, under which only 18% of households came out better off financially. In other words, more households "win" under this rebate scheme, though this figure is still lower than the 62% in the flat rebate scheme.

However, the distribution of "winners" is clearly regressive, as is evident in 15. The percentage of households with net negative tax incidence rises rapidly with income, suggesting that this wage-based rebate scheme makes the tax code overall more regressive.

4.4.2 Intra-Decile Heterogeneity

In terms of vertical equity, this rebate scheme is clearly regressive and shifts the tax code to the benefit of higher-earning households. But what about horizontal equity?

Under the wage-based rebate, the heterogeneity distribution roughly maintains the downward-sloping trend previ-

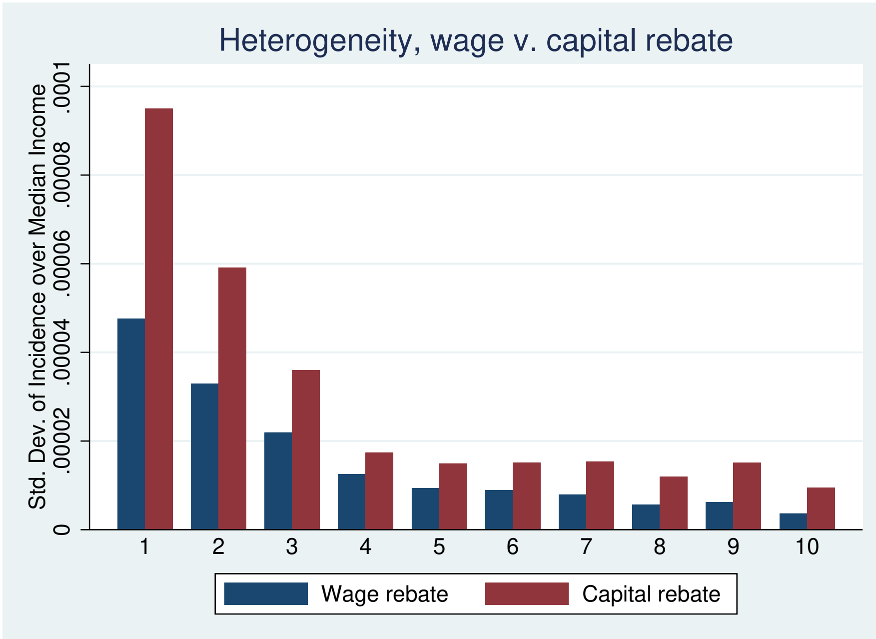

Figure 16: Heterogeneity of incidence by income decile, expressed as standard deviation, under wage-based vs capital-based rebate scenarios.

ous heterogeneity distributions (see figure 16. Furthermore, in every decile, the relative standard deviation of incidence is significantly lower under the wage rebate compared to the capital rebate. This result suggests that the wage-based rebate is moderately better from a horizontal equity perspective. However, the dispersion measures are still slightly higher than under the flat rebate (see figure 7), suggesting that the flat rebate remains the most horizontally equitable.

For closer analysis, I run the same regressions as in the previous two scenarios with the wage rebate. The results are shown in tables **??**, **??**, and **??** for deciles 1, 2, and 3 respectively.

Under the wage scheme, every characteristic except for the second decile fixed effect has a statistically-significant correlation. All the coefficients reflect the fact that the wage rebate rewards work and punishes capital income and transfers. Household size, Work Full Time, and Multiple Earners, have negative coefficient, because these households are likely to have more wage earners. Households with higher wage income receive a larger rebate, so their net incidence tends to be smaller. Meanwhile, Elderly, Unemployed, Has Children, and Depends on Transfers all return a positive coefficient, because these households tend to have lower wage income relative to other sources and relative to their consumption. Elderly people, the unemployed/transfer dependents, and children still consume, increasing the use-side burden, but do not earn a wage, meaning the household will receive a smaller rebate.

Meanwhile, the positive coefficients for home and vehicle ownership simply reflect higher energy consumption, as described before. This is a progressive result, as households that own their own home and vehicle are better off than

