Comparing Provincial Carbon Emission Regulation Policies in Canada: Impacts on Greenhouse Gas Emissions, Production, and Labor Measures

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Abstract

Carbon emissions regulation policies have been instituted in several countries and sub-national regions within the last 35 years to force firms to reduce emissions. However, these policies have been accused of reducing economic growth. This research utilizes a difference-in-differences model with two-way fixed effects to explore how carbon taxes, credit systems, and cap-and-trade systems instituted across 13 Canadian provinces from 2004-2022 impact emissions and economic outcomes (GDP, employment, hours worked, and earnings). Estimates demonstrate that, in general, none of the policies lower emissions at significant levels or hurt the economy overall. Carbon taxes have slight negative effects on GDP and earnings. Cap-and-trade systems have no effects on economic outcomes. Extending the model shows that the policies effectively target the highest-emitting economic sectors and the most emission-intensive industries. Cap-and-trade systems are more effective at accomplishing this than carbon taxes while also allowing for economic growth in less emission-intensive industries and reducing emissions directly rather than through decreased economic activity.

Keywords: Carbon tax, Cap-and-trade, Difference-in-differences, Macroeconomy, Industry-level, Canada

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Contents

1 Introduction

For centuries, pollution has been a free and largely unregulated luxury for firms, a necessary part of their production processes. On a global scale, businesses have made economic decisions based on their direct costs and profit opportunities and have not considered that the pollution they emit imposes indirect costs on the environment and society. However, with the emergence of the climate crisis and growing concerns about global warming, ocean acidification, poorer public health from low air quality, and many other indirect effects of excessive carbon pollution, it has become evident that the laissez-faire approach to industrial pollution can no longer be sustained, and that states cannot continue to allow businesses to pollute uninhibited.

How should states incorporate the negative costs of carbon emissions into their economies when they are difficult to quantify and often only surface years in the future? The Canadian government has turned to carbon taxes, baseline and credit systems, and cap-and-trade systems to regulate and disincentivize carbon emissions. Various Canadian provinces and territories (referred to as provinces throughout the rest of this paper) have implemented these emissions regulation systems with various intensities of economic penalties to deter firms from polluting and encourage them to rely on more sustainable sources of energy and production processes.

However, policymakers globally have challenged carbon policies regarding their effectiveness as tools to fight climate change. Politicians and public criticism claim that emissions regulations inflict substantial losses in GDP and employment in fossil fuel-reliant industries and exert heavy financial burdens on household incomes and consumers (Cassidy, 2023) (Lewis, 2021). Some claim that been the most aggressive carbon taxes would have negligible effects on the climate, and the costs to society would exceed the benefits (Lewis, 2021). This general skepticism regarding the reliability and impact of these policies is why it is critical to study and compare the macroeconomic impacts of carbon policies to evaluate their effectiveness.

In the past 16 years, various Canadian provinces have introduced three emissions regulation policies (referred to broadly as carbon policies throughout the rest of this paper) that imposed monetary penalties on carbon emissions at various times and at varying degrees of intensity, and the federal Canadian government also introduced a federal standard of carbon policies in 2019. This paper explores the effects of carbon policies on carbon emissions, GDP, employment, hours worked, and earnings in various Canadian provinces. This paper also explores how these effects vary by economic sector, as well as the emission intensity, energy intensity, and innovation level of the industry. In addition, it reveals mechanisms through which carbon policies reduce emissions (i.e. reduced economic activity).

This research includes the carbon policies of all Canadian provinces, not just British Columbia, which is where most papers on carbon tax policy in Canada are focused (Köppl & Schratzenstaller, 2023). Canada's thirteen provinces have implemented carbon taxes, credit systems, and cap-and-trade systems in various years beginning in 2007. In addition, policies have been imposed with different rates, imposing different economic penalties on firms. This research takes these differences into account.

Although the same data source (Statistics Canada) was used in Yamazaki's paper on the effect of the British Columbia carbon tax on macroeconomic measures, this research paper utilizes more recent years (2004-2022) (Yamazaki, 2017). This expands the scope of the research to study carbon policies implemented in the past four to five years. This includes carbon policies introduced at the provincial level after 2016, and the federal carbon tax policy implemented in 2019, which have not yet been studied.

Because the data is at the industry level, this research can explore the effects of the policy on different types of industries and economic sectors. Carbon policies that impose financial burdens on firms are more likely to hurt production and employment in fossil fuel-reliant industries and benefit industries that rely on sustainable energy sources and methods of production. This research examines the heterogeneous impacts of carbon policy shocks in the outcomes that vary by sector and several industry characteristics.

In addition, this research utilizes a mediating model to reveal mechanisms through which industries are reducing emissions. Emission reduction can happen directly or through reducing economic activity to cope with the added costs on emissions, and the mediating model reveals through which channels the reduction is being accomplished.

A DID model with two-way fixed effects is the baseline empirical model, in which a policy treatment indicator is utilized to denote pre- and post-policy periods within a province. The baseline model is extended by interacting the policy treatment variable with economic sectors as well as lagged industry characteristics (emission intensity, energy intensity, and innovations that reduce GHG emissions) to reveal the heterogeneous effects of the policy. Finally, a mediating model is used to decompose the direct and indirect economic mechanisms through which emission reduction is achieved.

This research paper finds that carbon policies generally do not severely hurt the economy. Carbon taxes show significant negative effects on GDP and earnings, but none on employment or hours worked. Cap-and-trade systems do not show significant negative impacts on any economic outcomes. While all carbon policies show reduced emissions, the results are not significant. Both carbon taxes and cap-and-trade systems are effective at reducing emissions in the most polluting sectors (Mining, Oil, Gas, Electricity and Manufacturing), with cap-and-trade systems being more effective than carbon taxes at reducing emissions in more sectors. In general, sectors that see emissions reductions will also see lower GDP, employment, and earnings. Both policies reduce emissions and economic activity in the most emission-intensive sectors while not impacting the less emission-intensive sectors as severely. Only cap-and-trade systems, however, actually allow for economic growth in the least emission-intensive sectors, creating some "winning" industries; carbon taxes had negative economic impacts on all industry types. These same patterns held for energy-intensive versus non-energy-intensive industries and industries with high versus low levels of innovation to reduce GHG emissions. Finally, the mediating model showed that cap-and-trade systems were more effective at directly reducing emissions while maintaining higher levels of economic activity, while carbon taxes reduced emissions mainly through reduced economic activity. Overall, cap-and-trade systems were more effective at reducing emissions in the most polluting sectors, targeting emission-intensive industries while allowing for economic growth in less emission-intensive industries, and reducing emissions directly rather than through economic downsizing.

The paper begins with a review of the previous literature on carbon policy in section 2.1, then background on Canadian provincial and federal carbon policy in section 2.2. Understanding this context is crucial to understanding the various conditions that affect a policy's effectiveness within a region. Section 3 illustrates the theoretical framework, explaining the channels through which we expect the policy to impact the outcome variables. Section 4 provides an overview of the data sources as well as summary statistics of the key variables. Section 5 defines the empirical models, explaining the analysis methods. The results of the models are displayed in section 6, followed by a discussion of results in section 7 and conclusions in section 8.

2 Background

2.1 Previous Literature

There are several nations and sub-national regions that have implemented carbon taxes and other emissions regulation policies in the past few decades. Because of the critique that such policies negatively affect economic growth, there is a growing area of literature dedicated to studying the impacts of such policies and whether they are affecting the environment and economies as intended.

Angelo Köppl and Margit Schratzenstaller provide a review of the empirical literature on carbon taxes (Köppl & Schratzenstaller, 2023). Carbon taxes have been implemented on almost every continent within the last thirty-five years, and there have been many empirical studies done on their environmental and economic effectiveness (Köppl & Schratzenstaller, 2023). The more recent empirical studies on the impacts of carbon taxes are generally considered more reliable than older simulation and projection-based studies because they analyze the actual outcomes of policies with concrete data (Köppl & Schratzenstaller, 2023). Most empirical studies on carbon taxes have been done on European countries and the British Columbia (BC) province in Canada. BC has been the subject of many studies because it implemented the most aggressive and comprehensive revenue-neutral carbon tax globally in 2008, a time when few neighboring regions had similar policies, making it an ideal subject for a difference-in-differences (DID) study (Azevedo et al., 2023). Studies on carbon taxes have been done at almost all levels of data analysis: firm, industry, regional, and country. Because my research focuses on carbon policies in Canada, the discussion on previous literature focuses on studies performed on single countries in this literature review.

Almost all empirical literature concludes that the implementation of carbon taxes distinctly reduces carbon emissions (Köppl & Schratzenstaller, 2023). However, there is some disagreement about the effect of the pricing of carbon on macroeconomic measures. Most studies find that carbon taxes have a null to slightly positive effect on GDP, employment, and productivity. A DID study done on BC's revenue-neutral carbon tax using industry-level data found that the carbon tax generated, on average, a small but statistically significant 0.74% annual increase in employment between 2007 and 2013 (Yamazaki, 2017). A DID study on the same BC carbon tax found that GDP growth in BC kept pace with the rest of Canada, and was not significantly positively or negatively impacted in the four years after the tax (Elgie & McClay, 2013). Another study on the BC carbon tax using a standard vector autoregression (VAR) framework found that there was no statistically significant impact on per capita GDP change (Bernard et al., 2018).

However, there are a few studies that find negative or more complex effects on these economic measures. One study on French manufacturing establishments found a trade-off between environmental and economic goals: a 10% increase in energy prices caused by a carbon tax brought down energy consumption by 5% and CO2 emissions by 11%, but also induced statistically significant modest negative impacts on employment by -0.8% and total factor productivity by -1.7% (Marin & Vona, 2021). The authors utilized an OLS regression model with logged outcome variables, utilizing detailed firm-level data on energy consumption and expenditure by energy input as well as detailed employee-level data on wages and overall employment (Marin & Vona, 2021). The study also found that this trade-off between environmental goals and job losses was amplified for energy-intensive and trade-exposed sectors, the latter being affected because those sectors could not pass higher energy prices over to their consumers (Marin & Vona, 2021). A study on BC's carbon tax utilizing a revised synthetic control method (SCM) tailored to their firm-level employment data found that impacts of the carbon tax on employment were heterogeneous – large emission-intensive firms reported negative impacts on employment, but small businesses in the service sector and food and clothing manufacturing reported positive impacts on employment, most likely due to the simultaneous tax cuts and transfers that increased the purchasing power of low-income households (Azevedo et al., 2023). The same study found that aggregate employment was not adversely affected by the policy, providing evidence to support the "job-shifting hypothesis" that employment will simply move from emission-intensive firms to other types of firms (Azevedo et al., 2023). These results run somewhat contrary to what most other literature has suggested and complicate the economic effects of the policy, implying there is still discussion to be had on the economic consequences of a carbon tax and how they may vary by region, industry, and sector.

There are a few gaps in the literature. Most studies only look at the effect of one policy on one region at a time. This provides clean treated and control groups and clean pre- and post-policy periods, which serve well for DID models. Few studies look into the effect of multiple types of carbon policies simultaneously. In the past few decades, Canada has enacted three different types of policies – carbon taxes, credit systems, and CAT systems – and no studies have looked into the effects of all three. This is most likely because most of these policies have only been provincially implemented in recent years (2017 and beyond). Very few studies have been done on Canada's most recent federal carbon policies implemented in 2019.

My research is similar to the work of Akio Yamazaki (2017). Yamazaki used industry-level data from Statistics Canada to perform his analysis of the carbon tax; his merged dataset included 68 industries, 11 provinces, and 13 years (2001-2013)[1] (Yamazaki, 2017). My research utilizes the same data source but includes data from 2004-2022 and all thirteen provinces. Yamazaki's theoretical model illustrates three channels through which a revenue-neutral carbon tax can affect employment: (1) the *output effect* where the tax reduces labor demand due to a decrease in output, thereby reducing output and employment, (2) the *re-distribution effect* where redistributing tax revenues through lump-sum transfers stimulates labor demand through increases in product demand and consequently raises output and employment, and (3) the *factor substitution effect* where energy is easily substitutable with

[1]For Yamazaki's research, industrial GHG emission data was only available at the national level from 1990-2008. The author assumed that national GHG emission intensity data for each industry serves as a proxy for each industry in all provinces. While the emission intensity level might be different across provinces for each industry, the relative emission intensity level across industries within provinces is likely to be the same. Thus, national GHG emission intensity data was deemed sufficient and the author imputed industrial and provincial level data for the necessary years for GHG emissions.

labor, raising employment. My research uses similar channels, outlined in section 3. Yamazaki performs the simplest model of DID analysis, comparing BC with the rest of Canada in the years before and after the provincial carbon tax (Yamazaki, 2017). My research expands beyond the BC carbon tax by accounting for multiple carbon policies enacted over the past two decades across all provinces. My research utilizes a DID model with two-way fixed effects, then expands it by interacting the policy variable with sectors, emission intensity, energy intensity, and innovation levels to see how the policy effects vary. In addition, my research utilizes a mediating model to decompose the direct and indirect effects of the policy on emissions through reduced economic activity.

2.2 Canadian Carbon Policy

Canadian carbon policy began at the provincial level; Quebec became the first Canadian province to impose a carbon tax on energy producers, at around \$3.50/ton CO_2e ("Fact Sheet — Carbon Pricing around the World", 2012). British Columbia followed close behind with a carbon tax in 2008 at \$10/ton CO_2e (Ministry of Finance, n.d.). In the years after, several provinces followed suit in implementing their own provincial carbon policies until 2019, when the Canadian government passed a federal policy requiring all provinces to implement carbon policies that met or exceeded federal standards. These federal standards will be referred to as the federal system. The only provinces not subject to the federal system were those that already possessed a carbon tax or emissions regulation system that met federal standards. Provinces that chose to opt out of the federal system had to prove their provincial standards were as or more stringent.

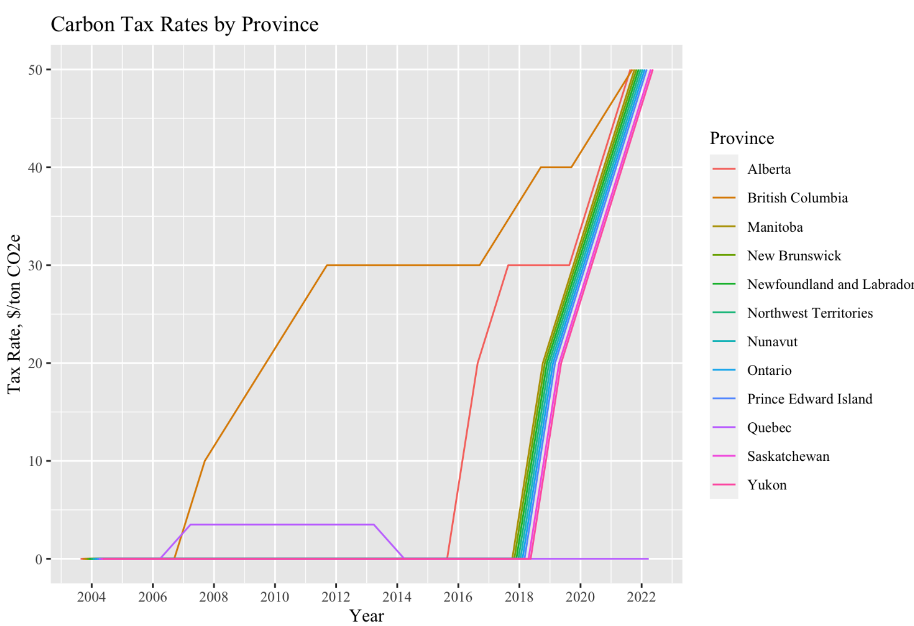
When federal carbon policy was enacted in 2019, six provinces adopted its regulations – Manitoba, New Brunswick, Nunavut, Ontario, Saskatchewan, and Yukon. The federal system has two mechanisms – a federal carbon tax (also known as a federal fuel charge) and a federal baseline and credit system, called the Federal Output-Based Emissions Pricing System (OBPS) ("Canadian Carbon Pricing Mechanisms", 2020). Not every province that chose to implement the carbon tax needed to have a baseline and credit system. The federal carbon tax applied at the following rates: \$20/ton CO_2e in 2019, \$30 in 2020, \$40 in 2021, and \$50 in 2022. The Federal OBPS applies only to industrial facilities that emit more than

50,000 tons of CO_2e/year ("Canadian Carbon Pricing Mechanisms", 2020).

There are three main categories of carbon pricing mechanisms in Canada: carbon taxes (also known as fuel charges), baseline and credit systems (credit systems), and cap-and-trade (CAT) systems ("Canadian Carbon Pricing Mechanisms", 2020). The numerous carbon pricing mechanisms in Canada all fit into these three categories.

Carbon taxes, the most common policy, apply an additional charge to the price of fossil fuels based on the fuel's carbon content, and consequently, how much CO_2 is expected to be released into the atmosphere upon fuel usage ("Canadian Carbon Pricing Mechanisms", 2020). Because different fuels have varying carbon contents (lower carbon fuels like propane will have lower fuel charges, higher carbon fuels like coal or diesel will have higher fuel charges), the price of the carbon tax is usually aggregated into a comprehensive dollar amount per ton of CO_2 emitted into the atmosphere. The data in this research utilizes these units for all carbon policies. Carbon taxes have been enacted at both the provincial and federal levels of government ("Canadian Carbon Pricing Mechanisms", 2020).

Figure 1: Carbon Tax Rates by Province (2004-2022)

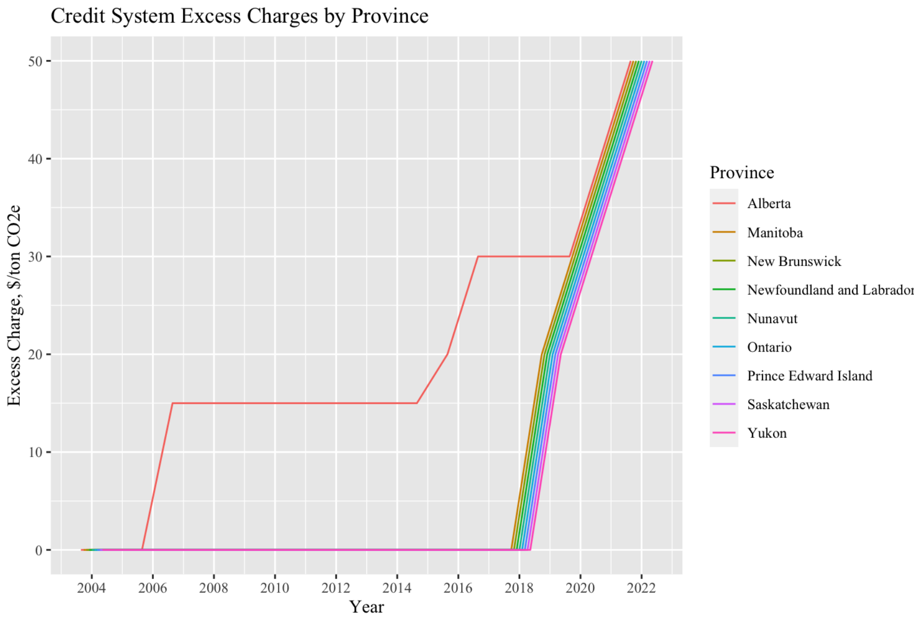


Note: Nova Scotia is omitted from this graph because it has never had a carbon tax. Several provincial policies had the same tax rates implemented at the same time, especially after 2019. For this reason, the positions of the lines representing the different provinces have been shifted slightly to distinguish them. No tax rates are displayed monthly; all rates are yearly. For example, 9 provinces implemented a carbon tax rate of \$20/ton CO_2 in the year 2019.

Figure 1 shows the timeline of carbon tax rates by province. The majority of provinces started carbon taxes in the year 2019, due to federal requirements. Quebec, British Columbia, and Alberta are the only three provinces with carbon taxes that do not match the federal carbon policy timeline. Quebec had the earliest tax rate in 2007, however, British Columbia's lasted longer, from 2008 to the present day. Alberta started its carbon tax significantly later in 2017.

