CLEAN ECONOMY
WORKING PAPER SERIES
March 2019 / WP 18-08

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This research project was supported by the Economics and Environmental Policy Research Network (EEPRN)

This project was undertaken with the financial support of:
Ce projet a été réalisé avec l'appui financier de :

Environment and Climate Change Canada | Environnement et Changement climatique Canada

Smart Prosperity Institute

uOttawa
Institut de l'environnement
Institute of the Environment

Do Carbon Taxes Kill Jobs? Firm-Level Evidence from British Columbia*

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Version: November 2018

Abstract

This paper investigates the employment impacts of British Columbia's revenue-neutral carbon tax. We develop a revised approach to implementing the synthetic control method to firm-level employment data, allowing us to estimate heterogeneous impacts across industries. We find that the employment effects vary across sectors, specifically small service firms see their employment increase, while employment of larger energy intensive and trade intensive manufacturing firms decreases. These results provide new evidence for the "job-shifting hypothesis" of the revenue neutral tax. Tax cuts increased the purchasing power of low income households benefiting locally operating businesses (such as restaurants, massage or yoga studios) at the expense of the more internationally-exposed larger manufacturing firms. In contrast to previous papers, we find that the aggregate employment was unaffected by the BC policy.

Key Words: Carbon tax; Employment; Unilateral climate policy; Firms

JEL Codes: E24, H23, J2, Q5

*We particularly thank Marc Hafstead, Krishna Pendakur and, Charles Séguin, Chi Man Yip for their insightful comments and also thank the participants at ASSA, AERE, CEA, WCERE and the WEAI for their comments. We like to thank members of the Economic Analysis Department at Statistics Canada for their advice on data. We acknowledge generous funding from the Economics and Environmental Policy Research Network (EEPRN), which is supported by Environment and Climate Change Canada (ECCC). Views expressed in this paper do not necessarily reflect those of Statistics Canada, or EEPRN. This paper has been screened to ensure that no confidential data are revealed. All remaining errors are our own.

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1. Introduction

For decades there has been a consensus in the economics literature that carbon taxes are efficient, but their precise economic impacts have remained hotly debated. Claims range from one extreme that these policies "kill jobs" to the opposite, that they generate economic growth and "spur innovation".[1] The concerns by politicians — which appear to make many governments hesitant to adopt such a tax — are that they displace workers, depress economic growth, and are regressive. However, when the tax revenues raised by carbon taxes are redistributed back to the economy, it is not clear how these concerns play out. To better inform policymakers and the public about the true benefits and costs of revenue-neutral carbon taxes, this paper investigates the employment effects of British Columbia's carbon tax.

On July 1st, 2008, British Columbia (BC) became the first jurisdiction in North America to implement a revenue-neutral carbon tax. Today, BC has the most aggressive and comprehensive revenue-neutral carbon tax worldwide.[2] Anecdotal evidence suggests the policy is a success — achieving large reductions in pollution at relatively modest cost to the economy.[3] The policy intervention has a number of characteristics that make it an ideal natural experiment with which to study the employment effects. First, the BC carbon tax is a textbook pollution tax — subjecting almost all sources of carbon pollution in the region to a uniform price per tonne of carbon emitted, making it easy to connect the predictions of theory to an empirical test. Second, the speed with which the policy was implemented made it a surprise to most stakeholders, ruling out the possibility that polluters would adjust their behavior in anticipation of the regulation. Third, the relatively high tax rate adopted meant that it provided a strong signal to polluters to change their behavior when the policy was introduced.

[1] The latter claim is referred to as the "Porter hypothesis" (Porter, 1991; Porter and van der Linde, 1995).

[2] The tax rate was initially \$10/tonne CO_2e when it was implemented in 2008, then increased \$5/tonne annually until it reached \$30/tonne in 2012 until April of 2018, when it increased to \$35 and will further increase to \$50 until 2021. Carbon dioxide equivalent (CO_2e) is a unit of measurement used to compare the global warming potential of various greenhouse gas (GHG) emissions to the global warming potential of CO2. In 2013, CO_2 made up 78% of BC's GHG emissions methane made up 16%, while N_2O made up 3% (measured in CO_2e) (Environment Canada, 2015).

[3] See https://www.cbc.ca/news/canada/british-columbia/b-c-carbon-tax-cut-fuel-use-didn-t-hurt-economy-1.1309766

We used firm-level employment data from the 2001-2013 Longitudinal Employment Analysis Program (LEAP) to estimate the employment effect of the BC carbon tax. We develop a revised synthetic control method (SCM) tailored to firm-level data. Instead of applying the SCM directly to the firm-level data, we first construct "representative firms" from all individual firms in each province, industry, and firm class size, and runs the SCM using these representative firms. This revised approach addresses several empirical difficulties of implementing the SCM with firm-level data. First, it allow us to avoid dropping a large portion of our dataset. Applying the SCM to the firm-level data would, for some industries, require us to drop over 50% of firms in our dataset. This is because the SCM requires a balanced panel of data; however, many firms enter and exit sometime during our period of analysis. Second, it allows us to obtain more robust statistical significance levels as more potential placebos are available in the donor pool (see Section 4.2). Lastly, it increases computational efficiency. We test this method in a Monte Carlo simulation to illustrate its validity.