Table 7: Correlates of Incidence, Wage Rebate

	(1) Incidence	(2) Incidence
HH Size	-0.0953***	-0.0535*
	(-4.03)	(-2.17)
Aged 40-65	0.0859*	0.0877**
	(2.57)	(2.64)
Multiple Earners	-0.135**	-0.141**
	(-2.70)	(-2.75)
Elderly	0.410***	0.457***
	(8.89)	(9.85)
Unemployed	0.410***	0.400***
	(8.69)	(8.54)
College	0.0833*	0.0912**
	(2.55)	(2.77)
Work Full Time	-0.197***	-0.158***
	(-4.52)	(-3.60)
Has Children	0.134*	0.0886
	(2.46)	(1.63)
Owns Home	0.167***	0.196***
	(4.37)	(5.06)
Owns Vehicle	0.0560	0.109*
	(1.02)	(1.97)
Owns Rec Vehicle	0.130**	0.144***
	(3.25)	(3.62)
Depends on Transfers	0.151**	-0.0280
	(2.94)	(-0.47)
Dec2		-0.111
		(-1.29)
Dec3		-0.153
		(-1.72)
Dec4		-0.357***
		(-3.88)
Dec5		-0.409***
		(-4.25)
Dec6		-0.410***
		(-4.21)
Dec7		-0.443***
		(-4.54)
Dec8		-0.414***
		(-4.21)
Dec9		-0.379***
		(-3.72)
Dec10		-0.361***
		(-3.57)
Constant	-0.172*	-0.00880
	(-2.39)	(-0.09)
Observations	1362	1362

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

those that do not, so the fact that they tend to bear a higher tax burden is consistent with progressivity.

Like the flat rebate scheme, this wage rebate produces a mix of progressive and regressive effects within income groups. The presence of multiple earners, elderly, unemployed, and full-time work all suggest that those who are better off tend to pay less than those worse-off. But elsewhere, the variables for age, college education, and home and vehicle ownership all suggest a progressive result, especially with regard to lifetime income effects.

4.5 Scenario 5: Transfer-Based Rebate

Given the regressive distributional impacts of both the capital and wage income-based rebate schemes, one might argue that the best way to offset the burden of increased consumption prices for lower-earning households would be to use to the revenues from the carbon tax to enhance government transfer programs, such as unemployment insurance, wage subsidies, and other transfers which predominantly benefit lower-earners.

In this scenario, I model the distributional effect of a rebate scheme that returns the revenue to households on the basis of their transfer income. To calculate the per-household rebate, I use the same basic equation as in the previous two scenarios, substituting capital income. Each representative household h with a transfer income x and sampling weight W_h receives a rebate R_x such that:

$$R_{x,W,h} = \$1,240,000,000 \times \frac{x_h \times W}{\sum (x_h * W_h)} \tag{24}$$

$$R_{x,h} = R_{x,W,h}/W_h \tag{25}$$

The result is that the rebate is distributed based on what proportion of the total transfer income goes to each household. For example, a household that collects 1% of the transfer income in the economy would receive 1% of the total rebate.

4.5.1 Inter-Decile Distribution

Perhaps unsurprisingly, boosting transfers has a highly progressive distribution, with net incidence rising at a decreasing rate as income rises.

Figure 20 shows the distribution of incidence across deciles. The beneficiaries of the scheme are overwhelmingly at the bottom end of the income distribution. Furthermore, under this transfer scheme, the distribution of net winners from the tax policy is much more progressively distributed. Figure 19 shows the percentage of households in each decile who are made financially better-off than they were before the implementation of the policy. The trend is overall

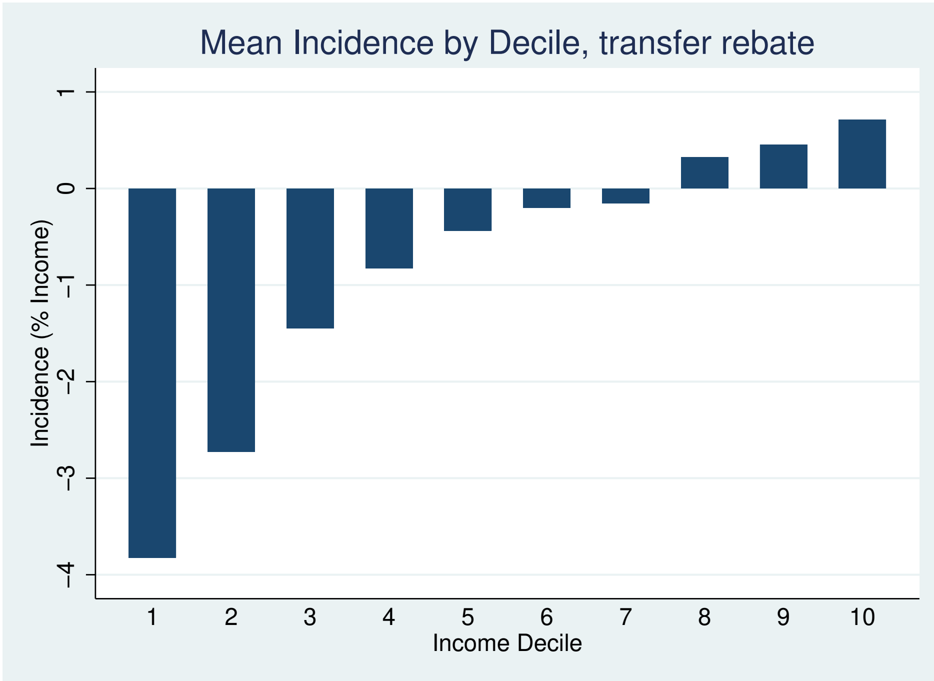

Figure 17: Mean incidence as a percentage of income by income decile.