Baseline and credit systems, the second most common type of policy, apply only to industrial emissions ("Canadian Carbon Pricing Mechanisms", 2020). The government allocates a "baseline" amount of emissions that each industrial facility is allowed to release. If the facility emits less than the baseline, it earns "credits" that can be used to offset emissions in the future, but if the facility emits more than the baseline, it will be required to buy credits from the government, and thus suffer a penalty ("Canadian Carbon Pricing Mechanisms", 2020). The data in this research uses these credit prices, or excess charges, to represent the monetary penalty firms experience. Credit system programs across Canada's provinces have several names – Output Based Pricing System (OBPS), Technology Innovation and Emissions Reduction (TIER) Regulation, Emissions Performance Standard System (EPS) – but all operate with the same basic guidelines ("Canadian Carbon Pricing Mechanisms", 2020). The main differences between the different credit systems are usually the threshold of emissions that qualify an industrial facility to be subject to the system, i.e. some systems apply to industrial facilities that emit more than 25,000 tons of CO_2e/year while others put the limit at 50,000 or 100,000 tons of CO_2e/year. Credit systems, like carbon taxes, have been enacted at both the provincial and federal levels.

Figure 2: Credit System Excess Charges by Province (2004-2022)

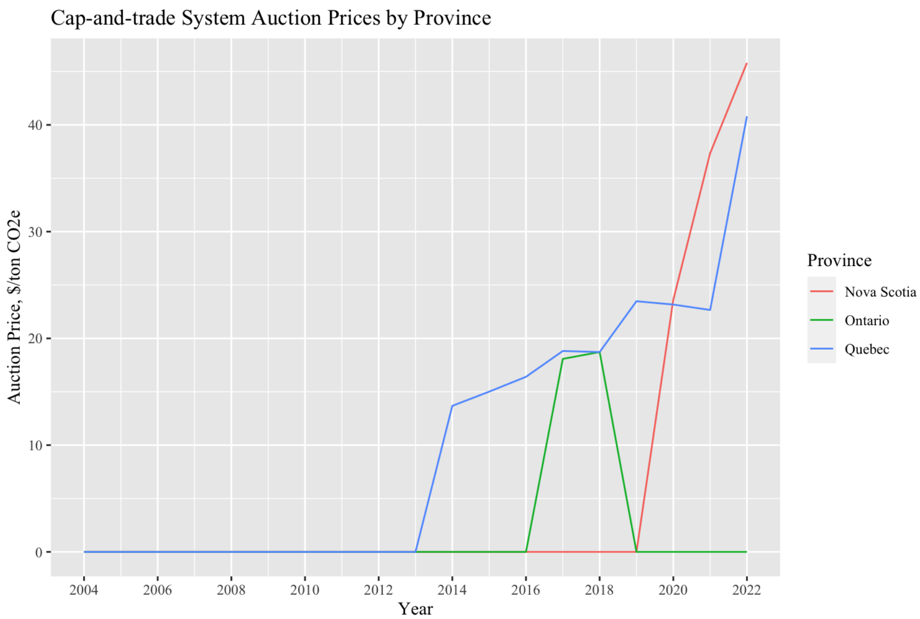


Note: British Columbia, Northwest Territories, Nova Scotia, and Quebec are omitted because they have never implemented credit systems. Like Figure 1, the positions of the lines representing the different provinces have been shifted slightly to distinguish them. No tax rates are displayed monthly; all rates are yearly.

Figure 2 shows a timeline of the excess charges of credit systems by province. The federal credit system's excess charge timeline starts in 2019, and most provinces follow this. Most credit systems are enacted only in conjunction with carbon taxes; Alberta is the only province that does not, starting in 2007.

CAT systems are the least common policy, and also only apply to industrial emissions ("Canadian Carbon Pricing Mechanisms", 2020). CAT systems set a "cap" on the total amount of emissions that can be released within a jurisdiction. Emissions underneath this cap are distributed credits that can be bought or sold between industrial facilities. If a facility releases less emissions than their allocated or purchased amount, they earn credits they can trade to other facilities in a carbon credit "market." The credits can also be directly auctioned off by the government. The price of the credits in this system is market-defined ("Canadian Carbon Pricing Mechanisms", 2020). Since market prices of these credits are allowed to fluctuate, the units used in the data to define the penalty of the CAT system is the average market-based credit price, or auction price. CAT systems have only been enacted at the provincial level.

Figure 3: Cap-and-Trade Auction Prices by Province (2004-2022)



Note: The only provinces included are Nova Scotia, Quebec, and Ontario, as these are the only provinces that have implemented CAT systems. All values correspond to a specific year, although the graph shows the lines slightly skewed to maintain visibility.

Figure 3 shows a timeline of auction prices in CAT systems by province. Quebec was the earliest to implement a CAT system in 2013, followed by Ontario in 2016 and Nova Scotia in 2019. Ontario dropped its CAT system in 2019, however, because it instituted provincial carbon policies that matched the federal system.

All three provinces that have instituted CAT systems use a combination of auctioning and free distribution to allocate carbon credits to emitters. In Quebec, most credits are distributed by auction, but some emitters that are exposed to national and international competition receive a certain amount of GHG emission units from the government without charge (Government of Quebec, 2024). In Nova Scotia, there is a regular auction for emission allowances two to four times a year, but participants in the CAT system who meet certain requirements can receive free emission allowances from the government from a few methods: (1) industrial facility allocation based on a production intensity benchmark, (2) direct allocation to Nova Scotia Power Inc. based on reduction from business-as-usual projection, and (3) fuel supplier allocation based on verified GHG reports (Department of Environment, 2019). In Ontario, there is a regular auction, and some eligible capped emitters will receive emission allowances free of charge[2] (Government of Ontario, 2024). However, the rate of free allowances decreases over time because the free allowances are meant to be used as a transitional measure for firms with infrastructure that rely heavily on emissions (Government of Ontario, 2024). Firms are heavily encouraged to take action to reduce their emissions, as free allowances will not be as available in future years.

The policy variables for the dataset are constructed by collecting information from various Canadian government websites and Statistics Canada on the implementation and rates of various policies. In the dataset, carbon taxes have three variables describing their implementation: a binary indicator variable indicating the implementation of the policy in the province for the specific year, a categorical variable denoting the governmental origin of the policy (federal or provincial), and a continuous variable for the carbon tax rate. Credit systems also have three variables: a binary indicator variable indicating implementation of the policy in the province for a specific year, a categorical variable denoting the governmental origin of the policy (federal, provincial, or federal and provincial), and a continuous variable the government-set excess charge of credits. CAT systems have two variables: a binary indicator variable indicating the implementation of the policy in the province for the specific year, and a continuous variable indicating the annual average market-defined auction price of credits. All continuous variables are measured in dollars per ton of CO_2e.

3 Theoretical Framework

This section introduces the theoretical framework underlying this research. Firms are the economic agents in the model; they are affected by carbon policies and the costs of emitting carbon, and their objective function is to maximize profits and minimize costs. Including the added cost of carbon, the cost function firms experience is modeled by equation (1).

[2] In Ontario, allowances are not given free of charge to fuel suppliers/distributors, electricity importers, and most electricity generators. These companies have to purchase allowances at auction or from the secondary market.

$$
\begin{aligned}
c(q; P_L, P_K, P_e) = \min_{L,K,e} P_L * L + P_K * K + P_e * e \\
\text{s.t. } q = f(L, K, e)
\end{aligned} \tag{1}
$$

L, K, and e are labor, capital, and emissions respectively, and P_L, P_K, and P_e represent the corresponding prices of each. The cost is dependent on the quantity of production q, which is a function of labor, capital, and emissions. When there is no carbon policy in place, the price of emissions P_e is zero, canceling out the third term. However, once the policy is instituted, the third term comes into play. The price of emissions is determined by the exact carbon tax rate instituted by the government, the excess charge of credits imposed by a credit system, or the auction price of emissions allowances in a CAT system.

Equation (2) displays the firm's profit function. p is the price of the good or service being produced and q is the quantity of production. Firms seek to maximize revenues minus costs.

$$
\pi = \max_{q} p * q - c(q) \tag{2}
$$

Firms are assumed to have control over inputs L, K, and e, which are all continuous inputs. When experiencing a novel cost on emissions, P_e rises and firms must choose how to restructure their internal processes to meet this new cost constraint. There are a few channels through which a firm's choices can affect emissions, production, and employment.

To minimize costs imposed by carbon policies, firms can respond by reducing overall production – this is the first channel. In this framework, production is assumed to be a function of L, K, and e. Reducing production decreases the levels of all inputs, including reducing employment and capital inputs. This will be referred to as the *direct cost channel*. In the context of emissions regulations, firms that emit carbon would simply stop producing as much of their product or shut down altogether because of the added cost of their byproduct. However, there are some spillover effects to this channel, as the policies may benefit some industries indirectly. A reduction in production and employment in emission-intensive industries can cause an increase in production and employment in clean-energy industries as workers move to industries with more stable future employment trends.

A second channel is for firms to replace emissions- and energy-intensive inputs with labor (L). When P_e increases, if a firm does not want to decrease production, it may have the ability to replace emissions-generating inputs with manpower. This would result in employment increasing and emissions decreasing. The effect on production would be ambiguous, as the increase in labor may or may not be able to adequately replace the productivity of the initial energy inputs. This will be referred to as the *energy-labor substitution channel*. In the context of emissions regulations, firms reduce the use of energy inputs like coal, natural gas, and petroleum, and replace those inputs with manpower and physical labor. This may increase employment among low-skilled workers who now have to make up in manpower the work that fossil fuels were originally accomplishing. However, for some firms, this might be improbable – the functions accomplished by energy sources may not be replaceable by human labor.[3]

A third channel is for firms to replace emissions- and energy-intensive inputs with capital (K). If a firm does not want to drastically decrease production when P_e increases, it may have the ability to replace emissions-producing inputs with different technologies or innovations. This would cause emissions to decrease, while the effect on production and employment would be ambiguous. The increase in capital may or may not be able to adequately replace the productivity of the initial energy inputs, and labor does not have a distinct positive or negative relationship with capital usage. This will be referred to as the *energy-capital substitution channel*. In the context of emissions regulations, firms can approach increasing the amount of capital in a number of ways. One, they can invest in energy technologies that are more sustainable and less polluting than previous energy sources. Two, they can invest in the innovation, research, and development of sustainable energy technologies for the future. Three, they could switch to different fuel sources that emit less carbon than previous energy sources, therefore reducing the amount of taxes they have to pay. Each of these would involve changing some production infrastructure to match new energy sources, which is why they are classified as capital substitutions. It is important to

[3]For example, fossil fuels are often burned to heat water, which turns into steam and drives turbines. This process of heating water to drive turbines is not achievable through human labor.

note that investing in different energy technologies, investing in innovations and development in sustainable energy technology, and changing infrastructure to switch to different fuel sources each take time to manifest. These changes may take months or years, which makes it important to consider lagging industry characteristics in our empirical model to view the impacts of carbon policies.

Finally, there is another channel through which production and employment can be bolstered by carbon policies, but it does not involve firm choices. Rather, it involves the government redistributing the revenue from carbon taxes. This will be referred to as the *redistributive effect*. The first way the government could redistribute the tax revenue is by giving it back to the population through tax returns or frequent payments. This puts more money in the pockets of consumers, who can then spend that money and increase the demand for goods and services, thereby increasing the demand for labor. This method increases both production and employment in specific industries, especially services and goods and manufacturing industries that interact the most directly with consumer disposable income. A second way is to subsidize firms that use, produce, are conducting research in, or innovating in sustainable energy. This lowers the costs of such firms, increasing their production and employment. It also incentivizes the investment and growth of sustainable energy in the overall economy.

Overall, each channel reduces overall emissions, except for the redistributive effect. The direct cost channel reduces production and employment. The energy-labor substitution effect increases employment. And the redistributive effect increases production and employment, just not in the industries that experience the costs of the carbon policy most severely. The balancing of each of these effects on the outcome variables is what this research studies. We hypothesize that all three policies will reduce carbon emissions and impact each outcome variable similarly, as they all impose some monetary penalty on the firm. Production, employment, hours worked, wages, and earnings will either be positively or neutrally impacted overall by carbon policies, aligning with previous literature. Carbon policies will most strongly affect the sectors that emit the most carbon (Mining, Oil, Gas, Electricity and Manufacturing), both in terms of emission reduction and economic activity. Continuing with this logic, we expect the most emission-intensive industries, energy-intensive industries, and industries that innovate the most to reduce emissions to be most affected by carbon policies, experiencing lower emissions, but also lower GDP, employment, and other labor measures.

4 Data

Primary data is compiled from Statistics Canada, the national statistical office legislated by the Canadian Statistics Act to provide statistics as a federal responsibility (Statistics Canada, 2008). The variables used in this analysis are broken down into three groups: outcome variables, industry characteristics, and control variables. The outcome variables are greenhouse gas (GHG) emissions measured in kilotons of CO_2e, GDP in 2012 dollars measured in millions, number of paid workers jobs, hours worked of paid workers measured in thousands of hours, and wages and salaries for paid work measured in thousands of dollars. The industry characteristics are GHG emission intensity measured in tons of CO_2e per $1000 of production[4], energy intensity measured in gigajoules (GJ) per $1000 of production, and percent innovations that reduce GHG emissions for the periods 2015-17 and 2017-19 measured in percentage points. The control variables are total population and working age population.

The chosen time range for the dataset is 2004-2022; it encompasses three years before the earliest carbon tax was implemented in Quebec until the most recent years after policy implementation. However, GHG emissions are only available from 2009-2021[5], and this limitation implies there is no pre-carbon policy period of emissions data for British Columbia and Quebec. The emission intensity and energy intensity variables are only available until 2019, so the range of time for these variables is from 2004 to 2019. Finally, the variable representing percent innovations that reduced GHG emissions for the end user consumer is available as a constant – one variable representing the innovation levels for the period 2015-17 and one for 2017-19. The regression analyses in this paper only utilize innovation data from the period 2015-17.

All data available at the province, industry, and year level is merged using these

[4]Emission intensity is not imputed from emissions and GDP measures because emissions data is only available after 2009, and this analysis requires data from all possible periods.

[5]Missing emissions data after 2009 are imputed as zeros.

characteristics.[6] However, data on industry characteristics are not classified by province, so they are merged by industry and year. And control variables are not classified by industry, so they are merged only by province and year. A description of all variables is shown in Table A1, and a table of all industries utilized in this analysis is shown in Table A2, both in the Appendix.

There are 24,947 observations in total. There are no missing values for all labor variables. However, several other variables are missing data. GHG emissions is missing 11,302 values, mostly due to a lack of data before 2009. Emission intensity, energy intensity, and innovations variables are each missing between 4000-7000 values.

Statistics Canada is particularly suited for this study because of the consistency in measurements over the past few decades and its categorization of data by NAICS code. This allows for the examination of the effects of the policy on outcomes using entries available by industry. The industries can also be easily classified into economic sectors using the pre-existing NAICS code structure, the heterogenous impacts of policies can be observed by sector. The span of available data is also well-suited to analyze the effects of more recently implemented policies.

4.1 Outcome Variables

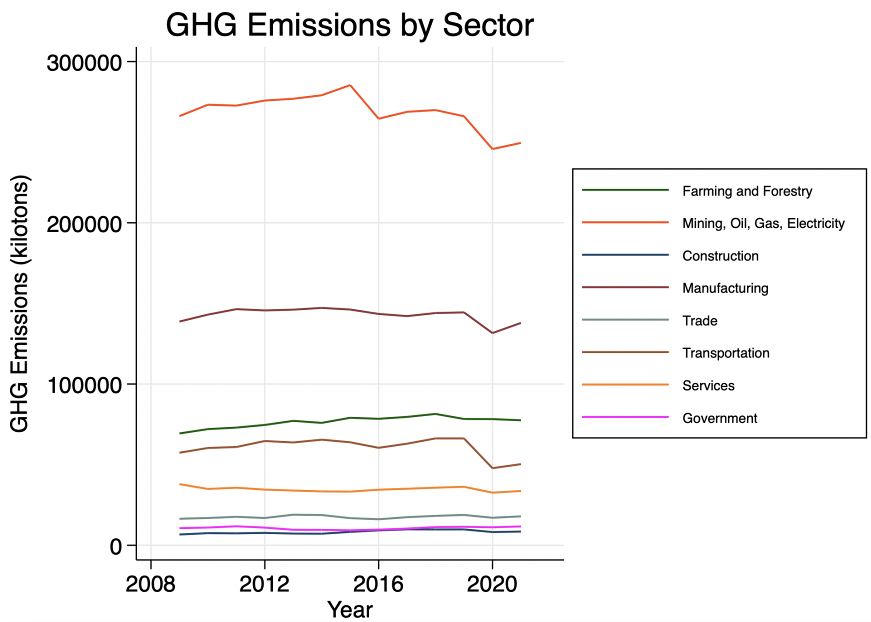
The outcome variables are chosen to see the direct environmental and economic impacts of carbon policies. It is pertinent, of course, to directly look at emission levels. To observe macroeconomic characteristics that represent the health of the economy in a way that is meaningful to policymakers, GDP, employment, hours worked, and earnings are chosen to highlight the impacts on production and employment health.

The dataset includes variables measuring greenhouse gas (GHG) emissions in kilotons of CO_2e (Statistics Canada, 2023g), GDP in 2012 dollars in millions (Statistics Canada, 2023d), and labor statistics, including number of paid workers jobs, hours worked of paid workers in thousands of hours, and wages and salaries for paid work in thousands of dollars (Statistics Canada, 2023f). Data is observed for all thirteen Canadian provinces.

[6] Due to small changes in industry specifications over time, crosswalks were utilized to merge the datasets properly. Industries were combined/renamed to be homogenous across all variables and years.

It is important to view trends and concentrations in outcome variables that vary by sector to note which sectors contribute the most to emissions and the economy. Figure 4 displays GHG emissions by sector[7], and Figure B1 in the Appendix displays GDP and employment by sector.

Figure 4: GHG Emissions By Sector (2009-2021)



Note: This figure plots GHG emissions over 12 years by sector to see the contributions of each sector to each measure.

Figure 4 shows that Mining, Oil, Gas, Electricity has the highest levels of emissions, followed by Manufacturing, then Farming and Forestry, and Transportation. Most sectors have remained fairly constant in their emission levels over the period displayed. All sectors experience a decline in emissions after 2019, which then either increases or levels out in each sector.

Figure B1 from the Appendix highlights that the Services sector contributes the most to GDP and employment. Mining, Oil, Gas, Electricity, Manufacturing, Farming and Forestry, and Transportation all have low employment and contributions to GDP compared to Services. GDP and employment have been steadily increasing in the Services sector over the period displayed, while all other sectors have remained fairly constant. All sectors

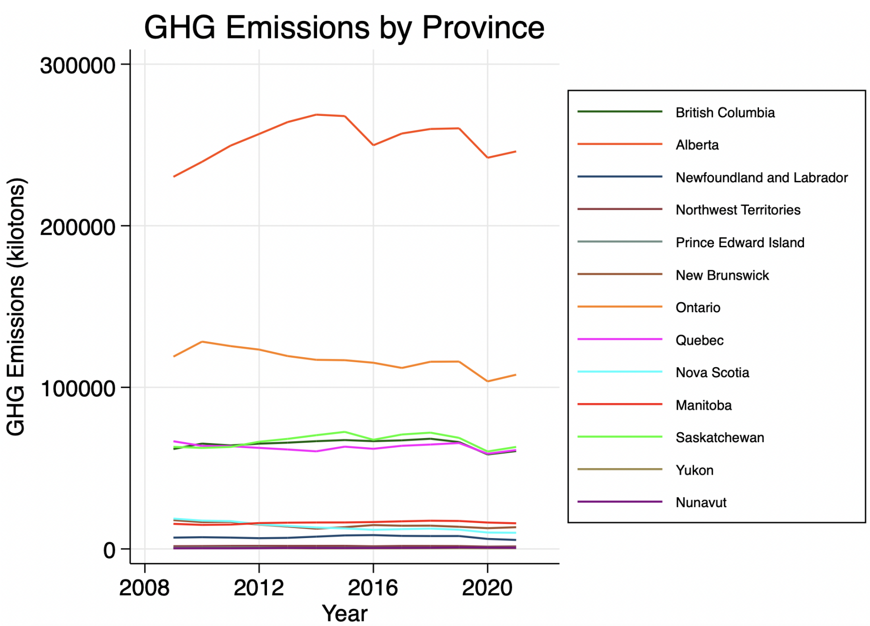
[7]Sectors are defined in the notes of Table A2 in the Appendix.

experience a slight decline in GDP and employment after 2019, which then increases or levels out.