Using our revised SCM, we find that the BC carbon tax caused larger companies in energy-intensive manufacturing sectors to contract, while it increased employment in smaller service sector industries, such as health services (e.g., massage therapists, dental), restaurants, tourism, small food manufacturers and small clothing companies. On the demand side, this shift is consistent with the recycling of the carbon tax, with households spending relatively more of their additional dollars (resulting from income tax reductions and government transfers) on smaller local business services than on products from large carbon-intensive sectors that trade globally. On the supply side, these results are also consistent with the fact that the small business tax was reduced by a larger percentage than the overall corporate tax rate. However, contrary to the previous studies on the BC carbon tax, we find that aggregate employment is not significantly affected by this policy. We argue that the estimates in the previous studies may be over- or under-estimated due to the violation of the parallel trends assumption.

Specifically, we can highlight a couple of results: a) we find that the manufacturing metal industry is hardest hit, and lost around 5,700 jobs, equivalent to a 15.3% decrease in jobs per capita in this industry. b) Overall, we show that the estimated employment effects are negatively correlated with emissions intensity across all industries. c) On the supply side, because the tax revenues were recycled to reduce the "small business income tax", we split the firms into size classes and ask, whether larger or smaller firms gained employment from the tax? Here we find that employment in smaller businesses in the health-care, food, clothing, retail and trade (online, department stores, hobby) significantly increased.[4] Overall, these "job shifts" in BC from large energy-intensive manufacturing firms to smaller service firms is consistent with the recycling feature of the carbon tax, and also provide further evidence for the "job-shifting hypothesis," first documented in Yamazaki (2017).

This paper makes several important contributions. First, despite a large existing theoretical literature on carbon taxes (e.g., Nordhaus (2016); Metcalf (2009); Hafstead and Williams (2018)), the empirical literature is still scant and inconclusive. To our knowledge, there are only a few empirical papers to examine the employment effects of the BC carbon tax. Using a differences-in-differences (DID) framework, Yamazaki (2017) finds that BC's aggregate employment increased by 4.5% over the six years following the implementation of the policy. In comparison, Yip (2018), also using DID, finds that the policy sharply increased unemployment by 1.3 percentage points which would be enormous as it would explain 41% of BC's total unemployment rate.[5] We identify a number of econometric challenges that could confound previous results. In particular, the BC carbon tax was implemented at a time of major macro-economic shifts, such as the great recession, rapid migration, and oil price shocks. Due to these confounding factors, our analysis of the pre-

[4] Small business in the accommodation and food services, and other small business service sectors also increased, but are not statistically significant at conventional levels.

[5] Rivers and Schaufele (2014) focus on the tax's effect on agricultural trade, finding that it did not adversely affect the sector's trade. Antweiler and Gulati (2016) investigate the tax's effect on gasoline consumption as well as vehicle choice, concluding that the policy has resulted in fuel demand per capita being 7% lower and the fuel efficiency of the average vehicle in the province being 4% higher than it otherwise would be. Thus far, only Martin, de Preux and Wagner (2014) investigated the effect of the UK's carbon tax, the Climate Change Levy (CCL), on manufacturing activities. Their results found no statistically significant impact of such tax on employment. This paper differs from Martin, de Preux and Wagner in several ways. First, although the CCL is considered a carbon tax, the CCL and BC carbon tax are designed differently, especially in sectoral coverage and exemptions. Second, this paper investigated the net effect of the carbon tax by considering many different sectors while Martin et al. focused on the manufacturing sector. In addition, Petrick and Wagner (2014) and Martin et al. (2014) investigate the effects of carbon pricing in the context of the European Trading Scheme.

treatment years (2001 to 2007) shows that the DID "parallel trends" assumption between BC and other Canadian provinces is violated. The methodology used in this paper is chosen to overcome these concerns. Through using the SCM we construct the counterfactual which best matches the pre-treatment trend in each industry in BC.

Our second contribution is that, to our knowledge, this is the first paper to study the employment effect using firm-level data, which includes the entire universe of employment in Canada. This highly confidential, but rich dataset allows us to include more industries/provinces whose data is suppressed in the public datasets used by previous researchers as well as to disaggregate our results by firm size. We show that the use of the suppressed data leads to different results.

Lastly, this paper provides a method to deal with the situation where not enough control units exist in the donor pool when implementing the SCM. This is a particularly pertinent issue for studies which focus on small regions.[6] It overcomes the issue by using individual-level data to construct representative firms.