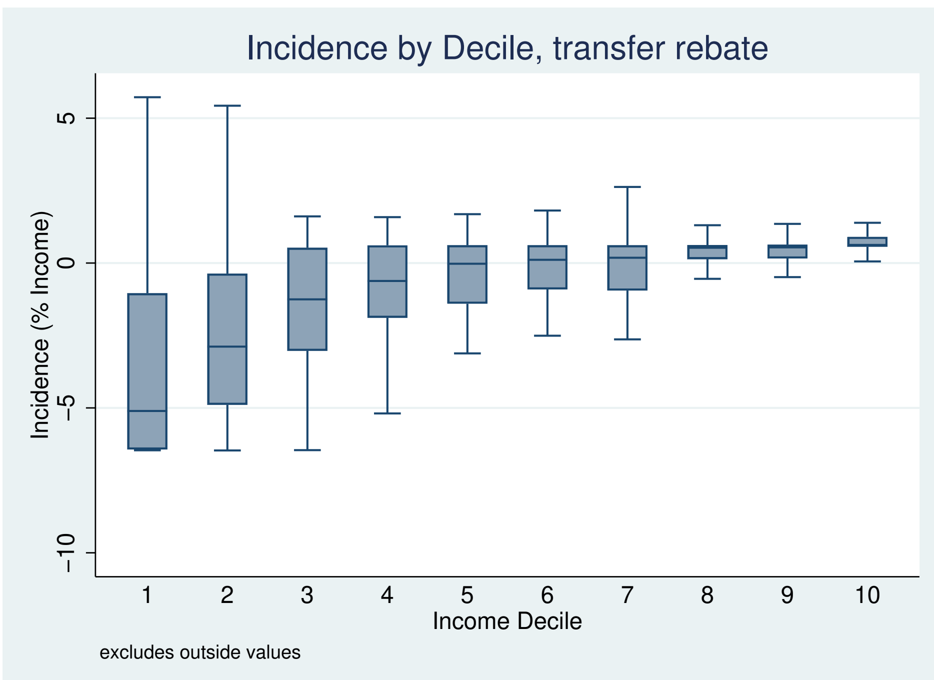

Figure 18: Incidence as a percentage of income by income decile.

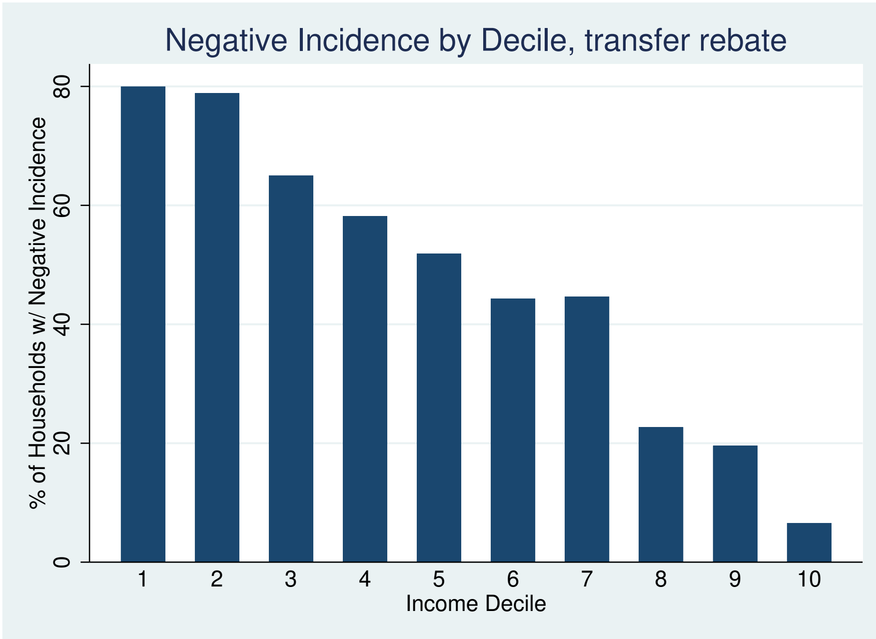

Figure 19: Percentage of householders with a net negative tax incidence under the transfer-based rebate scheme.

downward-sloping, with the number of net winners falling as income rises. This trend is consistent with what would be expected from a progressive tax policy.