It is important to highlight that Mining, Oil, Gas, Electricity and Manufacturing emit the most greenhouse gases, but employment in these sectors is fairly low. In addition, the Services sector employs the most people and contributes the most to GDP, but emits at relatively low amounts compared to other sectors. This implies that the majority of workers in Canada are not in sectors that produce heavy emissions, and there are relatively low numbers of workers and amounts of production concentrated in the Mining, Oil, Gas, Electricity and Manufacturing sectors.

It is also useful to view trends and concentrations in outcome variables by province to note which provinces contribute the most to emissions and have the largest economies. Figure 5 displays GHG emissions by province, and Figure B2 in the Appendix displays GDP and employment by province.

Figure 5: GHG Emissions By Province (2009-2021)



Note: This figure plots GHG emissions over 12 years by province to see the contributions of each province to each measure.

Figure 5 shows that Alberta and Ontario are the main polluters in Canada, with Alberta out-polluting Ontario by almost double. All other provinces are below the 100,000 kilotons/year mark. Most provinces have constant emission levels or show a slight downward trend, and almost all provinces show lower emission levels after 2019, which then level out or increase slightly in each province after 2020.

Figure B2 from the Appendix shows that employment and GDP follow each other fairly closely when broken down by province. Ontario, Quebec, Alberta, and British Columbia are the provinces with the highest GDP and employment levels, with Ontario leading in both measures over the period. All other provinces produce less than \$100 billion in GDP and employ under 2 million workers. Both GDP and employment seem to have upward trends throughout the period. There is a slight downward trend in 2019 in almost every province, which goes back up after 2020.

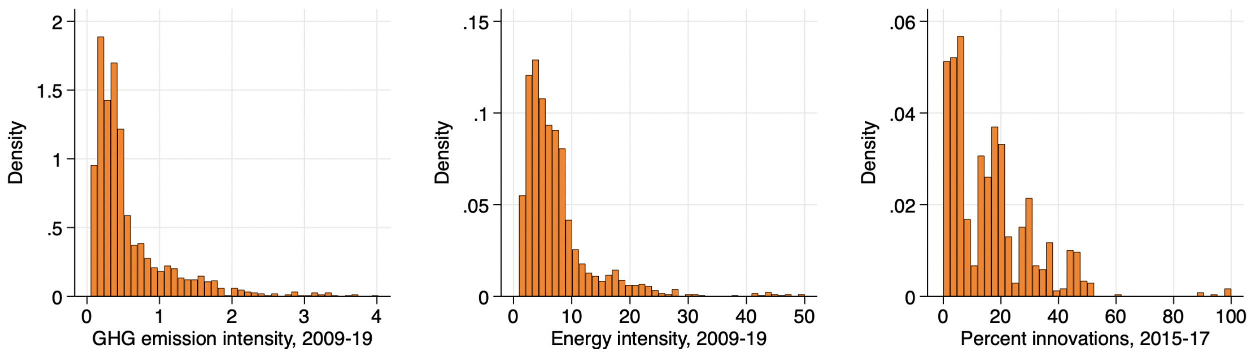
4.2 Industry Characteristics

Industry characteristics are used in the analysis to see the effects of carbon policies on industries that are more or less emission-intensive, energy-intensive, or likely to innovate to reduce emissions. Firms that are more emissions- or energy-intensive may be more inclined to utilize the direct-cost, energy-labor substitution, or energy-capital substitution channels to reduce emissions, so changes in employment and capital that reflect their internal changes are expected. Seeing the heterogeneous effects of carbon policies across industries of different functional conditions is useful in determining if industries that are the most carbon-intensive are truly affected.

Data on GHG emission intensity measured in tons of CO_2e per \$1000 of production, energy intensity measured in gigajoules (GJ) per \$1000 of production (Statistics Canada, 2023c) (Statistics Canada, 2023b) (Statistics Canada, 2023a), and percentage of firms that increased innovations that reduced GHG emissions in the periods 2015-17 and 2017-19 separately (Statistics Canada, 2023e) is included in the dataset. Figure 6 displays the distributions of each of these variables.[8] All three variables are skewed right, with most industries possessing low values of emission intensity, energy intensity, and percent innovations. Most industries have emission intensity values between 0 and 1 tons, energy intensity values between 0 and 10 GJ, and innovation levels between 0 and 20%.

[8] Innovation data from 2017-19 is not displayed because only data from 2015-17 is used in the analysis.

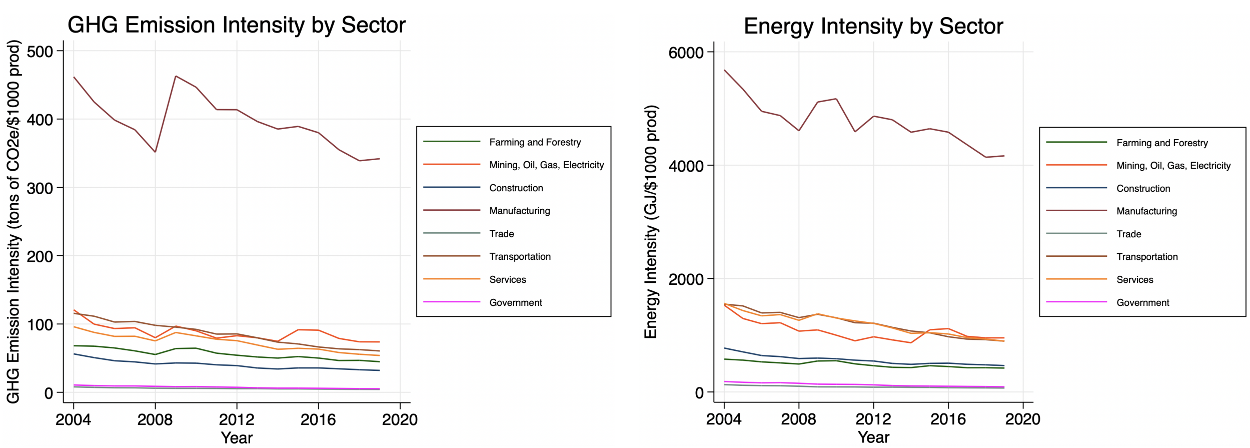
Figure 6: Distributions of Industry Characteristic Values



Note: These are histograms displaying the distribution of the values for each industry characteristic variable. The histograms utilize values for all years.

Figure 7 shows trends in average emission intensity and energy intensity by sector. Both measures have generally been declining over the observed periods. This may be due to increased efficiency in production processes over time. Manufacturing has the highest emission intensity and energy intensity – all other sectors are below 200 tons of CO_2e/\$1000 of production and below 2000 GJ/\$1000 of production. Manufacturing is also the second-largest emitting sector, as seen in Figure 4, so impacts on this sector will have widespread effects on the economy. Government and Trade have the lowest intensities for both measures.

Figure 7: Emissions and Energy Intensity by Sector (2004-2019)



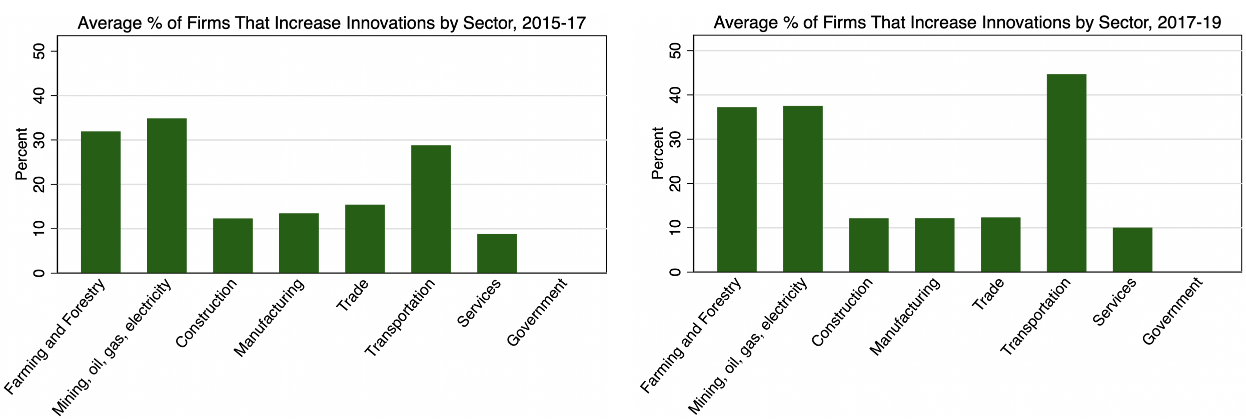
(a) GHG Emission Intensity by Sector **(b)** Energy Intensity by Sector

Note: These graphs plot GHG emission intensity and energy intensity amounts by sector to see which sectors are the most intensive.

Normalizing emission and energy intensity for each sector to 2004 levels is useful to see how each sector's intensity levels have reacted and changed over time. Figure B3 in the Appendix shows this. The trends are fairly volatile, but all sectors show decreasing emission and energy intensity after 2004. No sector reaches under 45% of 2004 intensity levels. The Mining, Oil, Gas, Electricity and Construction sectors see the most drastic relative decreases in both measures for earlier years (roughly 2004-2010). In later years, the Manufacturing and Farming and Forestry sectors seem to have relatively declined the least for both measures.

Because innovations are only present for specific periods (2015-17 and 2017-19), they are fixed and will represent the innovative tendencies of each industry. They will still be referred to as industry characteristics in this paper. Only entries that aggregate all enterprise sizes is utilized in the dataset. Data quality for each measure is considered reliable, except innovations data, which has quality levels ranging from "excellent" (A) to "use with caution" (E). Figure 8 shows the average percentage of firms in each sector that increased innovations to reduce GHG emissions in each period.

Figure 8: Average Percent of Firms that Increased Innovations to Reduce Emissions, By Sector



(a) 2015-2017 **(b)** 2017-2019

Note: These bar graphs plot innovations data by sector to see which sectors innovate the most. There is no data on innovations in the government sector for either period.

For the 2015-17 period, Farming and Forestry, Mining, Oil, Gas, Electricity, and Transportation were the sectors with the highest average innovation levels. Services consistently had the lowest average innovation levels. Overall, there are higher average percentages of innovation levels in 2017-2019 than in 2015-2017, especially in Farming and Forestry, Mining, Oil, Gas, Electricity, and Transportation, all sectors with high emissions. This may imply that as carbon policies are implemented, emitting sectors feel more encouraged to innovate to reduce emissions and use less carbon-reliant processes.

4.3 Control Variables

Population variables are included as controls in the analysis to account for the number of people in society and the economy that are directly contributing to levels of production, employment, and emissions.

Data on population (Statistics Canada, 2023h) is included in the dataset, and then subset to create the variables used in the analysis. For the total population variable, entries from both sexes and all ages were aggregated. To create the working age population variable, entries from both sexes but only ages 15-64 were aggregated. Both population and working age population were steadily increasing over the time range of this study.

4.4 Comparative Summary Statistics

Table 1 displays the main summary statistics of the outcome, moderating, and control variables included in the analysis.

Table 1: Summary Statistics of Outcome, Moderating, and Control Variables

Variable Name	Obs	Mean	Std. Dev.	Min	Max
GHG emissions (kilotons)	17069	472.38	3999.31	0	136430
GDP in 2012 dollars (millions)	24947	1321.88	4134.04	0	84385.3
Number of paid workers jobs	24947	14079.43	49041.61	0	766260
Hours worked of paid workers (thousands)	24947	23785.8	77726.52	0	1247764.3
Wages and salaries for paid work (thousands)	24947	704738.16	2325961.4	0	43346648
GHG emission intensity (tons/$1000 production)	20800	.58	.57	.05	4.02
Energy intensity, (GJ/$1000 production)	20475	7.44	6.31	.94	50.01
Percent innovations that reduced GHG emissions 2015-17	18981	16.1	14.59	0	100
Province total population	24947	2705615.2	3904969.3	29857	15109416
Province working age population	24947	1838812.9	2654625.2	18815	10047573

Note: The first section is outcome variables, the second is moderating variables (industry characteristics), and the third is control variables. Each variable in this table summarizes the statistics for all years that the variable is available for.

GHG emissions has significantly fewer observations than the maximum number of observations from the variables by almost half because of the year limitations. All moderating variables also have fewer observations. Note the mean values of the moderating variables – similar values will be used in predicting the effects of carbon policies on carbon-intensive firms in the mediating models.

In the following subsections, different sections of the data are compared to better understand the distributions and trends in the variables.

4.4.1 Before and After Federal Carbon Tax

The federal carbon policy went into effect in 2019, applying to all Canadian provinces except those that already had provincial carbon policies that met federal standards. This federal policy is a significant shock to the Canadian economy, so one would expect to see a decrease in average emissions after 2019. Table 2 depicts the summary statistics before and after the federal carbon policy went into effect to highlight changes in key variables.

Table 2: Summary Statistics Before and After Federal Carbon Policy

	Before 2019		2019 and After	
Variable	Obs	Mean (Std. Dev.)	Obs	Mean (Std. Dev.)
GHG emissions (kilotons)	13130	477.66 (3978.44)	3939	454.77 (4068.56)
GDP in 2012 dollars (millions)	19695	1277.49 (3927.73)	5252	1488.34 (4826.64)
Number of paid workers jobs	19695	13762.75 (47850.76)	5252	15266.98 (53258.81)
Hours worked of paid workers (thousands)	19695	23330.55 (75946.97)	5252	25492.96 (84050.76)
Wages and salaries for paid work (thousands)	19695	649134.51 (2103238.7)	5252	913251.86 (3009297.8)
GHG emission intensity (tons/$1000 production)	19500	.59 (.57)	1300	.47 (.46)
Energy intensity (GJ/$1000 production)	19201	7.52 (6.36)	1274	6.25 (5.49)
Percent innovations that reduced GHG emissions 2015-17	14985	16.1 (14.59)	3996	16.1 (14.6)
Province total population	19695	2643703 (3811200.7)	5252	2937785 (4230488.4)
Province working age population	19695	1812396 (2611952.6)	5252	1937878 (2806925.3)

Note: Each variable in this table summarizes the statistics for all years that the variable is available for.

Average GHG emissions went down after the federal carbon policy, but both measures had fairly large standard deviations. GDP in 2012 dollars increased, as did all labor statistics (paid workers' jobs, hours worked, and earnings). Average values for both emission intensity and energy intensity decreased after 2019, which may suggest that energy efficiency increased after 2019. Average values of population and working age population increased after 2019.

4.4.2 Variables by Level of Emission Intensity

It is useful to view summary statistics of the outcome variables by different emission intensity levels, so differences across industries that rely more versus less on emissions can be discerned. Table 3 displays the summary statistics of the outcome and industry characteristics based on defined low, medium, and high emission intensity groupings. The category delineations are specified in the note below the table.

Table 3: Summary Statistics by Level of Emission Intensity

Emission Intensity Level:	**Low**		**Medium**		**High**	
Variable	Obs	Mean (Std. Dev.)	Obs	Mean (Std. Dev.)	Obs	Mean (Std. Dev.)
GHG emissions (kilotons)	11986	144.17 (574.95)	1937	1836.6 (9142.7)	2873	517.08 (3974.5)
GDP in 2012 dollars (millions)	17420	1357.73 (3921.69)	2678	950.24 (4449.05)	4355	1396.64 (4635.49)
Number of paid workers jobs	17420	15926.32 (52624.92)	2678	3760.48 (9150.49)	4355	14169.27 (50498.29)
Hours worked of paid workers (thousands)	17420	26751.14 (83296.8)	2678	7537.32 (18979.54)	4355	23684 (79846.95)
Wages and salaries for paid work (thousands)	17420	749971.7 (2330004.5)	2678	234023.24 (769596.96)	4355	862719.05 (2940299.1)
Energy intensity (GJ/$1000 production)	17277	5.51 (2.92)	2522	14.89 (4.74)	208	40.21 (9.37)
Percent innovations that reduced GHG emissions 2015-17	13002	14.53 (12.59)	2364	22.12 (20.41)	3189	16.33 (14.74)
Province total population	17420	2661253 (3837388)	2678	2663023 (3839721.2)	4355	2921459 (4211606.9)
Province working age population	17420	1820222 (2624253.6)	2678	1821552 (2626026)	4355	1929435 (2796113.3)

Note: The levels of emission intensity are defined as follows: emission intensity less than or equal to 1 ton/$1000 of production is considered low, over 1 and less than or equal to 2 tons/$1000 of production is considered medium, and greater than or equal to 3 tons/$1000 of production is considered high. Each variable in this table summarizes the statistics for all years that the variable is available for.

Most observations fall within the low intensity category. The high and low intensity categories contain the largest GDP, employment, number of hours worked, and earnings, while industries with medium emission intensity seem to have much lower means for all four measures. As expected, energy intensity also increases along with emission intensity. The percent of innovations that reduced GHG emissions was highest in the medium category, and lower for the most emission-intensive firms, showing this variable does not align as closely with emission intensity. Percent innovations also has relatively higher standard deviations.

5 Empirical Models

5.1 Baseline Empirical Model: DID with Two-way Fixed Effects

The baseline empirical model is a DID model with two-way fixed effects. This model is able to compare changes in outcomes in periods before and after policy enactment for many provinces with different policy enactment times. A policy treatment variable to indicate the presence or treatment intensity of the policy is used. Fixed effects for industry, province, and year are included.[9] The baseline empirical model is presented in equation (3).

$$Y_{jpt} = \gamma P_{pt} + \beta Z_{pt} + \sigma_j + \varphi_p + \theta_t + \epsilon_{jpt} \tag{3}$$

Y_{jpt} represents an outcome variable: GHG emissions, GDP in 2012 dollars, employment, hours worked, or earnings. A different regression can be estimated for each outcome variable. P_{pt} is the policy treatment variable; it can represent the presence of treatment (binary), the level of treatment (categorical)[10], or treatment intensity (continuous). When indicating the presence of treatment, P_{pt} takes on a binary value denoting the presence of a carbon tax, credit system, or CAT system. When indicating treatment intensity, P_{pt} takes on continuous numerical values representing the actual carbon tax rate, the excess charge of credits determined by the government, or the auction price of credits in CAT systems, all measured in \$/ton CO_2e. γ represents the percent change in the outcome variable caused by the presence of a carbon policy or a \$1 increase in the carbon policy rate (depending on

[9] The inclusion of province and year fixed effects makes this a two-way fixed effects model.

[10] Level of treatment is not utilized in any regressions as the policy treatment variable, but the data is there.

whether P_{pt} is indicating presence of treatment or treatment intensity). Z_{pt} denotes a vector of control variables, which includes total population and working age population. σ_j denotes industry fixed effects, to control for conditions that vary across different industries, but are constant over provinces and time. φ_p denotes province fixed effects, to control for conditions that vary across different provinces, but are constant across industries and time. θ_t denotes time fixed effects, to control for conditions that are specific to the year.

Our error term has several key assumptions. The policy shock is assumed to not be correlated with the error term ($cov(P_{pt},\, \epsilon_{it}) = 0$). All covariates are assumed to be exogenous. It is assumed that changes in outcome variables do not affect policy implementation, or their corresponding continuous values, in any way. In other words, the lawmakers and politicians involved in determining the implementation and monetary penalties of carbon policies are assumed to not be influenced by changing levels of GHG emissions, GDP, or labor characteristics. This assumption implies the model does not suffer from reverse causality, as changes in the outcome variables cannot influence the policy. Because our model is a DID model with two-way fixed effects, it cannot be tested for the parallel trends assumption; there are too many policy shocks implemented at different times, each requiring unique sets of treated and control groups.

5.2 DID with Sector Breakdown

Now that the previous model shows the effects of carbon policies on the overall economy, we look to separate the effects of the policies on outcomes in different economic sectors. The theoretical model shows that firms that are more carbon-reliant for their processes will be more negatively affected economically by carbon policies and vice versa. This is predicted through the direct cost, energy-labor substitution, and energy-capital substitution channels. It follows that sectors that are more carbon-reliant will be more intensely affected by carbon policies. For example, the Mining, Oil, Gas, and Electricity sector is more likely to be negatively impacted by a carbon policy given how carbon-intensive firms in the sector are. On the other hand, the Services sectors may not be impacted as negatively. Identifying the sectors of the economy that are most negatively impacted by specific carbon policies is insightful for policymakers who may be deciding whether to support carbon policy legislation or how best to inform their constituents of a policy change. A model incorporating industry sectors is presented in equation (4).

$$Y_{jpt} = \sum_{S=1}^{n_S} \gamma_S (P_{pt} * S_j) + \beta Z_{pt} + \sigma_j + \varphi_p + \theta_t + \epsilon_{jpt} \tag{4}$$

S_j is a categorical variable indicating the sector of an industry, and is interacted with the policy treatment P_{pt}. γ_S represents the percent change in the outcome variables caused by a carbon policy for sector S. n_S represents the number of sectors; since there are eight economic sectors, the model will produce eight separate γ_S coefficients for each sector.[11]

This model allows us to test the hypothesis by revealing how different economic sectors react to a carbon policy.

5.3 DID with Lagged Industry Characteristics

The effects of the policy on outcomes can also be broken down to show how effects vary for industries that are more or less carbon-reliant. The theoretical framework predicts that firms that rely more on emissions for their processes will be more negatively affected economically by carbon policies and vice versa. This is again predicted through the direct cost, energy-labor substitution, and energy-capital substitution channels. It follows that more emissions- and energy-intensive firms and firms that need to innovate more in technologies that reduce emissions will be affected more intensely by carbon policies than other firms; these are the firms that are more carbon-reliant. To view these variations in the effects of the policy, the policy treatment variable can be interacted with lagged industry characteristics representing emission intensity, energy intensity, and innovation level of the industry. The industry characteristic values are lagged so they are not correlated with the outcomes and represent the propensity of an industry to be reliant on carbon-intensive processes. Industries with different levels of these industry characteristics will have different coefficients representing the effect of the policy on their outcomes. A model incorporating lagged industry characteristics is presented in equation (5).

[11] The sector denominations and the industries encompassed within each are listed in the notes of Table A2 in the Appendix.

$$Y_{jpt} = \gamma_1 P_{pt} + \gamma_2 M_{j,t-2} + \gamma_3 (P_{pt} * M_{j,t-2}) + \beta Z_{pt} + \sigma_j + \varphi_p + \theta_t + \epsilon_{jpt} \tag{5}$$

$M_{j,t-2}$ is a lagged industry condition, taken 2 years before the observation. The lagged variable can represent emission intensity or energy intensity, which vary by industry. The lagged variable can also represent the percentage of firms that increased technological innovations aimed at reducing GHG emissions, but this variable is available as a constant from the years 2015-2017 ($M_{j,t=2015-17}$). For simplicity's sake, the subscript will remain $t-2$ in equation (5). P_{pt} and $M_{j,t-2}$ are interacted to observe the true effect of the carbon policy on the outcome variables by the lagged industry characteristic.[12] γ_1 represents the percent change in the outcome variable for an industry with an industry characteristic value of 0 caused by the presence of a carbon policy, or by a \$1 increase in the carbon policy rate. γ_2 represents the percent change in the outcome variable when there is no carbon policy from a one-unit increase in the lagged industry characteristic measure. γ_3 represents the percent change in the outcome variables when a carbon policy is present based on a one-unit increase in the lagged industry characteristic measure. Industries with higher intensities of characteristics will be more intensely impacted by γ_3.

This model allows us to test the hypothesis by showing the differing impacts of carbon policies on outcomes based on the carbon reliance of the industry.

5.4 Mediating Model

Revealing the varying effects of the carbon policy based on certain industry conditions is useful, but it is also important to understand the mechanisms through which the carbon policy is reducing emissions. As the direct cost channel in the theoretical framework shows, firms may rely on reducing production and employment to reduce their costs and comply with the policy, and this may cause lower emission measurements. This is the indirect method of reducing emissions. To model this relationship and decompose the direct and indirect effects of the policy on emissions, a mediating model is used, presented in equation (6).

[12] The model is only estimated with binary values of P_{pt}, indicating presence of the policy.

$$Y_{2jpt} = \alpha Y_{1jpt} + \gamma_1 P_{pt} + \gamma_2 M_{j,t-2} + \gamma_3 (P_{pt} * M_{j,t-2}) + \beta Z_{pt} + \sigma_j + \varphi_p + \theta_t + \epsilon_{jpt}$$
$$Y_{1jpt} = \gamma_1' P_{pt} + \gamma_2' M_{j,t-2} + \gamma_3' (P_{pt} * M_{j,t-2}) + \beta' Z_{pt} + \sigma_j' + \varphi_p' + \theta_t' + \epsilon_{jpt}' \tag{6}$$

This model has two equations, the first being the main one. We begin with the second equation: it is a baseline DID model with an interaction with a lagged industry characteristic. There are a few specifications. Y_{1jpt} represents a macroeconomic outcome variable like GDP, employment, etc. – any outcome variable but emissions. This equation shows the impact of the carbon policy on an economic outcome, quantified by adding $\gamma_1' + \gamma_3'$.[13]

The first (main) equation is the same as the second, but the outcome variable Y_{2jpt} only represents emissions, and the equation includes Y_{1jpt} (the outcome from the second equation) as an explanatory variable. This structure purports that emissions can be reduced by reductions in economic variables like production and employment. Firms cutting back on production, employment, etc. can cause lower emissions. From the mediating model, the decomposed direct, indirect, and total effects of the carbon policy on emissions are shown in the expressions below.

$$\begin{aligned} \text{Direct effect} &= \gamma_1 + \gamma_3 \\ \text{Indirect effect} &= \alpha(\gamma_1' + \gamma_3') \\ \text{Total effect} &= \gamma_1 + \gamma_3 + \alpha(\gamma_1' + \gamma_3') \end{aligned} \tag{7}$$

The direct effect is the portion of the percent reduction in emissions caused by directly reducing emissions, while the indirect effect is the portion of the percent reduction in emissions caused by the percent of reduced economic activity. The total effect is the percent change in emissions caused by the previous two effects. The expressions in (7) represent the decomposed effects assuming an emission intensity, energy intensity, or percent innovation level of 1. To calculate the decomposed effects for industries of emissions intensities other

[13] In calculating the effect of the carbon policy on the economic outcome using this expression, $M_{j,t-2}$ is assumed to be an emission intensity, energy intensity, or percent innovation level of 1. To calculate the effect for any other industry characteristic value, multiply γ_3' by the value and evaluate the rest of the expression as normal.

than 1, multiply each γ_3 and γ_3' by the emission intensity value and evaluate the rest of the expressions as normal.

Using this model, the mechanisms through which the carbon policies are impacting emissions are made clear. This model can help determine which policies have the least negative effects on economic activity while reducing emissions.

6 Results

6.1 DID with Two-way Fixed Effects

The results section begins with estimates of the baseline empirical DID model with two-way fixed effects (equation (3)) in Table 4. In this model, all three policies are included separately, and take on binary values indicating the presence of the policy. The purpose is to see the distinct overall impact of each policy type on each outcome. The regression is repeated multiple times for each outcome variable (GHG emissions, GDP in 2012 dollars, jobs, hours worked, and earnings). All regressions include industry, province, and year fixed effects, as denoted in the bottom rows of the table, as well as population and working population as control variables, which are excluded from the table. In addition, all entries with less than 500 employees were removed from the analysis to remove industries that are extremely small and may skew results. Note that since the natural logarithm was applied to all outcome variables, the coefficients represent percent changes in the outcome variables caused by the presence of a carbon policy.

Table 4: Outcome Variables Regressed on Carbon Policies

VARIABLES	(1) Emissions	(2) GDP (2012 Dollars)	(3) Paid jobs	(4) Hours worked	(5) Earnings
Carbon tax	-0.047	-0.051*	-0.029	-0.032	-0.094***
	(0.047)	(0.030)	(0.024)	(0.024)	(0.025)
Cap-and-trade system	-0.050	-0.031	-0.007	-0.004	-0.054
	(0.050)	(0.039)	(0.032)	(0.033)	(0.033)
Credit system	-0.035	0.030	0.022	0.025	0.059**
	(0.058)	(0.036)	(0.027)	(0.028)	(0.029)
Observations	9,961	14,537	14,537	14,537	14,537
R-squared	0.841	0.788	0.849	0.838	0.837
Industry FE	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: The natural logarithm was applied to the outcome variable in each regression. Each of the policies is a binary variable. Control variables (population and working population) are included in the regressions but omitted from the table. Industries with less than 500 employees are removed from the regression.

At first glance, the three carbon policies seem to have almost no statistically significant effects on the outcome variables, meaning they do not substantially affect emissions, GDP, employment, hours worked, or earnings. There are a few exceptions – carbon taxes have a significant negative effect on GDP and earnings, and credit systems have a positive effect on earnings. The CAT system, however, does not significantly affect any economic outcomes. As for the coefficients that are not significant at the 90% level, the signs indicate the direction of impacts. All carbon policies negatively impact emissions (a good sign, as emission reduction was their primary intention), but the coefficients are not significant. Carbon taxes and CAT systems negatively impact economic outcomes, while credit systems positively impact them.

This same model was run again with carbon policy rates in \$/100 tons CO_2e[14] instead of carbon policy indicators. The results of these regressions can be found in Table C1 in the Appendix. Since the natural logarithm was applied to all outcome variables, the coefficients represent percent changes in the outcome variables caused by a \$1 increase in the carbon

[14]The units were switched to \$/100 tons CO_2e so the significant figures of the coefficients were more visible.

policy's rate. Overall, the results matched closely with the results in Table 4 – there were no statistically significant coefficients on the policy rate variables for any outcomes other than a negative effect on earnings from the carbon tax rate. The expected effect of the policy rates on economic outcomes is assumed to be zero for all other outcomes. Again, all three policies had negative effects on emissions, although they were not significant.

To identify whether the presence of a policy is more impactful or the rate itself, the model was run with both carbon policy rates and indicator variables – an indicator for each of the three carbon policies, and the policy rates for the carbon tax and CAT system.[15] The results of these regressions can be found in Table C2. The carbon tax policy indicator was the only policy variable (binary or continuous) that significantly negatively impacted any outcome variables, specifically paid jobs, hours worked, and earnings. All other policies had no significant effects on outcomes, so it is assumed that the presence of a carbon policy is more impactful on economic outcomes than the rate of that policy.

6.2 DID with Sector Breakdown

In the DID model with a sector breakdown (equation (4)), policy indicator variables are interacted with various economic sectors.[16] The purpose of this model is to see how the effect of the policies on the outcome variables varies by economic sector, as some sectors may be more affected by carbon policies than others because of the types of processes they utilize. For example, mining is likely to be more negatively affected by a carbon tax because mining processes involve emitting large amounts of CO_2 (Azadi et al., 2020).

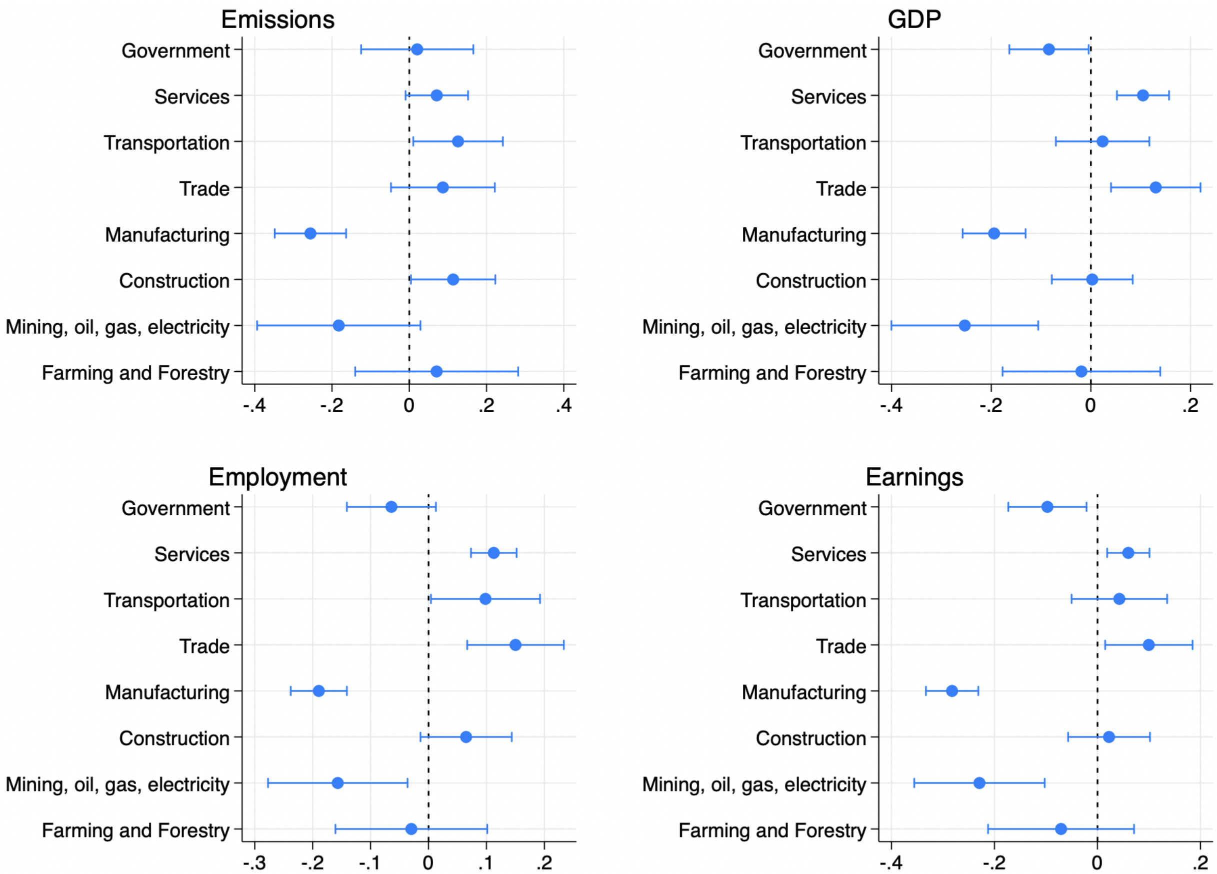
There are two models estimated: one in which the carbon tax indicator is interacted with every sector and one in which the CAT system indicator is interacted with every sector. In both models, controls are included for the presence of the other two carbon policies. Since credit systems are usually enacted in conjunction with carbon taxes, it is pertinent to utilize its indicator as a control in both models instead of also examining its individual impact on every sector. Tables C3 and C4 in the Appendix show the results of these regressions in

[15] Credit system excess charge rates were omitted because credit systems mainly work in conjunction with carbon taxes, and the credit system indicator is considered a control variable.

[16] Sector designations are outlined in the notes of Table A2.

table format.

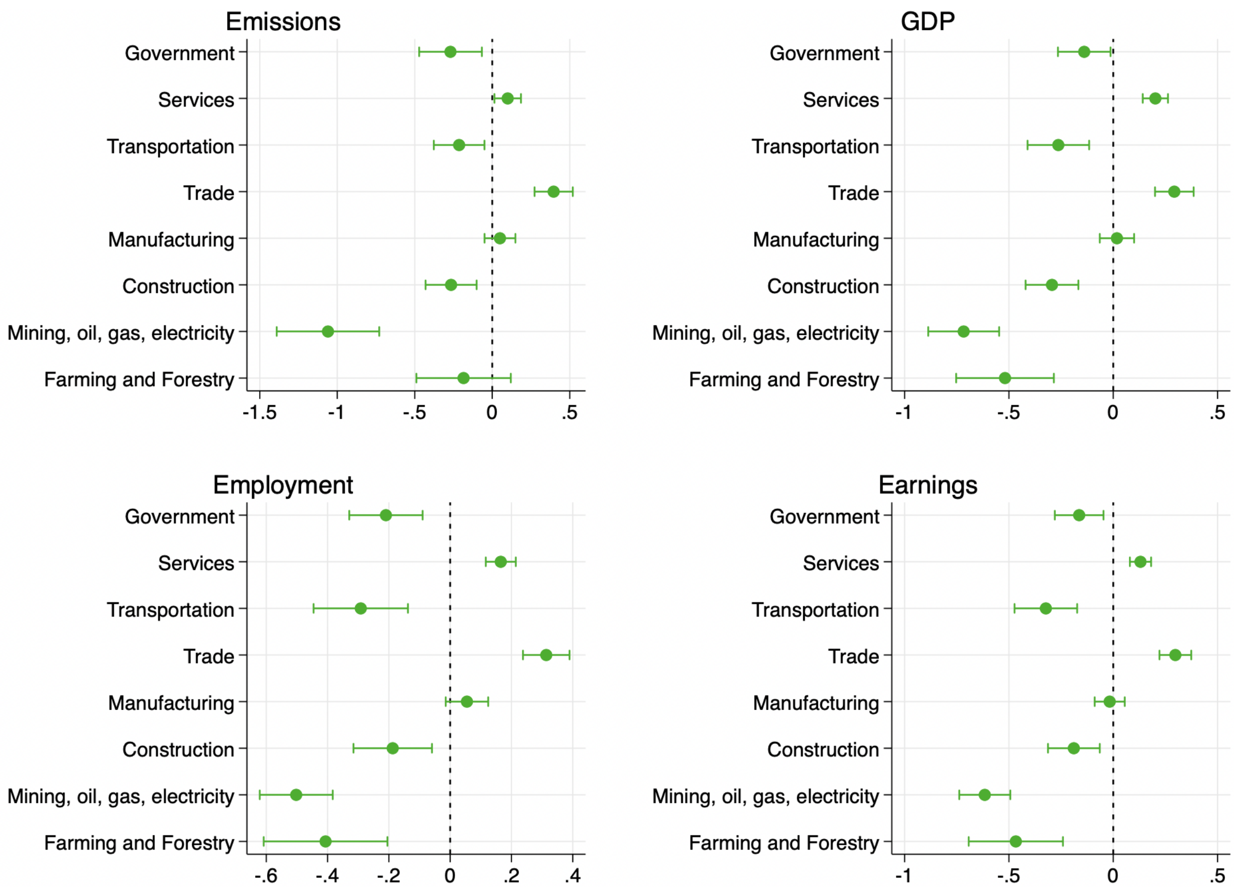
Figure 9: Effects of Carbon Tax Presence by Sector



Note: The natural logarithm was applied to the outcome variable in each regression. CAT system and credit system indicators are included as controls. Industries with less than 500 employees are removed. The confidence interval displayed is 90%. A vertical line is plotted at zero to highlight the direction of the policy's impact.

Figure 9 displays the coefficients on each interaction term of carbon taxes presence and sector for four key outcomes: emissions, GDP, employment, and earnings. Because the natural log was applied to the outcome variables, the coefficients represent percent changes in the outcome variables induced by the policy. Manufacturing sees the most significant emission reductions from the presence of a carbon tax, with Mining, Oil, Gas, Electricity (the most carbon-intensive and highest emitting sector) also seeing emission reductions, although not at significant levels. Since these sectors emit carbon heavily, these percent decreases indicate strong reductions in emissions. The other sectors, interestingly, see increases in emissions (although most effects are not significant). For sectors that do not emit carbon as heavily, these percent increases in emissions are negligible in terms of actual emissions. Regarding economic outcomes, Services and Trade sectors consistently experience slight positive effects from a carbon tax, while Manufacturing and Mining, Oil, Gas, Electricity see stronger negative effects. Generally (though not with every sector), the sectors that see negative effects on emissions will see negative effects on outcome variables, and vice versa.

Figure 10: Effects of CAT Systems by Sector



Note: The natural logarithm was applied to the outcome variable in each regression. Carbon tax and credit system indicators are included as controls. Industries with less than 500 employees are removed. The confidence interval displayed is 90%. A vertical line is plotted at zero to highlight the direction of the policy's impact.