The total number of net winners (45% of households) is larger than under the capital-income scheme, but slightly less than the 62% under the flat rebate scheme or the 57% under the wage-income scheme. However, the distribution of net winning households is slightly more progressive with respect to income than under the flat rebate policy and much more progressive than under the wage income scheme.

4.5.2 Intra-Decile Heterogeneity

In terms of horizontal equity, the transfer-based rebate has considerable heterogeneity in the lowest deciles, but that heterogeneity rapidly declines as income rises. This result is not surprising, given that high-earning households would collect very few transfers in proportion to their total income, if any.

Overall, heterogeneity in incidence under the transfer-based rebate is comparable to that of the capital- and wage-based rebates, but slightly higher in the lower deciles. This result can be explained intuitively by the significant heterogeneity in transfer income at the lower deciles.

I run the same regression analysis as before for the transfer rebate scheme. The results of the regressions are presented in tables 8.

Under the transfer rebate scheme, all the variables except household size, the age dummy, presence of multiple

Table 8: Correlates of Incidence, Transfer Rebate

	(1) Incidence	(2) Incidence
HH Size	-0.0219	-0.193***
	(-0.55)	(-4.90)
Aged 40-65	0.0564	0.00800
	(0.99)	(0.15)
Multiple Earners	0.0765	-0.0796
	(0.90)	(-0.97)
Elderly	-0.835***	-0.960***
	(-10.68)	(-12.96)
Unemployed	-0.450***	-0.412***
	(-5.63)	(-5.52)
College	0.235***	0.135*
	(4.25)	(2.56)
Work Full Time	0.225**	0.0848
	(3.04)	(1.22)
Has Children	-0.469***	-0.316***
	(-5.08)	(-3.64)
Owns Home	0.356***	0.169**
	(5.51)	(2.74)
Owns Vehicle	0.330***	0.169
	(3.53)	(1.91)
Owns Rec Vehicle	0.178**	0.108
	(2.63)	(1.71)
Depends on Transfers	-3.453***	-2.856***
	(-39.58)	(-30.17)
Dec2		0.646***
		(4.72)
Dec3		1.083***
		(7.65)
Dec4		1.236***
		(8.40)
Dec5		1.357***
		(8.83)
Dec6		1.506***
		(9.70)
Dec7		1.488***
		(9.57)
Dec8		1.690***
		(10.77)
Dec9		1.998***
		(12.29)
Dec10		2.090***
		(12.92)
Constant	-0.291*	-0.950***
	(-2.39)	(-6.28)
Observations	1362	1362

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

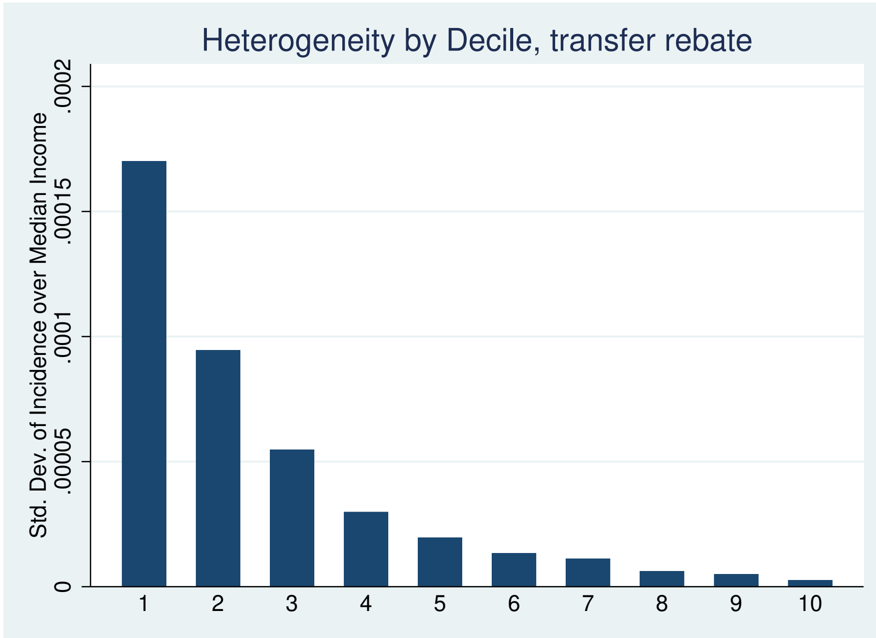

Figure 20: Heterogeneity of incidence, expressed as standard deviation, by income decile.

earners, and ownership of recreational vehicles return a statistically-significant correlation before the addition of income fixed effects. As would be expected from the premise of the policy design, the tax package tends to benefit households with larger numbers of dependents and households that depend on transfer income as a large portion of their total. The regression returns a negative coefficient for household size, presence of elderly, unemployed, presence of children, and dependence on transfers. Each of these variables suggests the household is more likely to derive a large share of their income from transfers, and so their rebate will be larger than average. Thus, they tend to have a lower incidence on average

The variables with positive coefficients, meanwhile, are those that suggest the opposite: college education, full-time employment, and home ownership. These households are more likely to have a larger wage share of income, and so they will receive a smaller rebate and pay more net tax on average.