Figure 10 displays the effects of CAT systems by sector for the four key outcomes. The confidence intervals for CAT systems are more compact than for carbon taxes. More sectors experience significant reductions in emissions from a CAT system – Mining, Oil, Gas, Electricity, Construction, Transportation, and Government – while only Services and Trade see a significant increase in emissions. In addition, the coefficients on the x-axes for CAT systems are much higher in magnitude than for carbon taxes (in some cases twice as large or greater), indicating the percent changes in outcome variables caused by CAT systems are much larger than those by carbon taxes. Manufacturing does not see emission reductions from CAT systems, which is a different effect than carbon taxes. Economic outcomes seem to follow similar patterns across sectors: the same sectors that saw significant decreases in emissions see significant negative impacts on GDP, employment, and earnings, and vice versa. Services and Trade see significant positive impacts from a CAT system, but again, since these sectors do not emit carbon as heavily, these percent increases in emissions are negligible in terms of actual emissions.

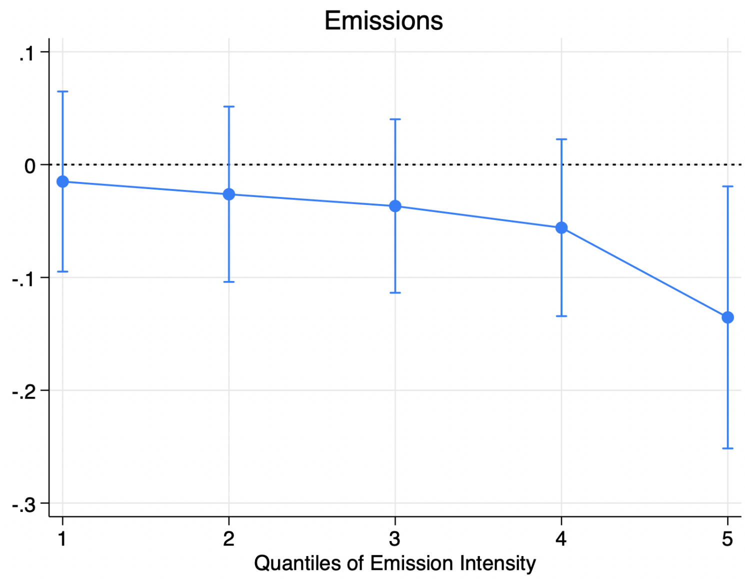
Some general trends to note are that emissions tend to be impacted in the same direction as the economic outcomes for both policies. This makes sense, as sectors that see reductions in emissions are more likely to suffer economically and cut back on production and employment to comply with the monetary penalties of carbon policies.

The regressions used to produce Figures 9 and 10 were performed again, using carbon policy rates instead. Visualizations of the effects of the carbon tax rate and CAT system auction price by sector are available in the Appendix, Figures C1 and C2, respectively. These figures show the same patterns and directions as the models above (using just policy indicators), further reinforcing the reliability of the effects found.

6.3 DID with Lagged Industry Characteristics

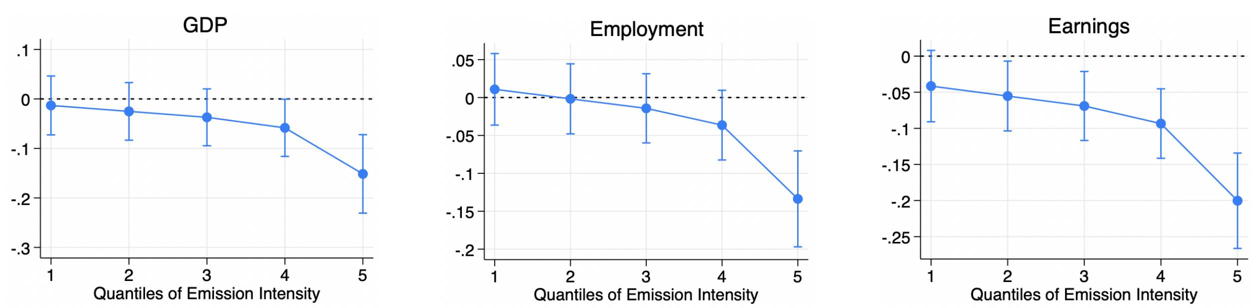
This section displays the results of the DID model interacted with lagged industry characteristics (equation (5)). Different models are estimated for different carbon policies and the various lagged industry characteristics ($M_{j,t-2}$). The first model estimated interacts the carbon tax indicator (the policy variable) with emission intensity lagged by two years (the lagged industry characteristic). To isolate the impacts of carbon taxes, CAT and credit system indicators are included as controls. The marginal effects of carbon taxes on GHG emissions by varying levels of emission intensity are shown in Figure 11 and the effects on economic outcomes (GDP, employment, and earnings) are shown in Figure 12.

Figure 11: Marginal Effects of Carbon Taxes on Emissions



Note: The natural logarithm was applied to GHG emissions. CAT system and credit system indicators are included as controls. Industries with less than 500 employees are removed. The confidence interval displayed is 90%. Quantiles are created by dividing the emission intensity variable. A horizontal line is plotted at 0 to highlight the direction of the carbon tax's impact.

Figure 12: Marginal Economic Effects of Carbon Taxes by Emission Intensity

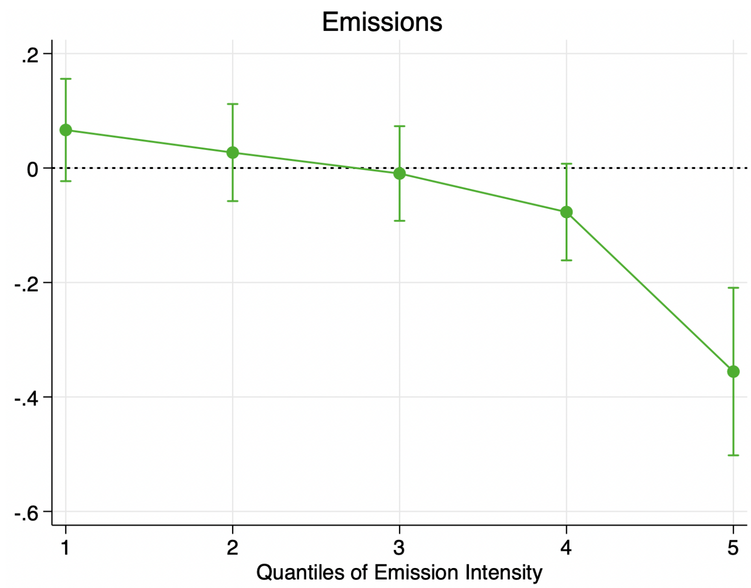


Note: The natural logarithm was applied to each outcome. CAT system and credit system indicators are included as controls. Industries with less than 500 employees are removed. The confidence interval displayed is 90%. Quantiles are created by dividing the emission intensity variable. A horizontal line is plotted at 0 to highlight the direction of the carbon tax's impact.

From Figure 11, industries of all emission intensities are predicted to see lower emissions with a carbon tax, and the more emission-intensive an industry is, the more its emissions are predicted to reduce. This shows the carbon tax is effective in lowering emissions in more emission-intensive firms. The confidence intervals do not lend much certainty to this effect, given they cross the zero line for most quantiles, but the general trend remains.

From Figure 12, similar trends are seen across all measures – more emission-intensive industries experience more negative economic impacts from carbon taxes than less emission-intensive industries. Across all outcomes, quantile 5 (the most emission-intensive industries) experience the most severe negative economic impacts from carbon taxes. Employment interestingly sees some potential for positive economic impacts for the least emission-intensive industries (quantile 1), but overarching trends suggest the impact is negative for all industries. The confidence intervals do not provide much certainty for these predicted impacts, except those on earnings, but again, the general trend remains.

Figure 13: Marginal Effects of CAT Systems on Emissions

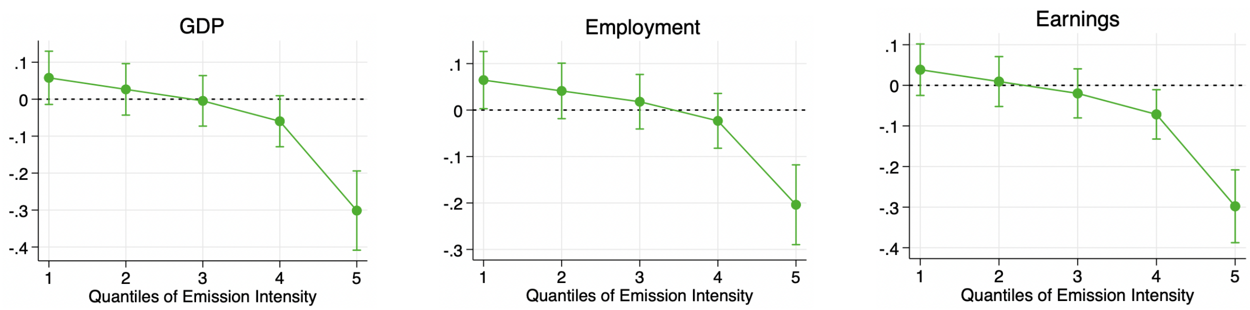


Note: The natural logarithm was applied to GHG emissions. Carbon tax and credit system indicators are included as controls. Industries with less than 500 employees are removed. The confidence interval displayed is 90%. Quantiles are created by dividing the emission intensity variable. A horizontal line is plotted at 0 to highlight the direction of the carbon tax's impact.

To view the heterogeneous effects of a CAT system on outcomes, a second model is estimated utilizing the CAT system indicator as the policy variable, keeping emission intensity as the lagged industry characteristic. Carbon tax and credit system indicators are included as controls. Figure 13 shows the marginal effects of CAT systems on GHG emissions by varying levels of emission intensity, and Figure 14 shows the effects on economic outcomes.

Figure 13 shows CAT systems affecting a trend similar to carbon taxes – more emission-intensive industries see lower emissions. However, there is a difference: lower emission-intensive industries (corresponding to quantiles 1 and 2) see positive percent changes in emissions from a CAT system, while carbon taxes consistently showed lower percent changes in emissions for all industries. The confidence intervals indicate some shroud of uncertainty on these predicted impacts, but results above the zero line are indicative that industries with low emission intensity may actually be increasing emissions under CAT systems. Since these industries have low emission intensities, however, these changes are negligible in terms of actual emissions.

Figure 14: Marginal Economic Effects of CAT Systems by Emission Intensity



Note: The natural logarithm was applied to each outcome. Carbon tax and credit system indicators are included as controls. Industries with less than 500 employees are removed. The confidence interval displayed is 90%. Quantiles are created by dividing the emission intensity variable. A horizontal line is plotted at 0 to highlight the direction of the carbon tax's impact.

Figure 14 shows that CAT systems affect similar trends across all economic measures – the more emission-intensive an industry is, the harder it will be hit economically. However, it is also shown that industries with lower emission intensities (corresponding to quantiles 1 and 2) can benefit from a CAT system's presence, seeing percent increases in economic outcomes. Across all three panels, the most emission-intensive industries experience statistically significant lower percent changes in GDP, employment, and earnings. Again, the confidence intervals show this effect is uncertain, but CAT systems seem to be economically "rewarding" industries that emit less and "punishing" industries that emit more.

Instead of emission intensity, energy intensity and percent innovations that reduce GHG emissions can be used as the lagged industry characteristics in the model to see the heterogeneous effects of different carbon policies by levels of other industry characteristics. Visualizations of the heterogeneous effects of carbon taxes and CAT systems on selected outcomes by varying quantiles of energy intensity can be viewed in Figures C3 and C4 in the Appendix, respectively, and the same visualizations by varying quantiles of percent innovations that reduce emissions can be viewed in Figures C5 and C6.

Looking at the effects of carbon taxes (Figures C3 and C5), the trends in outcome variables using energy intensity closely follow those produced using emission intensity, which makes sense. More emission-intensive industries are also likely to be energy-intensive and would be impacted in similar ways by an economic policy targeting emissions. The confidence intervals are overall larger for the results using energy intensity, but the underlying trends are still present. Innovations also presents similar trends for economic outcomes, but not for emissions. The effect of a carbon tax for industries across all levels of innovation is negative, but does not intensify as much as percent innovation increases. Also, the confidence intervals are quite large, indicating the effect may not be strong.

Looking at the effects of CAT systems (Figures C4 and C6), the trends in outcome variables using both energy intensity and percent innovations closely follow those produced using emission intensity, with very little deviation. CAT systems seem to be characterized by having positive impacts on outcomes for industries that are less emission-intensive, energy-intensive, and have lower innovation levels, while having strong negative impacts on outcomes for industries that are more emission-intensive, energy-intensive, and have higher innovations levels.

6.4 Mediating Model

The mediating model (equation (6)) is utilized to decompose the effects of the carbon policy on emissions by potential mediating variables representing economic activity – macroeconomic outcomes. The direct effect is the sole effect of the carbon policy on emissions, the indirect effect is the effect of the carbon policy on emissions through change in another economic variable, and the total effect is the sum of the previous two. The potential mediating effects of GDP, employment, hours worked, and earnings are explored.

The first model estimated utilizes emission intensity as the lagged industry characteristic and decomposes the impact of the presence of a carbon tax. Credit and CAT system indicators are included as controls in the model, along with population and working population. The model is estimated separately for each of the following mediating variables:

GDP, paid jobs, hours worked, and earnings. The direct, indirect, and total effects of each estimated model using an emission intensity of 1 are shown in Table 5.

Table 5: Decomposed Effects of Carbon Tax on Emissions through Mediating Variables

GDP (2012 dollars)	**Coefficient**	**Std. Error**	**z**	**P >|z|**	**[95% Confidence**	**Interval]**	**Indirect/Total**
Direct effect:	-0.0086	0.0400	-0.22	0.829	-0.0871	0.0698	
Indirect effect:	-0.0833	0.0372	-2.24	0.025	-0.1562	-0.0103	90.6%
Total effect:	-0.0919	0.0547	-1.68	0.093	-0.1991	0.0152	
Paid jobs							
Direct effect:	-0.0196	0.0419	-0.47	0.640	-0.1016	0.0624	
Indirect effect:	-0.0724	0.0352	-2.05	0.040	-0.1415	-0.0032	78.8%
Total effect:	-0.0919	0.0547	-1.68	0.093	-0.1991	0.0152	
Hours worked							
Direct effect:	-0.0124	0.0416	-0.30	0.766	-0.0939	0.0691	
Indirect effect:	-0.0796	0.0351	-2.26	0.024	-0.1484	-0.0107	86.6%
Total effect:	-0.0919	0.0547	-1.68	0.093	-0.1991	0.0152	
Earnings							
Direct effect:	0.0370	0.0405	0.92	0.360	-0.0423	0.1164	
Indirect effect:	-0.1290	0.0363	-3.55	0.000	-0.2002	-0.0578	140.4%
Total effect:	-0.0919	0.0547	-1.68	0.093	-0.1991	0.0152	

Note: The natural logarithm was applied to emissions and all macroeconomic variables. The policy variable used is the carbon tax indicator, and the lagged industry characteristic is emission intensity. The heading of each section indicates the mediating variable used. The effects are evaluated at an emission intensity of 1. The controls include credit and CAT system indicators, population, and working population. Industries with less than 500 employees are removed. See equation (7) for a breakdown of how each effect is calculated. *Indirect/Total* represents the percent of the total effect that the indirect effect covers.

The indirect effects are much stronger (greater proportion of total effect) and much more significant (low P-values) than the direct effects for all models, as shown in the last column of the table. The indirect effects of carbon taxes on emissions through GDP, paid jobs, and hours worked make up 90.6%, 78.8%, and 86.6% of the total effect, respectively. For earnings in particular, the indirect effect has a direction opposite to the direct effect and accounts for all of the total effect of the carbon tax on emissions. This indicates that carbon taxes are, for the most part, not reducing emissions directly; rather, firms are choosing to downsize and reduce economic activity to comply with the monetary penalty on emissions by reducing production, firing employees, reducing hours worked, and cutting back on earnings. When a carbon tax is used, one can expect the reductions in economic processes to be the main cause of emission reductions.

The effects of a CAT system on emissions are decomposed as well; the results are displayed in Table 6. The lagged industry characteristic is still emission intensity.

Table 6: Decomposed Effects of CAT System on Emissions through Mediating Variables

GDP (2012 dollars)	Coefficient	Std. Error	z	P >|z|	[95% Confidence Interval]		Indirect/Total
Direct effect:	-0.0667	0.0517	-1.29	0.197	-0.1680	0.0345	
Indirect effect:	-0.1365	0.0429	-3.18	0.001	-0.2205	-0.0525	67.2%
Total effect:	-0.2032	0.0633	-3.21	0.001	-0.3273	-0.0791	
Paid jobs							
Direct effect:	-0.1083	0.0514	-2.11	0.035	-0.2091	-0.0076	
Indirect effect:	-0.0948	0.0401	-2.37	0.018	-0.1734	-0.0163	46.7%
Total effect:	-0.2032	0.0633	-3.21	0.001	-0.3273	-0.0791	
Hours worked							
Direct effect:	-0.1095	0.0509	-2.15	0.032	-0.2094	-0.0097	
Indirect effect:	-0.0937	0.0402	-2.33	0.020	-0.1724	-0.0150	46.1%
Total effect:	-0.2032	0.0633	-3.21	0.001	-0.3273	-0.0791	
Earnings							
Direct effect:	-0.0598	0.0503	-1.19	0.234	-0.1584	0.0387	
Indirect effect:	-0.1434	0.0411	-3.49	0.000	-0.2239	-0.0629	70.6%
Total effect:	-0.2032	0.0633	-3.21	0.001	-0.3273	-0.0791	

Note: The natural logarithm was applied to emissions and all macroeconomic variables. The policy variable used is the CAT system indicator, and the lagged industry characteristic is emission intensity. The heading of each section indicates the mediating variable used. The effects are evaluated at an emission intensity of 1. The controls include carbon tax and credit system indicators, population, and working population. Industries with less than 500 employees are removed. See equation (7) for a breakdown of how each effect is calculated. *Indirect/Total* represents the percent of the total effect that the indirect effect covers.

For CAT systems, the direct and indirect effects of the policy are more balanced than they were for carbon taxes. The mediating (indirect) effects of GDP and earnings make up 67.2% and 70.6% of the total effect of CAT systems on emissions (not as large as the proportions seen with carbon taxes). For paid jobs and hours worked, the direct effect exceeds the indirect effect. The results are also fairly significant, almost all at the 95% level. These results imply that CAT systems are more effective at forcing firms to directly reduce emissions instead of cutting down on production, employment, and other economic processes. While firms do downsize, it is not to the extent that is seen with carbon taxes.

These same mediating models can be calculated using energy intensity as the lagged industry characteristic. The results for models estimating the effects of carbon taxes and CAT systems with energy intensity are shown in Tables C5 and C6 in the Appendix. The direct, indirect, and total effects are all evaluated with an energy intensity of 10. The results align similarly to the results utilizing emission intensity. For carbon taxes, the indirect effect through all macroeconomic variables makes up a large proportion of the total effect, and are almost all significant at the 95% level. Even in the case of earnings, the indirect effect has a direction opposite to the direct effect and accounts for all of the total effect of the carbon tax on emissions. For CAT systems, the indirect effect makes up a large proportion of the total effect for GDP and earnings (though not as large as those seen for carbon taxes), but for paid jobs and hours worked, the direct and indirect effects are fairly balanced – again, the same thing observed with emission intensity.

The mediating models are calculated once more using percent innovations that reduce GHG emissions as the lagged industry characteristic. The results for models estimating the effects of carbon taxes and CAT systems are shown in Tables C7 and C8 in the Appendix. The direct, indirect, and total effects are all evaluated with a percent innovations level of 20. Similar trends are noted as with the other two industry characteristics, although the significance levels of the effects are not as high, indicating less reliability.

7 Discussion

The initial DID model with two-way fixed effects shows that each of the three carbon policies reduces emissions, but the results were not statistically significant. This is concerning, as the policies may not be reliably accomplishing their goal of emission reduction. In addition, none of the three carbon policies significantly impact macroeconomic measures, save for a few negative impacts on GDP and earnings from carbon taxes and a positive impact on earnings from credit systems. Regarding the direction of impacts, carbon taxes and CAT systems hurt macroeconomic measures, while credit systems benefit them. Since credit systems are almost always enacted in concurrence with carbon taxes, they will tend to cancel out its effects. Based on these preliminary results, carbon policies act to reduce emissions while not significantly impacting the economy at large, which aligns with the goal of the policy.

The DID model with the sector breakdown provides key insights into the sectors and industries most affected by carbon policies. In general, sectors that see emission reductions are also likely to see negative impacts on macroeconomic measures, and vice versa. This makes sense, as sectors experiencing emission reductions are probably also lowering production and employment to comply with the monetary penalties of carbon policies. From carbon taxes, Manufacturing and Mining, Oil, Gas, Electricity saw the greatest percent reductions in emissions, as well as GDP, employment, and earnings. It is a good sign that Mining, Oil, Gas, Electricity and Manufacturing, the first and second largest emitting sectors, are experiencing strong percent reductions in emissions from both policies. Given they contribute so largely to pollution, these percent decreases will translate to large actual emission reductions. Services and Trade saw slight percent increases in emissions from the tax and positive effects on GDP, employment, and earnings. Since these sectors do not emit much and are not emission-intensive, these impacts on actual emissions are negligible. With CAT systems, Mining, Oil, Gas, Electricity, Construction, Transportation, and Government all saw percent reductions in emissions and macroeconomic measures, while Services and Trade saw percent increases. The magnitude of these effects is much greater than for carbon taxes. Policymakers and the public may find this information useful in anticipating the effects of carbon policies when planning their future employment, investment, or job training.

The DID models including lagged industry characteristic interactions reveal the heterogeneous effects of the carbon policies. Examining different levels of emission intensity, all figures displaying the marginal effects of carbon taxes and CAT systems show the same general trend – the more emission-intensive an industry is, the lower emissions, GDP, employment, and earnings it will experience. This indicates both policies are effective at economically targeting the most carbon-intensive industries. It also indicates that lower emissions often correspond with lower economic activity. For carbon taxes (Figures 11 and 12), most marginal effects are below zero, indicating that while the taxes reduce emissions, they also economically punish industries of all emission intensities. One exception is that for industries with very low emission intensities, there is a small predicted increase in employment, indicating there may be greater employment in the least emission-intensive industries. However, the error bar crosses the zero line, so this may be a negligible prediction.

However, for CAT systems (Figures 13 and 14), a different story emerges. More emission-intensive industries see drastic reductions in emissions and economically suffer, but less emission-intensive industries see increases in emissions and benefit economically. These less emission-intensive industries may be emitting more under a CAT system because they already emit less emissions and can afford the auction prices. The more intensive industries, on the other hand, must now deal with high auction prices for the sheer amount of emissions they release, and their only option is to reduce emissions because they cannot simply pay extra money to the government for excess emissions under a CAT system (as they might have been able to do under the other carbon policies). This punishes emission-intensive industries strongly while allowing the less emission-intensive ones space to emit. These less emission-intensive industries may also see increases in production and employment because of a perceived increased allowance for emissions, as well as shifting public preferences away from "losing" higher emission-intensive industries that must downsize and reduce production to comply with CAT system restrictions. In addition, the confidence intervals on the results for CAT systems are smaller than those for carbon taxes, indicating higher reliability for the predicted impacts of CAT systems compared to carbon taxes.

Results of the same model utilizing energy intensity (Figures C3 and C5) and percent innovations that reduce GHG emissions (Figures C4 and C6) as the lagged industry characteristics showed the same trends for both carbon taxes and CAT systems, though with slightly larger confidence intervals than the results using emission intensity. Carbon taxes see emission reductions and lower macroeconomic measures for all industries, while CAT systems see some positive effects on these variables for industries that are less energy-intensive and have lower innovation levels. These results reinforce the relationships found. Industries that are more energy-intensive or innovate more to reduce emissions are more likely to see greater emission reductions and suffer economically from carbon policies.[17] CAT systems are the carbon policies that produce some "winning" industries that can benefit from the policy, while carbon taxes generally hurt all industries.

The mediating models show that carbon taxes are reducing emissions largely indirectly through reduced economic activity. The indirect effect calculated through these models makes up a very large portion of the direct effects – the indirect effects on emissions of reduced GDP, jobs, hours worked, and earnings from a carbon tax are all greater than 75% of the total effect of the carbon tax on emissions. However, for CAT systems, the indirect effect through economic mechanisms is not nearly as large, with the direct effect actually

[17]The usage of energy in production is often correlated with emissions, implying that energy-intensive industries are also likely emission-intensive. Industries that do not emit much have no need to innovate to reduce emissions, and therefore will not experience as drastic negative impacts on emissions and other economic measures.

exceeding the indirect effect for paid jobs and hours worked. This implies that CAT systems are more effective than carbon taxes in directly reducing emissions, and are less likely to cause firms to reduce production, lower employment, reduce hours worked, or cut earnings to comply with the policy.

8 Conclusions

The results of this analysis present several policy implications. First, carbon policies are not severely hurting the economy. The results from the baseline DID model show there are very few statistically significant relationships between the presence of a carbon policy and GDP, employment, hours worked, or earnings, which is a good thing from a policy standpoint. There are a few exceptions – carbon taxes show a slight negative effect on GDP and a strong negative effect on earnings, while credit systems have a positive effect on earnings – but overall the economy seems largely unaffected. CAT systems show no statistically significant effects at all on any economic measures. However, the carbon policies also do not appear to have statistically significant effects on emissions, which are the intended target of the policy. The direction of the impact is at least negative for all three policies, indicating emissions are at least being reduced, and not increased.

Both carbon taxes and CAT systems are effective at reducing emissions in the two largest emitting sectors, Manufacturing and Mining, Oil, Gas, Electricity; these sectors also suffer economically. Conversely, Services and Trade see negligible increases in emissions along with positive economic effects from both policies. Generally, any sectors that see emission reductions from the policy will also likely see lower production, employment, and earnings, and vice versa for sectors that see emission increases. Policymakers and the public can therefore pinpoint the sectors that will see job losses and reduced production and anticipate those changes. Comparing the policies themselves, policymakers can expect that CAT systems will reduce emissions in and economically hurt more sectors than carbon taxes will.

The CAT system is the most effective carbon policy at reducing emissions in the most carbon-intensive industries while not hurting overall macroeconomic growth. The DID model with lagged industry characteristics shows that CAT systems allow some "winning" industries to prosper economically while targeting those that intensely emit carbon. This shows a potential shift in economic activity towards less carbon-intensive industries, an ideal effect in an economy trying to move away from non-renewable energy towards more renewable and sustainable processes. Carbon taxes, on the other hand, adversely economically impact all industries, no matter the level of emission or energy intensity. Overall, however, both policies punish the most emissions- and energy-intensive industries the most, reducing their emissions as well as GDP, employment, and earnings.

Finally, the mediating models show that carbon policies do not simply reduce emissions directly – some emission reduction happens indirectly from firms downsizing, reducing production, and firing employees. Most emission reduction from carbon taxes occurs through downsizing. With CAT systems, on the other hand, relatively less emission reductions are caused through downsizing – rather than cutting back on economic processes, firms directly reduce emissions through other methods.

Overall, CAT systems seem to be the safer and more reliable policy to back. They are effective at not hurting the overall economy, reducing emissions in more sectors, targeting emission- and energy-intensive industries, reducing emissions directly rather than by downsizing, and allowing room for economic growth in less emission- and energy-intensive industries to allow the economy to thrive and shift while limiting pollution.

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9 Appendix A

Table A1: Variable Descriptions

Variable Name	Vector	Variable Description	Type
Explanatory Variables			
Carbon tax presence	P_{pt}	=1 if there is a carbon tax in the province that year	Binary
Carbon tax rate (\$/ton CO_2 equivalent)	P_{pt}	Dollar amount of tax rate per ton of CO_2 equivalent by province and year	Continuous
Baseline and credit system presence	P_{pt}	=1 if there is a baseline and credit system in the province that year	Binary
Baseline and credit system excess charge (\$/ton CO_2 equivalent)	P_{pt}	Dollar amount of excess charge per ton of CO_2 equivalent by province and year	Continuous
Cap-and-trade system presence	P_{pt}	=1 if there is a cap-and-trade system in the province that year	Binary
Cap-and-trade system auction price (\$/ton CO_2 equivalent)	P_{pt}	Dollar amount of average auction price for carbon credit per ton of CO_2 equivalent by province and year	Continuous
Outcome Variables			
GHG emissions (kilotons)	Y_{jpt}	Measure of greenhouse gas emissions by province and industry in kilotons for that year, 2009-2021	Continuous
GDP in 2012 dollars (millions)	Y_{jpt}	GDP by industry, province, and year, chained in 2012 dollars and collected from all establishments in Canada, 2004-2022	Continuous
Number of paid workers' jobs	Y_{jpt}	Number of paid workers' jobs by industry, province, and year, 2004-2022	Continuous
Hours worked of paid workers (thousands)	Y_{jpt}	Hours worked of paid work in thousands by industry, province, and year, 2004-2022	Continuous
Wages and salaries for paid work (thousands)	Y_{jpt}	Wage/salary for paid workers in thousands of dollars by industry, province, and year, 2004-2022	Continuous
Moderating Variables (Industry Characteristics)			
GHG emission intensity (tons/\$1000 of production)	$M_{j,\,t\text{-}2}$	Direct plus indirect greenhouse gas emissions in tons divided by thousand current dollars of production, by industry and year, 2004-2019	Continuous
Energy intensity (GJ/\$1000 of production)	$M_{j,\,t\text{-}2}$	Direct plus indirect energy in gigajoules divided by thousand current dollars of production, by industry and year, 2004-2019	Continuous
Percent innovations that reduced GHG emissions 2015-17	$M_{j,\,t=2015\text{-}17}$	Percent of innovations that reduced GHG emissions by industry in reference period 2015-2017	Continuous
Percent innovations that reduced GHG emissions 2017-19	$M_{j,\,t=2017\text{-}19}$	Percent of innovations that reduced GHG emissions by industry in reference period 2017-2019	Continuous
Control Variables			
Province total population	Z_{pt}	Population of all people by province and year, 2004-2022	Continuous
Province working age population	Z_{pt}	Population of individuals between 15-64 years of age by province and year, 2004-2022	Continuous

Table A2: NAICS Industries, Codes and Sectors

Industry Code	Industry Name	Sector	Freq.
11300	Forestry and logging	1	247
11400	Fishing, hunting and trapping	1	247
11500	Support activities for agriculture and forestry	1	247
11A00	Crop and animal production	1	247
21100	Oil and gas extraction	2	247
21210	Coal mining	2	247
21220	Metal ore mining	2	247
21230	Non-metallic mineral mining and quarrying	2	247
21300	Support activities for mining and oil and gas extraction	2	247
22110	Electric power generation, transmission and distribution	2	247
221A0	Natural gas distribution, water, sewage and other systems	2	247
23A00	Residential building construction	3	247
23B00	Non-residential building construction	3	247
23C10	Transportation engineering construction	3	247
23C20	Oil and gas engineering construction	3	247
23C30	Electric power engineering construction	3	247
23C40	Communication engineering construction	3	247
23C50	Other engineering construction	3	247
23D00	Repair construction	3	247
23E00	Other activities of the construction industry	3	247
31110	Animal food manufacturing	4	247
31130	Sugar and confectionery product manufacturing	4	247
31140	Fruit and vegetable preserving and specialty food manufacturing	4	247
31150	Dairy product manufacturing	4	247
31160	Meat product manufacturing	4	247
31170	Seafood product preparation and packaging	4	247
311A0	Miscellaneous food manufacturing	4	247
31211	Soft drink and ice manufacturing	4	247
31212	Breweries	4	247
3121A	Wineries and distilleries	4	247
31220	Tobacco manufacturing	4	247
31A00	Textile and textile product mills	4	247
31B00	Clothing and leather and allied product manufacturing	4	247
32100	Wood product manufacturing	4	247
32210	Pulp, paper and paperboard mills	4	247
32220	Converted paper product manufacturing	4	247
32300	Printing and related support activities	4	247
32400	Petroleum and coal product manufacturing	4	247
32510	Basic chemical manufacturing	4	247
32530	Pesticide, fertilizer and other agricultural chemical manufacturing	4	247
32540	Pharmaceutical and medicine manufacturing	4	247
325C0	Miscellaneous chemical product manufacturing	4	247
32610	Plastic product manufacturing	4	247
32620	Rubber product manufacturing	4	247
32730	Cement and concrete product manufacturing	4	247

Industry Code	Industry Name	Sector	Freq.
327A0	Non-metallic mineral product manufacturing (except cement and concrete products)	4	247
33100	Primary metal manufacturing	4	247
33200	Fabricated metal product manufacturing	4	247
33300	Machinery manufacturing	4	247
33410	Computer and peripheral equipment manufacturing	4	247
334B0	Electronic product manufacturing	4	247
33520	Household appliance manufacturing	4	247
335A0	Electrical equipment and component manufacturing	4	247
33610	Motor vehicle manufacturing	4	247
33620	Motor vehicle body and trailer manufacturing	4	247
33630	Motor vehicle parts manufacturing	4	247
33640	Aerospace product and parts manufacturing	4	247
33650	Railroad rolling stock manufacturing	4	247
33660	Ship and boat building	4	247
33690	Other transportation equipment manufacturing	4	247
33700	Furniture and related product manufacturing	4	247
33900	Miscellaneous manufacturing	4	247
41000	Wholesale trade	5	247
4A000	Retail trade	5	247
48100	Air transportation	6	247
48200	Rail transportation	6	247
48300	Water transportation	6	247
48400	Truck transportation	6	247
48600	Pipeline transportation	6	247
48B00	Transit, ground passenger and scenic and sightseeing transportation, taxi and limousine service and support activities for transportation	6	247
49300	Warehousing and storage	7	247
49A00	Postal service and couriers and messengers	7	247
51200	Motion picture and sound recording industries	7	247
51510	Radio and television broadcasting	7	247
51B00	Publishing, pay/specialty services, telecommunications and other information services	7	247
52410	Insurance carriers	7	247
52B00	Depository credit intermediation and monetary authorities	7	247
53110	Lessors of real estate	7	247
53B00	Rental and leasing services and lessors of non-financial intangible assets (except copyrighted works)	7	247
54180	Advertising, public relations and related services	7	247
541C0	Legal, accounting and architectural, engineering and related services	7	247
541D0	Computer systems design and other professional, scientific and technical services	7	247
56100	Administrative and support services	7	247
56200	Waste management and remediation services	7	247
61000	Educational services	7	247
61130	Universities	7	247
611B0	Educational services (except universities)	7	247

Industry Code	Industry Name	Sector	Freq.
62000	Health care and social assistance	7	247
62200	Hospitals	7	247
62300	Nursing and residential care facilities	7	247
62400	Social assistance	7	247
71000	Arts, entertainment and recreation	7	247
72000	Accommodation and food services	7	247
81100	Repair and maintenance	7	247
81300	Religious, grant-making, civic and professional and similar organizations	7	247
81310	Religious organizations	7	247
81A00	Personal services and private households	7	247
91100	Federal government public administration	8	247
91200	Provincial and territorial public administration	8	247
91300	Local, municipal and regional public administration	8	247
91400	Aboriginal public administration	8	247
Total			24947

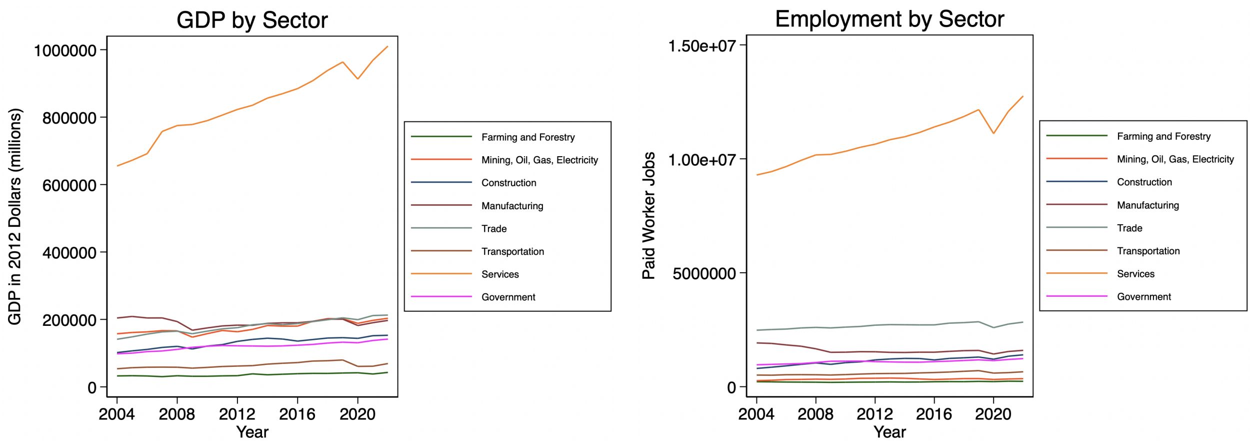
Note: Industries are defined by the North American Industry Classification System (NAICS) and denoted in the data by the corresponding NAICS codes. The NAICS system indicates each industry by a code that goes up to 6 digits. The system uses a hierarchical structure: the more digits in the code, the more specific it is, and the fewer digits in the code, the more agglomerated it is (US Census Bureau, n.d.). For example, codes 113 (Forestry and logging), 114 (Fishing, hunting and trapping), and 115 (Support activities for agriculture and forestry) would all be included in the measurements for code 11, which denotes Agriculture, Forestry, Fishing and Hunting. Sectors have a 2-digit code, subsectors have 3, industry groups have 4, NAICS industries have 5, and national industries have 6. (US Census Bureau, n.d.). Codes beginning with similar sets of numbers denote industries similar to one another. All codes in the dataset use 5 digits or less, and are displayed in the first column of the table.

There are 101 industries in the dataset, and the author defined her own sectors by grouping similar industries by codes. The sectors in this table are defined as follows: 1 = Farming and Forestry, 2 = Mining, Oil, Gas, Electricity, 3 = Construction, 4 = Manufacturing, 5 = Trade, 6 = Transportation, 7 = Services, 8 = Government.

In the process of merging variables by industry, several of the naming conventions for the NAICS codes were different across datasets and had to be matched externally. A crosswalk was created containing the industry naming conventions for each variable specifically and matched up to a common industry code. The classification was not consistent over time, so some smaller, more specific industries had to be merged into larger industries in order to ensure continuity throughout the timeline.

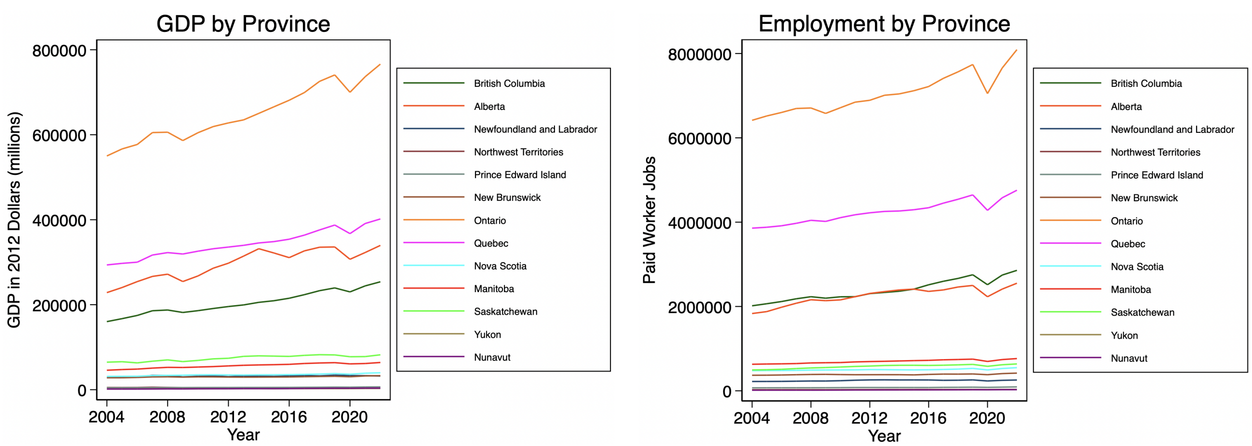
10 Appendix B

Figure B1: Outcome Variables Over Time By Sector



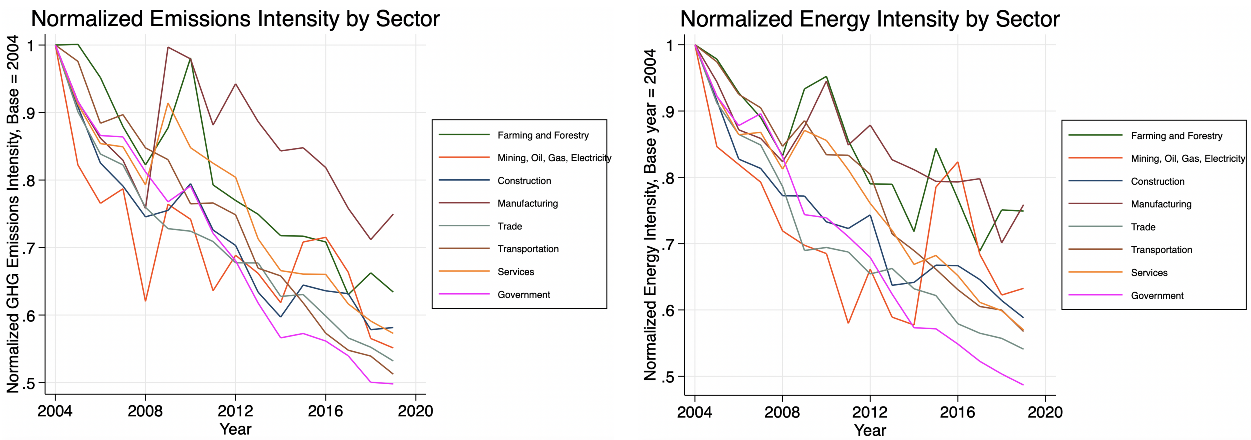
Note: These figures plot GDP (2012 dollars) and employment over 18 years by sector to see the contributions of each sector to each measure.