Including fixed effects from income groups removes multiple earners and vehicle ownership as statistically significant correlates and includes household size. Interestingly, the coefficient is negative, meaning larger households tend to pay less tax on average. One potential explanation is that larger households with low income might be eligible for more transfers (for example, benefits for children or elderly dependents) and that these transfers are enhanced by the rebate.

The correlates of these regressions all suggest progressive results. Households with elderly members, the unemployed, and households that depend on transfers all tend to pay less tax on average, while households who are employed full time, who own their own home, and who are headed by a college graduate all tend to pay more. Overall, the horizontal results from the transfer rebate are highly progressive, disproportionately benefiting worse-off households.

However, there may be efficiency issues created by the policy, as it tends to reward households that rely on transfer payments and punish those that do not. This incentive structure could encourage workers to drop out of the labor force and collect enhanced transfers, which would produce welfare effects not captured in this analysis.

5 Conclusion

The most significant conclusion from these results for policy is that the distributional effect of a carbon tax will be driven to a large degree by what happens to the revenues – whether they are spent or rebated and how. While distributional analyses of a policy like a carbon tax usually ask, "Who pays the taxes?" my results suggest that the more important question is – who gets the revenue? The impact of a carbon tax alone does not appear to be significantly progressive or regressive, given the consumption-cost and income effects that offset each other in terms of distribution. It is only when the use of the revenues is considered that significant trends emerge. Different rebate policies produce different distributional results, both in terms of vertical and horizontal equity.

The most progressive results occur as a result of the flat rebate and the transfer rebate. Under these policies, the revenue rebate is either uncorrelated with any household characteristic (the flat rebate) or it is directly linked to households' transfer income. Because lower-earners tend to rely on transfers as a greater share of their income than wealthier households (who tend to have very little transfer income, if any), these policies tend to provide the greatest relative benefit to households in lower income groups.

The more regressive results come from policies that are correlated with higher household income, such as the wage and capital income rebates. In these designs, the rebate to each household grows as their income grows and as their transfer share of income declines. In other words, the rebate increases as households become better-off. Thus, it is not surprising that they would produce a regressive result in proportional incidence.

Considering the heterogeneity within deciles and analyzing some potential sources adds an additional level of analysis regarding the distributional impact by indicating which households tend to do better than their peers in the same income group under different policies. The flat rebate produces the most horizontally equitable result, because, again, it is uncorrelated with any household characteristic. Thus, tax incidence is driven entirely by household energy consumption. The wage and transfer rebates produce higher heterogeneity, because they benefit specific (and opposite) households. The wage rebate rewards households that earn income, meaning at least their head of household is employed. But having an employed head of household, one might argue, makes that household better off than their unemployed peers, so rewarding them is regressive. The transfer rebate, meanwhile, compensates those households that collect high levels of transfers. Eligibility for transfers itself is an indication that a household is not well off, so a policy that benefits them is more horizontally progressive.

Furthermore, although it is mostly outside the scope of this study, the heterogeneity analysis also gives some indication of potential efficiency benefits or drawbacks from the different policies – in other words, the extent or absence of the "double dividend." Since the transfer rebate rewards households for collecting transfers, one could argue that it creates a disincentive to actively seek employment and could even create an incentive to drop out of the labor force, which would carry a cost to economic efficiency. The wage rebate, meanwhile, rewards employment and could encourage the unemployed to more actively seek employment, which would provide an efficiency benefit. The flat rebate, meanwhile, is similar to a lump-sum tax and transfer, which is considered the most "neutral" tax policy, because it does not change the incentives to work, consume, or invest.

5.1 Lessons for Policy

Determining which policy is the optimal design depends on what policymakers choose to prioritize and what type of social welfare function they seek to satisfy, which requires the consideration of some normative preferences (Atkinson and Stiglitz, 2015).