Figure B2: Outcome Variables Over Time By Province



Note: These figures plot GDP (2012 dollars) and employment over 18 years by province to see the contributions of each province to each measure.

Figure B3: Normalized Emissions and Energy Intensity by Sector (2004-2019)



Note: These graphs plot GHG emission intensity and energy intensity by sector normalized to 2004 values.

11 Appendix C

11.1 DID with Two-way Fixed Effects

Table C1: Outcome Variables Regressed on Policy Rates

VARIABLES	(1) Emissions	(2) GDP (2012 Dollars)	(3) Paid jobs	(4) Hours worked	(5) Earnings
Carbon tax rate, $/100 tons CO2e	-0.011	-0.161	0.013	0.004	-0.306***
	(0.308)	(0.148)	(0.111)	(0.112)	(0.116)
Auction price, $/100 tons CO2e	-0.057	-0.071	0.062	0.076	-0.146
	(0.224)	(0.154)	(0.135)	(0.136)	(0.141)
Excess charge, $/100 tons CO2e	-0.211	0.010	-0.004	0.005	0.060
	(0.280)	(0.129)	(0.102)	(0.103)	(0.107)
Observations	9,961	14,537	14,537	14,537	14,537
R-squared	0.841	0.788	0.849	0.838	0.837
Industry FE	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: The natural logarithm was applied to the outcome variable in each regression. Each explanatory variable is continuous and corresponds to a carbon policy – carbon tax rate is for carbon taxes, excess charge is for credit systems, and auction price is for CAT systems. All policy rates have been divided by 100 to make the significant figures of the coefficients easier to read. Control variables (population and working population) are included in the regressions but omitted from the table. Industries with less than 500 employees are removed from the regression.

Table C2: Outcome Variables Regressed on Policy Rates and Indicators

VARIABLES	(1) Emissions	(2) GDP (2012 Dollars)	(3) Paid jobs	(4) Hours worked	(5) Earnings
Carbon tax rate, $/100 tons CO2e	0.063	-0.074	0.176	0.180	-0.088
	(0.272)	(0.176)	(0.142)	(0.142)	(0.148)
Carbon tax	-0.054	-0.035	-0.057*	-0.061*	-0.076**
	(0.059)	(0.042)	(0.034)	(0.034)	(0.035)
Auction price, $/100 tons CO2e	0.251	0.152	0.204	0.214	0.143
	(0.396)	(0.246)	(0.221)	(0.221)	(0.233)
Cap-and-trade system	-0.094	-0.062	-0.043	-0.042	-0.083
	(0.085)	(0.062)	(0.053)	(0.053)	(0.055)
Credit system	-0.036	0.036	0.020	0.023	0.065**
	(0.061)	(0.036)	(0.028)	(0.028)	(0.029)
Observations	9,961	14,537	14,537	14,537	14,537
R-squared	0.841	0.788	0.849	0.838	0.837
Industry FE	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: The natural logarithm was applied to the outcome variable in each regression. The explanatory variables include indicators for all 3 carbon policies, as well as continuous variables for carbon taxes and CAT systems. All policy rates have been divided by 100 to make the significant figures of the coefficients easier to read. Control variables (population and working population) are included in the regressions but omitted from the table. Industries with less than 500 employees are removed.

11.2 DID With Sector Breakdown

Table C3: Outcome Variables Regressed on Carbon Tax with Industry Sectors

VARIABLES	(1) Emissions	(2) GDP (2012 dollars)	(3) Paid jobs	(4) Hours worked	(5) Earnings
Carbon tax policy (CT)	0.071	-0.019	-0.030	-0.027	-0.071
	(0.128)	(0.096)	(0.080)	(0.082)	(0.086)
CT X Mining, Oil, Gas, Electricity	-0.253	-0.234*	-0.127	-0.119	-0.158
	(0.171)	(0.126)	(0.104)	(0.105)	(0.111)
CT X Construction	0.043	0.022	0.095	0.076	0.093
	(0.133)	(0.102)	(0.088)	(0.091)	(0.094)
CT X Manufacturing	-0.327**	-0.175*	-0.160**	-0.168**	-0.212**
	(0.128)	(0.098)	(0.081)	(0.083)	(0.087)
CT X Trade	0.016	0.149	0.180**	0.176*	0.170*
	(0.142)	(0.105)	(0.090)	(0.092)	(0.096)
CT X Transportation	0.055	0.043	0.128	0.104	0.113
	(0.136)	(0.106)	(0.095)	(0.097)	(0.099)
CT X Services	0.000	0.124	0.142*	0.141*	0.131
	(0.126)	(0.095)	(0.079)	(0.081)	(0.085)
CT X Government	-0.050	-0.065	-0.034	-0.034	-0.027
	(0.146)	(0.102)	(0.088)	(0.090)	(0.094)
Cap-and-trade system	-0.065	-0.034	-0.011	-0.009	-0.058*
	(0.050)	(0.039)	(0.032)	(0.033)	(0.033)
Credit system	-0.064	0.008	-0.001	0.001	0.033
	(0.059)	(0.036)	(0.028)	(0.028)	(0.029)
Observations	9,961	14,537	14,537	14,537	14,537
R-squared	0.843	0.790	0.851	0.840	0.839
Industry FE	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Note: The natural logarithm was applied to the outcome variable in each regression. The omitted sector is Farming and Forestry. The notes of Table A2 explain how sectors are defined. Control variables (population and working population) are included in the regressions but omitted from the table. Industries with less than 500 employees are removed.

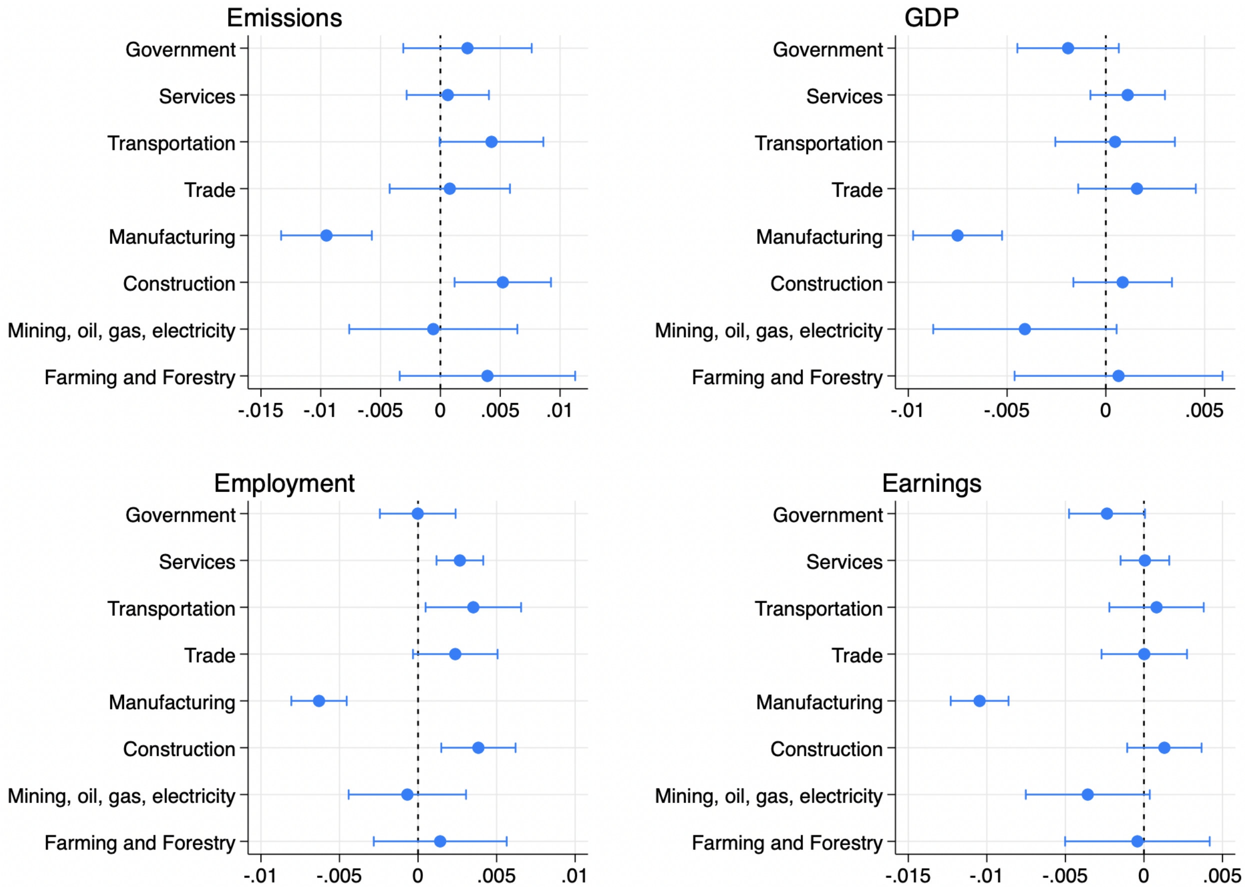
Table C4: Outcome Variables Regressed on CAT System with Industry Sectors

VARIABLES	(1) Emissions	(2) GDP (2012 dollars)	(3) Paid jobs	(4) Hours worked	(5) Earnings
Cap-and-trade system (CAT)	-0.185	-0.519***	-0.406***	-0.383***	-0.467***
	(0.185)	(0.142)	(0.123)	(0.125)	(0.137)
CAT X Mining, Oil, Gas, Electricity	-0.875***	-0.198	-0.096	-0.116	-0.149
	(0.265)	(0.169)	(0.136)	(0.137)	(0.149)
CAT X Construction	-0.081	0.225	0.219	0.168	0.278*
	(0.198)	(0.153)	(0.139)	(0.140)	(0.150)
CAT X Manufacturing	0.235	0.536***	0.461***	0.443***	0.450***
	(0.180)	(0.141)	(0.122)	(0.124)	(0.136)
CAT X Trade	0.581***	0.811***	0.720***	0.698***	0.764***
	(0.186)	(0.144)	(0.124)	(0.126)	(0.138)
CAT X Transportation	-0.029	0.255	0.115	0.086	0.144
	(0.197)	(0.160)	(0.148)	(0.149)	(0.158)
CAT X Services	0.285	0.720***	0.571***	0.556***	0.597***
	(0.177)	(0.138)	(0.119)	(0.121)	(0.134)
CAT X Government	-0.085	0.380**	0.197	0.174	0.304**
	(0.208)	(0.153)	(0.137)	(0.138)	(0.148)
Carbon tax	-0.047	-0.051*	-0.029	-0.032	-0.095***
	(0.047)	(0.030)	(0.023)	(0.024)	(0.024)
Credit system	-0.034	0.032	0.023	0.025	0.060**
	(0.058)	(0.036)	(0.027)	(0.028)	(0.029)
Observations	9,961	14,537	14,537	14,537	14,537
R-squared	0.843	0.790	0.851	0.840	0.838
Industry FE	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

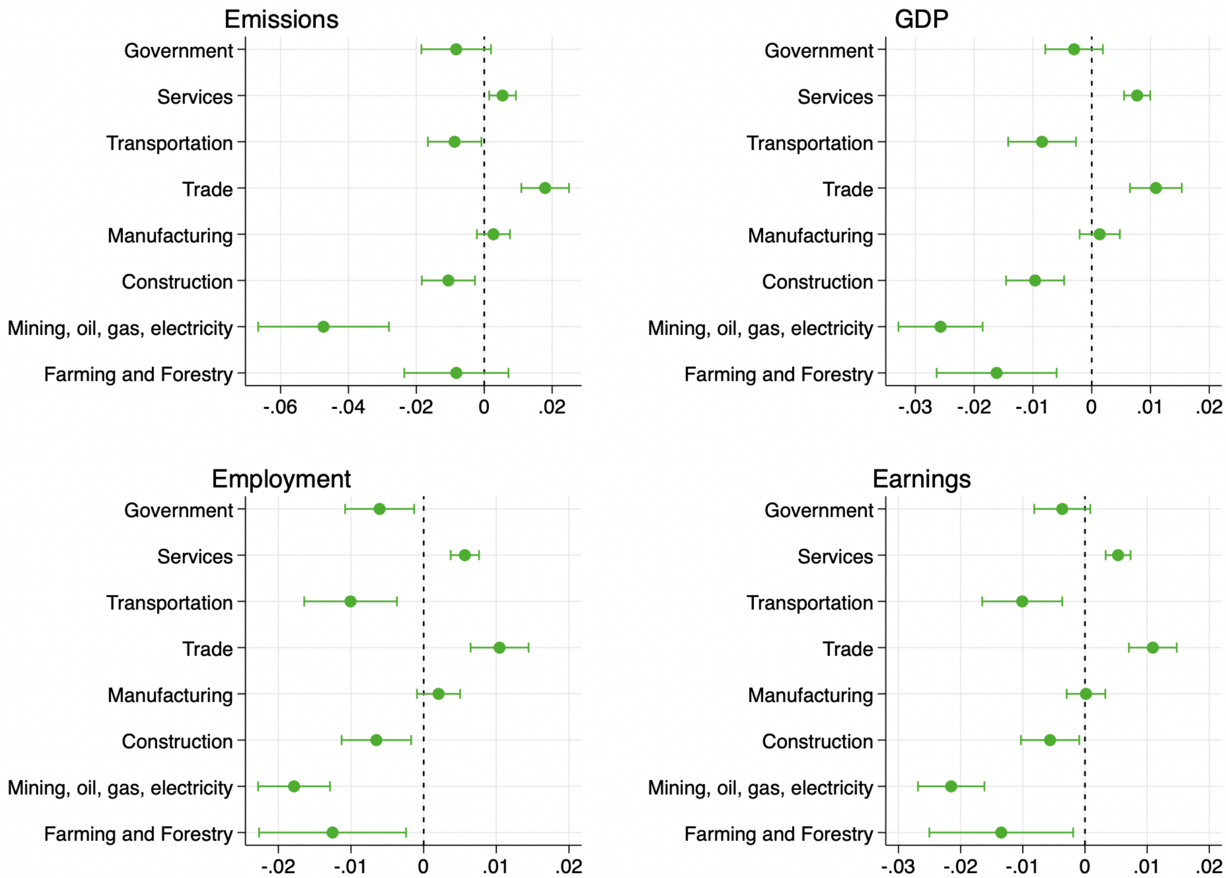
Note: The natural logarithm was applied to the outcome variable in each regression. The omitted sector is Farming and Forestry. The notes of Table A2 explain how sectors are defined. Control variables (population and working population) are included in the regressions but omitted from the table. Industries with less than 500 employees are removed.

Figure C1: Effects of Carbon Tax Rate by Sector



Note: The natural logarithm was applied to the outcome variable in each regression. The policy variable interacted with each sector is the carbon tax rate in \$/ton CO_2e. CAT system and credit system indicators are included as controls. Industries with less than 500 employees are removed. The confidence interval displayed is 90%.

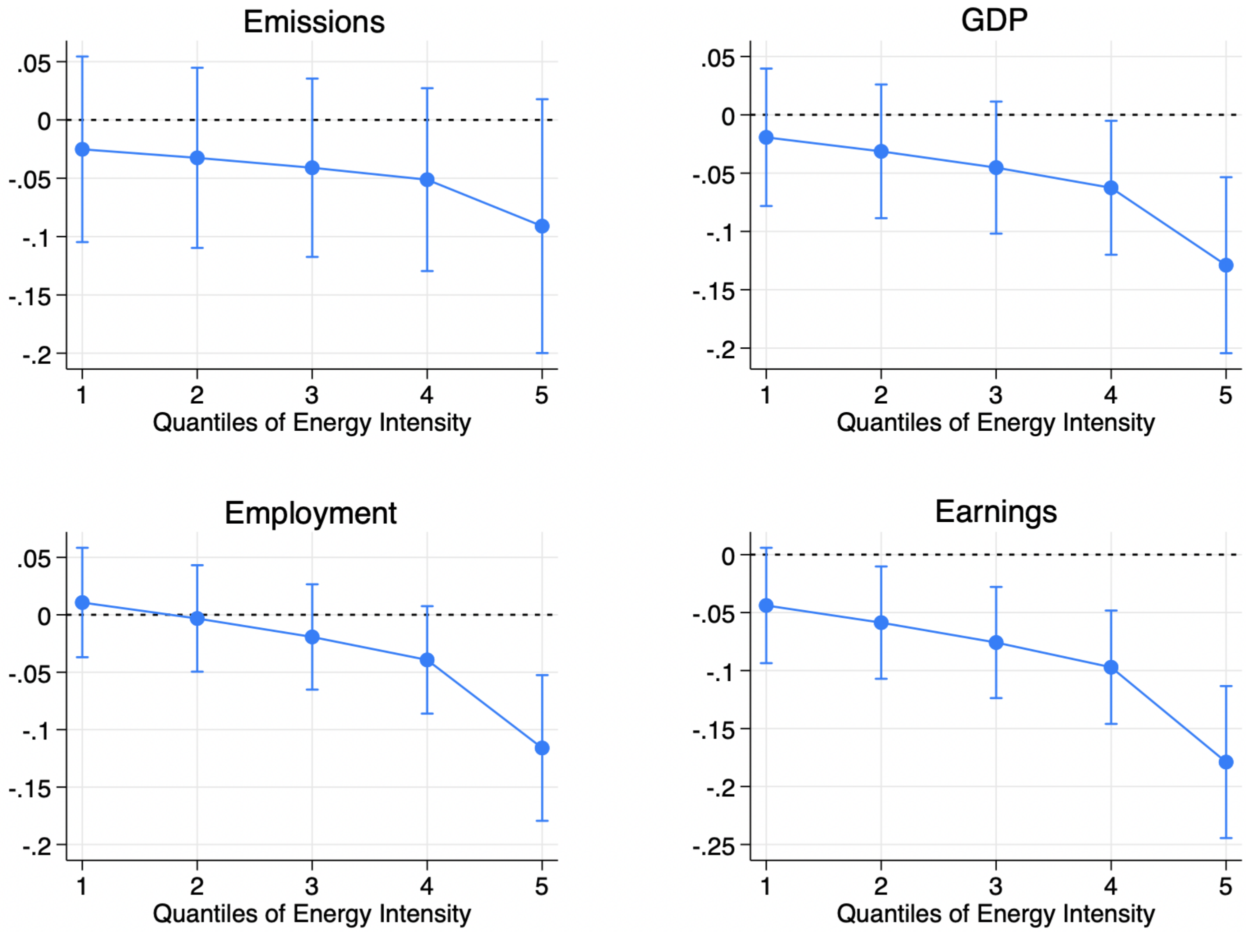
Figure C2: Effects of CAT System Auction Price by Sector



Note: The natural logarithm was applied to the outcome variable in each regression. The policy variable interacted with each sector is the CAT system auction price in \$/ton CO_2e. Carbon tax and credit system indicators are included as controls. Industries with less than 500 employees are removed. The confidence interval displayed is 90%.