If policymakers prioritize vertical equity in the distribution of the carbon tax burden (in other words, they want the wealthier to pay more tax overall, regardless of differences within income groups), then the transfer-based rebate (i.e. using the revenues to enhance existing transfer programs like welfare) in subsection 4.5 produces the most progressive result, with a regression coefficient of $\beta_1 = 0.41$. The benefits accrue predominantly to lower-earning households at the expense of higher-earning ones. However, the total number of households who are net beneficiaries of this policy is lower than for flat or wage-based rebate scheme. Of the rebate schemes analyzed, this one is the most in line with a Rawlsian social welfare function, which seeks to maximize the relative benefits for the least well-off (Rawls, 1971). However, from a utilitarian or Benthamite perspective, which seeks to maximize benefits for the largest number of people, unweighted by other considerations, (Ng, 1975), the transfer rebate is less advantageous than the flat rebate (best) or the wage-based rebate (second-best), which produce net benefits for a greater number of households.

The second-best policy with regard to overall vertical equity would be the flat rebate scheme in subsection 4.2, which produces a progressive distribution with a coefficient of $\beta_1 = 0.27$. The distribution of incidence with regard to income is slightly more proportional than under the transfer rebate, but it is still markedly progressive overall. As it produces slightly less net benefit for lower-earners, it is less optimal for a Rawlsian objective, but it is better for a utilitarian goal, as it leaves a greater number of households (62% better off). In this regard, it is the best policy of the scenarios modeled.

This scheme may also have some political benefits that could make it advantageous to the transfer scheme. For one, it may be more appealing to those of center-right political leanings, as it is less of an explicit redistribution of wealth than the transfer scheme. Using the revenues to enhance existing transfer programs would fulfil generally left-wing policy objectives, which could alienate support on the moderate right. Indeed, one of the unique aspects of BC's carbon tax was that it was implemented by a center-right government with the support of the business community (Harrison, 2013). Voters may see a carbon tax and transfer package as simply an attempt to raise revenue for welfare programs, which can be politically contentious. A flat rebate, while still redistributive in its overall effect, may be less explicitly so than outright welfare spending. Furthermore, it could be easier for leaders to build political coalitions in favor of a flat rebate, given that the policy produces a greater quantity of net winners (62%) than the transfer program (45%). If political leaders can effectively argue that the policy would make a large majority of households financially better-off, voters may be more willing to support the carbon tax package.

The two policies that policymakers should avoid, at least in terms of vertical equity, are the capital-income or wage-income rebates (which, in practice would likely take the forms of reductions in corporate and income tax respectively). Both scenarios produce an overall regressive distribution of the tax burden, with regression coefficients of $\beta_1 = -0.06$ and $\beta_1 = -0.07$ respectively, and tend to benefit higher-earning households at the expense of poorer ones. The capital income rebate is particularly regressive at the upper end of the distribution, with the largest benefits accruing to the top 10% of households. Granted, these types of tax shifts would likely have general equilibrium effects that are not accounted for in this simple estimation. Advocates of "trickle-down" policies, for example, would argue that reductions in corporate income tax (the capital rebate) would encourage businesses to hire and invest (not just pass on the savings to shareholders), which would likely have a more progressive impact. Estimating these effects would require an integrated CGE model and is beyond the scope of this paper.

In terms of horizontal equity, the most desirable policy is that which produces the smallest relative standard deviation in its impact within income groups. Horizontal equity, as a principle, simply means that people with the same characteristics should be treated the same (Atkinson and Stiglitz, 2015). In terms of the distributional implications of the carbon tax, heterogeneity of impact within deciles could capture certain aspects of the tax's impact that may lead some to call it "unfair" even when the tax burden is progressively distributed across income groups.

The flat rebate package produces the lowest per-decile standard deviation of incidence, especially for the lower income deciles where heterogeneity in impact is likely to be a more potent source of political backlash (ex: working-class rural-dwellers finding the tax to be unfair). Furthermore, the intra-decile incidence does not seem to have a

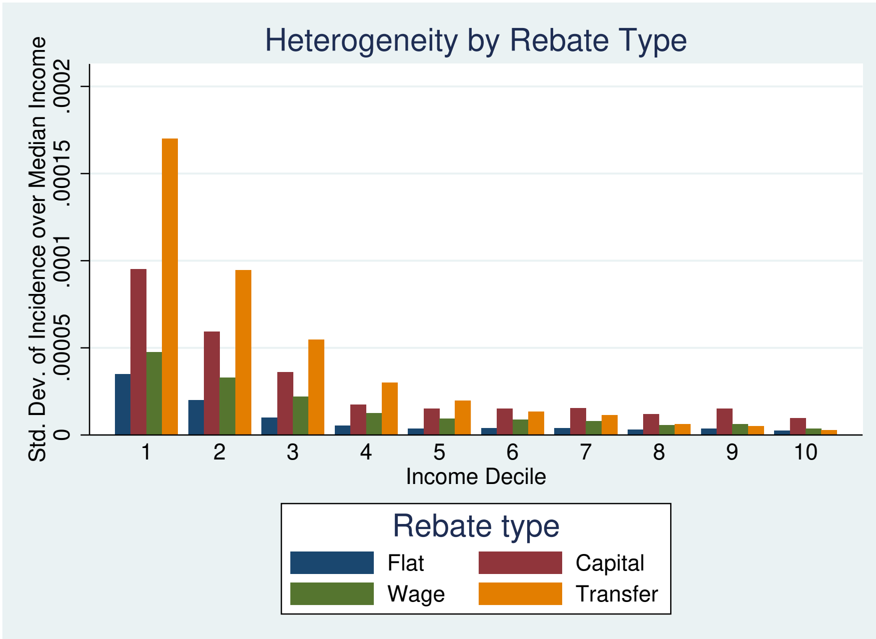

Figure 21: Comparison of intra-decile heterogeneity for each rebate scheme. The flat per-household rebate produces the lowest heterogeneity in incidence for each decile.

clear progressive or regressive trend; some characteristics associated with higher incidence suggest households are better off, while others suggest the opposite. Thus, one can conclude that the flat rebate is the best policy with regard to horizontal equity. This conclusion is not necessarily surprising, given that the flat rebate is given to all households regardless of their characteristics. Whether a household is urban or rural, dependent on carbon-intensive industries, needs more heating, or drives more, the rebate is the same. This reduces the likelihood that the rebate would be correlated with any other factor that might drive intra-decile heterogeneity, like different income sources or eligibility for government support, which could explain why the other income source-linked rebate schemes produce a higher degree of heterogeneity. Some of the efficiency concerns discussed earlier may also factor in to policymakers' decisions about optimal horizontal equity

5.2 Caveats

There are several caveats to consider in interpreting the results of this study on which further research would be insightful.

Marginal Utility Considerations My analysis of incidence is based purely on financial incidence, treating each dollar the same regardless of who it belongs to. In reality, the marginal utility of consumption is likely subject to some degree of diminishing returns. For example, a 2% reduction in income for a poor person may constitute a significant negative impact, whereas a 2% reduction income for a billionaire would hardly register. To account for this marginal utility issue, one would need to apply a utility function for each household and calculate a measure of equivalent variation.

However, this caveat is really only relevant to the analysis in scenario 1, in which all households have a positive incidence. For the scenarios in which households in lower deciles tend to be net beneficiaries of the policies, this utility issue does not significantly impact whether one can conclude that the tax is progressive or regressive. If lower earners tend to benefit while higher earners tend to lose out, the tax can still be considered progressive. A utility measure would simply affect the degree of progressivity. These results are broadly consistent with the established literature.

General Equilibrium Effects of the Rebate Just as the carbon tax itself is subject to general equilibrium effects, it is likely that the rebate scheme would also be subject to such effects, particularly for households who are net beneficiaries from the tax policy. These households would experience a positive income effect, which could lead to reductions in the overall labor supply, in turn raising wages and reducing capital returns.

Furthermore, the tax and rebate could incentivize households to substitute their consumption of carbon-intensive goods for less carbon-intensive goods (one of the goals of the policy) in an effort the maximize their net rebate. Modeling these effects would require an integrated general equilibrium model beyond the scope of this study.

Salience It is possible that there is a significant difference in the salience of the income- and consumption-side impacts of the carbon tax, which may cause the tax to "feel" regressive if the public associates the tax mainly with the increased prices. While higher prices at the pump are easy to attribute to the carbon tax, tax credits/reductions or other income-side rebates may be less salient. Thus, the individual may feel that the tax has made them worse-off even if they are among the net winners from the revenue rebates. This salience issue is part of the rationale for the Climate Leadership Council's proposed "carbon dividend" check, with the idea that receiving the check will make the benefits more obvious (Schultz and Halstead, 2018).

Benefits of Climate Mitigation This distributional analysis ignores the economic benefits that would also accrue to households over the long term from reducing emissions and mitigating the damages due to climate change. Including this consideration would also affect the distributional analysis, as there is significant evidence that the damages of climate change would, in fact, be regressively distributed, disproportionately impacting poorer people, as wealthier individuals have more resources to mitigate the damage to themselves.

Effects of climate change like extreme weather, sea level rise, crop yield declines, depletion of water resources, and the overall impact to economic growth would most likely hit the poor the hardest (Busch, 2014). Accounting for these regressive impacts would tend to enhance the progressivity of any carbon-abating policy such as a carbon tax (Budolfson et al., 2017). It would also revise any estimates of growth, income, and employment impacts over the long term.