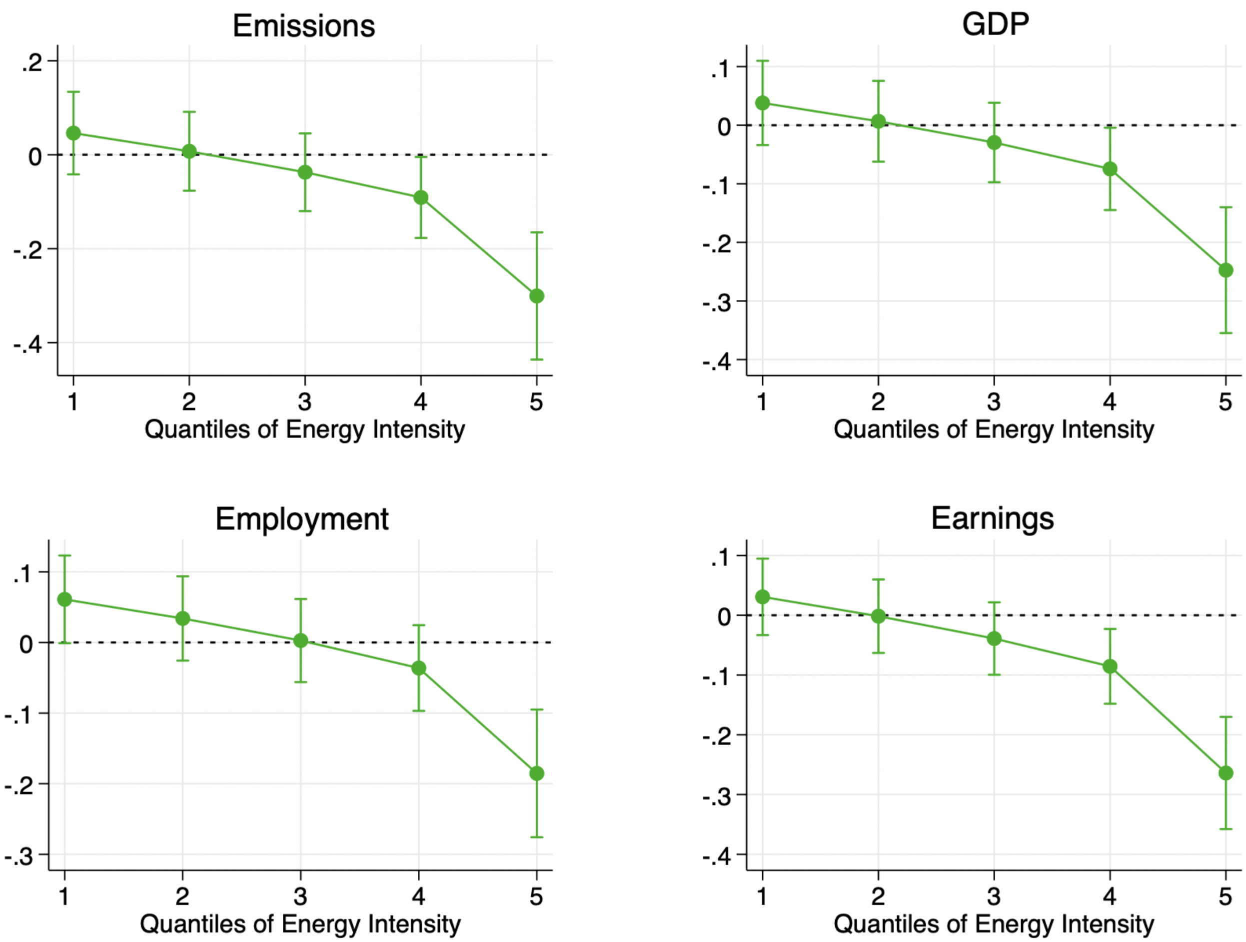
11.3 DID with Pre-treatment Industry Characteristics

Figure C3: Marginal Effects of Carbon Taxes on Outcomes by Energy Intensity



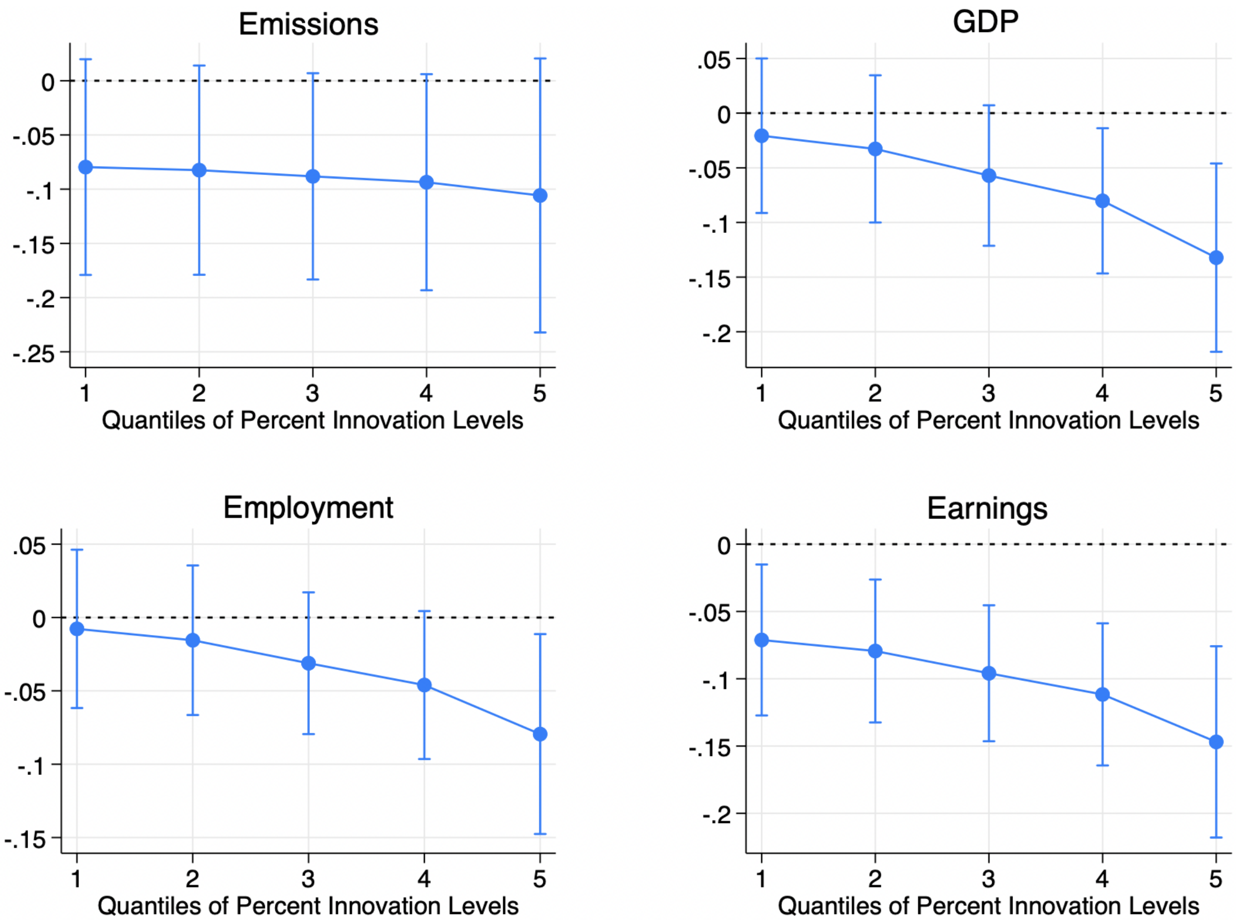
Note: The natural logarithm was applied to all outcomes. CAT and credit system indicators are included as controls. Industries with less than 500 employees are removed. The confidence interval displayed is 90%. Quantiles are created by dividing the energy intensity variable. A horizontal line is plotted at 0 to highlight the direction of the carbon tax's impact.

Figure C4: Marginal Effects of CAT Systems on Outcomes by Energy Intensity



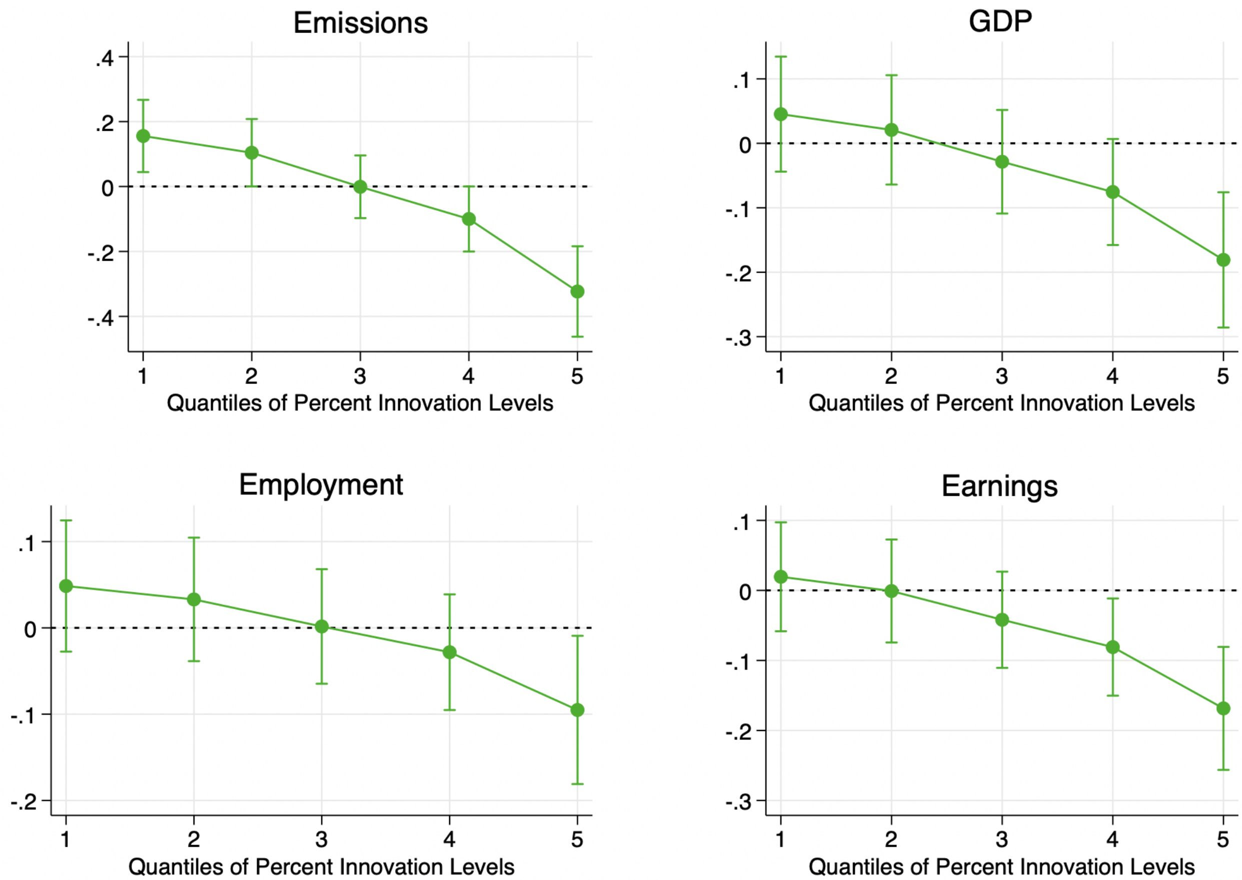
Note: The natural logarithm was applied to all outcomes. Carbon tax and credit system indicators are included as controls. Industries with less than 500 employees are removed. The confidence interval displayed is 90%. Quantiles are created by dividing the energy intensity variable. A horizontal line is plotted at 0 to highlight the direction of the carbon tax's impact.

Figure C5: Marginal Effects of Carbon Taxes on Outcomes by Percent Innovation Levels



Note: The natural logarithm was applied to all outcomes. CAT and credit system indicators are included as controls. Industries with less than 500 employees are removed. The confidence interval displayed is 90%. Quantiles are created by dividing the variable representing percent innovations that reduce GHG emissions. A horizontal line is plotted at 0 to highlight the direction of the carbon tax's impact.

Figure C6: Marginal Effects of CAT Systems on Outcomes by Percent Innovation Levels



Note: The natural logarithm was applied to all outcomes. Carbon tax and credit system indicators are included as controls. Industries with less than 500 employees are removed. The confidence interval displayed is 90%. Quantiles are created by dividing the variable representing percent innovations that reduce GHG emissions. A horizontal line is plotted at 0 to highlight the direction of the carbon tax's impact.

11.4 Mediating Model

Table C5: Decomposed Effects of Carbon Tax on Emissions through Mediating Variables (Energy Intensity)

GDP (2012 dollars)	Coefficient	Std. Error	z	P >|z|	[95% Confidence Interval]	
Direct effect:	0.0130	0.0358	0.36	0.716	-0.0571	0.0831
Indirect effect:	-0.0734	0.0350	-2.10	0.036	-0.1420	0.0047
Total effect:	-0.0603	0.0498	-1.21	0.226	-0.1580	0.0373
Paid jobs						
Direct effect:	-0.0025	0.0369	-0.07	0.946	-0.0748	0.0698
Indirect effect:	-0.0578	0.0342	-1.69	0.091	-0.1249	0.0093
Total effect:	-0.0603	0.0498	-1.21	0.226	-0.1580	0.0373
Hours worked						
Direct effect:	0.0034	0.0367	0.09	0.925	-0.0684	0.0753
Indirect effect:	-0.0638	0.0342	-1.87	0.062	-0.1307	0.0032
Total effect:	-0.0603	0.0498	-1.21	0.226	-0.1580	0.0373
Earnings						
Direct effect:	0.0534	0.0360	1.48	0.138	-0.0171	0.1240
Indirect effect:	-0.1138	0.0352	-3.24	0.001	-0.1827	-0.0449
Total effect:	-0.0603	0.0498	-1.21	0.226	-0.1580	0.0373

Note: The natural logarithm was applied to emissions and all macroeconomic variables. The policy variable used is the carbon tax indicator, and the lagged industry characteristic is energy intensity. The heading of each section indicates the mediating variable used. The effects are evaluated at an energy intensity of 10. The controls include credit and CAT system indicators, population, and working population. Industries with less than 500 employees are removed. See equation (7) for a breakdown of how each effect is calculated.

Table C6: Decomposed Effects of CAT System on Emissions through Mediating Variables (Energy Intensity)

GDP (2012 dollars)	Coefficient	Std. Error	z	P >|z|	[95% Confidence Interval]	
Direct effect:	-0.0478	0.0414	-1.16	0.248	-0.1289	0.0333
Indirect effect:	-0.0912	0.0406	-2.25	0.025	-0.1708	-0.0117
Total effect:	-0.1391	0.0564	-2.47	0.014	-0.2495	-0.0286
Paid jobs						
Direct effect:	-0.0696	0.0422	-1.65	0.099	-0.1522	0.0131
Indirect effect:	-0.0695	0.0391	-1.78	0.075	-0.1461	0.0071
Total effect:	-0.1391	0.0564	-2.47	0.014	-0.2495	-0.0286
Hours worked						
Direct effect:	-0.0708	0.0419	-1.69	0.091	-0.1528	0.0113
Indirect effect:	-0.0683	0.0393	-1.74	0.082	-0.1453	0.0086
Total effect:	-0.1391	0.0564	-2.47	0.014	-0.2495	-0.0286
Earnings						
Direct effect:	-0.0319	0.0410	-0.78	0.436	-0.1124	0.0485
Indirect effect:	-0.1071	0.0399	-2.69	0.007	-0.1852	-0.0290
Total effect:	-0.1391	0.0564	-2.47	0.014	-0.2495	-0.0286

Note: The natural logarithm was applied to emissions and all macroeconomic variables. The policy variable used is the CAT system indicator, and the lagged industry characteristic is energy intensity. The heading of each section indicates the mediating variable used. The effects are evaluated at an energy intensity of 10. The controls include carbon tax and credit system indicators, population, and working population. Industries with less than 500 employees are removed. See equation (7) for a breakdown of how each effect is calculated.

Table C7: Decomposed Effects of Carbon Tax on Emissions through Mediating Variables (Innovations)

GDP (2012 dollars)	Coefficient	Std. Error	z	P >|z|	[95% Confidence	Interval]
Direct effect:	-0.0236	0.0390	-0.60	0.546	-0.1000	0.0529
Indirect effect:	-0.0689	0.0442	-1.56	0.119	-0.1554	0.0177
Total effect:	-0.0924	0.0592	-1.56	0.119	-0.2085	0.0236
Paid jobs						
Direct effect:	-0.0343	0.0417	-0.82	0.411	-0.1160	0.0474
Indirect effect:	-0.0582	0.0424	-1.37	0.170	-0.1412	0.0249
Total effect:	-0.0924	0.0592	-1.56	0.119	-0.2085	0.0236
Hours worked						
Direct effect:	-0.0315	0.0414	-0.76	0.447	-0.1126	0.0497
Indirect effect:	-0.0609	0.0423	-1.44	0.149	-0.1438	0.0219
Total effect:	-0.0924	0.0592	-1.56	0.119	-0.2085	0.0236
Earnings						
Direct effect:	0.0194	0.0399	0.49	0.626	-0.0587	0.0976
Indirect effect:	-0.1119	0.0439	-2.55	0.011	-0.1979	-0.0258
Total effect:	-0.0924	0.0592	-1.56	0.119	-0.2085	0.0236

Note: The natural logarithm was applied to emissions and all macroeconomic variables. The policy variable used is the carbon tax indicator, and the lagged industry characteristic is percent innovations that reduce GHG emissions in the time period 2015-17. The heading of each section indicates the mediating variable used. The effects are evaluated at an innovations percent of 20. The controls include credit and CAT system indicators, population, and working population. Industries with less than 500 employees are removed. See equation (7) for a breakdown of how each effect is calculated.

Table C8: Decomposed Effects of CAT System on Emissions through Mediating Variables (Innovations)

GDP (2012 dollars)	Coefficient	Std. Error	z	P >|z|	[95% Confidence Interval]	
Direct effect:	-0.0277	0.0391	-0.71	0.478	-0.1043	0.0488
Indirect effect:	-0.0508	0.0467	-1.09	0.277	-0.1424	0.0407
Total effect:	-0.0785	0.0594	-1.32	0.186	-0.1950	0.0379
Paid jobs						
Direct effect:	-0.0486	0.0404	-1.20	0.288	-0.1277	0.0305
Indirect effect:	-0.0299	0.0453	-0.66	0.509	-0.1188	0.0589
Total effect:	-0.0785	0.0594	-1.32	0.186	-0.1950	0.0379
Hours worked						
Direct effect:	-0.0473	0.0401	-1.18	0.239	-0.1260	0.0314
Indirect effect:	-0.0313	0.0457	-0.68	0.494	-0.1208	0.0583
Total effect:	-0.0785	0.0594	-1.32	0.186	-0.1950	0.0379
Earnings						
Direct effect:	-0.0162	0.0389	-0.42	0.678	-0.0924	0.0601
Indirect effect:	-0.0624	0.0463	-1.35	0.178	-0.1531	0.0284
Total effect:	-0.0785	0.0594	-1.32	0.186	-0.1950	0.0379

Note: The natural logarithm was applied to emissions and all macroeconomic variables. The policy variable used is the CAT system indicator, and the lagged industry characteristic is percent innovations that reduce GHG emissions in the time period 2015-17. The heading of each section indicates the mediating variable used. The effects are evaluated at an innovations percent of 20. The controls include carbon tax and credit system indicators, population, and working population. Industries with less than 500 employees are removed. See equation (7) for a breakdown of how each effect is calculated.