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Sector	Emissions (kt CO2 eq)	Required Revenue (scaled)
Public Electricity and Heat Production	504	$13,881,364
Petroleum Refining Industries	587	$16,181,751
Oil and Gas Extraction	7070	$194,872,399
Mining	458	$12,619,454
Manufacturing Industries	4435	$122,241,754
Construction	71	$1,954,864
Commercial and Institutional	2416	$66,587,817
Residential	3954	$108,999,333
Agriculture and Forestry	413	$11,376,319
Domestic Aviation	1309	$36,084,486
Road Transportation	16788	$462,746,827
Railways	665	$18,322,390
Domestic Navigation	1814	$49,88,436
Other Transportation	4504	$124,142,806

A Required Revenues by Sector

The table shows the revenues required from each sector as a scaled product of the emissions from that sector times the carbon price.

B Groups of Input-Output Industries to Emissions Sectors

The industries in the system of national accounts (SNA) are grouped to match the disaggregated emissions sectors in the BC provincial emissions inventory based on the best approximations of the descriptions of each sector in the emissions inventory user guide (British Columbia Ministry of Environment and Climate Change Strategy, 2019).

Emissions Sector	SNA Industries
Public Electricity and Heat Production	Electric power generation, transmission and distribution
Petroleum Refining	Petroleum refineries
Oil and Gas Extraction	Conventional oil and gas extraction
Mining	All mining industries
Manufacturing Industries	Manufacturing industries
Construction	Construction industries
Commercial and institutional	Retail, commerce, health, education, finance, business etc.
Residential	Natural gas
Agriculture and forestry	All agriculture
Road transportation	Gasoline
Misc. transportation	Transportation except private vehicles

C Consumer Price Change Results

The table shows the percent change in price for each consumer good as calculated with the general equilibrium-adjusted input-output model.

Category	Percent Change in Price
Food	1.1
Non-alcoholic beverages	1
Alcoholic beverages	0.8
Tobacco	1
Garments	0.8
Cleaning of clothing	1
Footwear	0.8
Paid rental fees for housing	0.6
Imputed rental fees for housing	0
Materials for the maintenance and repair of the dwelling	1.1
Services for the maintenance and repair of the dwelling	0.7
Electricity	0.7
Gas	0.4
Other fuels	1.9
Water supply and sanitation services	0.5
Furniture and furnishings	0.8
Carpets and other floor coverings	0.8
Household textiles	0.8
Major household appliances	0.7
Small electric household appliances	0.8
Major tools and equipment	0.8
Small tools and miscellaneous accessories	0.8
Other semi-durable household goods	1
Other non-durable household goods	1.1
Repair of personal and household goods except vehicles	0.8
Renting and leasing of personal and household goods except passenger vehicles	0.8
Other services related to the dwelling and property	0.3
Therapeutic appliances and equipment	0.6
Pharmaceutical products and other medical products	0.7
Out-patient services	0.5
Hospital services	0.5
New passenger cars	0.8
Used motor vehicles	0.6
Other vehicles	0.9
Spare parts and accessories for vehicles	0.7
Fuels and lubricants	2.7
Maintenance and repair of vehicles	0.7
Parking	0.7
Passenger vehicle renting	0.7
Other services related to the operation of transport equipment	0.6
Railway transport	0.9
Urban transit	0.5
Interurban bus	0.9
Taxi and limousine	2.2
Air transport	1.7
Water transport	1.6
Other transport services	1.1

Category	Percent Change in Price
Postal services	1.3
Telecommunication equipment	0.6
Telecommunication services	0.4
Information processing equipment	0.7
Recording media	0.9
Audio-visual and photographic equipment	0.6
Major durables for outdoor recreation	0.8
Musical instruments and major durables for indoor recreation	0.8
Veterinary and other services for pets	0.8
Pets and pet food	1.2
Recreational and sporting services	0.6
Cinemas	0.8
Photographic services	0.8
Other cultural services	0.8
Games of chance	4.8
Books	0.9
Newspapers and periodicals	1
Miscellaneous printed matter and stationery and drawing materials	1
University education	0.8
Other education	0.5
Food and non-alcoholic beverage services	0.9
Alcoholic beverage services	0.9
Accommodation services	0.6
Life insurance	0.4
Health insurance	0.4
Insurance related to transport	0.4
Property insurance	0.4
Implicit loan charges	0.3
Implicit deposit charges	0.3
Stock and bond commissions	0.5
Other actual financial charges	0.4
Trusteed pension funds	0.5
Mutual funds	0.5
Personal grooming services	0.8
Electrical appliances for personal care	0.8
Other personal effects	0.8
Child care services outside the home	0.4
Child care services in the home	0
Other social services	0.4
Undertaking and other funeral services	1.2
Legal and other services	0.7