The results of this paper are timely for Canada as the federal government now mandates the provinces to implement carbon pricing of $50/tonne by 2021. In addition, our results are of interest globally, as most countries today are actively debating which policies to implement to curb GHG emissions in order to achieve national emissions targets. In fact, the BC carbon tax is now actively discussed in many policy forums as the role model (World Bank Group, 2018).

The remainder of the paper is structured as follows. Section 2 describes the design of the BC carbon tax. Section 3 explains the data while section 4 presents the research design. The empirical findings are presented in section 5. Finally, section 6 provides further discussion and concludes. An additional table is provided in the Appendix.

[6] If we were to use the SCM with the industry-level data, always less than 9 control units are available in the donor pool for the placebos (because the data for many industries in small provinces is either suppressed or nonexistent). Note that at least 9 control units are required to interpret the estimates with a pseudo-10% statistical significance level.

2. Background of the BC Carbon Tax

The British Columbia Ministry of Finance formally announced their intention of implementing a carbon tax in their budget plan on February 2008. Only five months later, on July 1st, 2008, the policy was initiated. It was introduced with the objective of reducing emissions by a minimum of 33% below the 2007 levels by 2020 (Ministry of Finance, 2013). Given past political actions taken by the Liberal government in the province, the announcement of the carbon tax took the public by surprise (Harrison, 2013).

Starting at $10/tonne CO2e, the rate increased by $5/tonne CO_2e annually until it reached $30 in 2012, making it among the highest carbon prices in the world (Murray and Rivers, 2015). The rate was kept at $30 until 2018; however, it increased to $35 on April 1, 2018, and is expected to annually increase by $5 until it reaches $50/tonne in 2021 (Ministry of Finance, 2017). These increases are set to meet the carbon pricing requirements in the Pan-Canadian Framework on Clean Growth and Climate Change. This framework is a collective plan set out by the federal government to reduce emission in Canada. British Columbia joined this framework in 2016. Under this framework, the carbon tax rate is required to be at $50 by 2022. As each fuel has different carbon contents, the rate is adjusted accordingly. For example, the carbon tax increased the price of gasoline by 2.34 cents per liter in 2008, rising gradually to 6.67 cents per liter by 2012 (Ministry of Finance, 2010). Table 1 provides the tax rate per unit volume for selected fuel types and the percent of the final fuel price that the tax is responsible for.

The revenue neutrality of the policy is implemented in a number of ways. Firstly, the bottom two income tax brackets in BC were reduced by 5% (Ministry of Finance, 2012). This resulted in BC having the lowest income tax rate in Canada for individuals earning up to $122,000 (Ministry of Finance, 2012). A "low-income climate action" tax credit, and the Northern and Rural Homeowner benefit, further distribute the revenue collected by the policy (Ministry of Finance, 2012). Second, the general corporate tax rate was initially reduced from 12% to 11% in 2008 and was reduced further to 10.5% and 10% in 2010 and 2011 (Ministry of Finance, 2012). It was reverted back to the 2008 level of 11% in 2014. The small business corporate income tax rate was also reduced from 4.5% to 2.5% in 2008 (Ministry of Finance, 2012).[7] A number of additional tax credits, which make up a relatively small portion of the redistributed revenue, have also been implemented since 2008 (Ministry of Finance, 2012). These tax credits range from the BC Seniors Home Renovation Tax Credit, to the Film Incentive BC tax credit. According to the Budget and Fiscal Plan (Ministry of Finance, 2015), the carbon tax has raised about $1.2 billion revenue annually since 2012, when the rate stopped increasing at $30/tonne CO_2e.

The carbon tax covers nearly all carbon emissions from fuel combustion in BC, which amounts to about 75% of all greenhouse gas (GHG) emissions in the province (Murray and Rivers, 2015). Exemptions are made for fuels exported from BC, all GHG emissions that are not directly produced from the combustion of fossil fuels (e.g., methane produced from landfills), and all emissions produced outside BC's borders (Ministry of Finance, 2014). These exemptions result in a significant portion of emissions from the air transportation and non-metallic mineral product manufacturing industry being exempt from the tax. Additionally, since the carbon tax is only levied on fossil fuels, emissions from non-fossil fuel sources, such as fugitive emissions or from chemical processes, are not covered by the tax.[8]

3. Data Sources

We use the most detailed firm-level employment dataset available from Statistics Canada, the Longitudinal Employment Analysis Program (LEAP). This dataset is confidential and consists of the universe of employment data from all Canadian firms covering the time period from 2001 to 2013. The employment measure used in this dataset is the average labour unit (ALU). The ALU employment estimate is derived by dividing the business's annual payroll (collected from

[7] In BC, "Small business" for tax purposes is defined as a company with business income of less than $500,000/year (before 2010 the limit was $400,000/year).

[8] The non-metallic mineral product manufacturing industry includes the cement and concrete manufacturing industry which, as a result of chemical processes involved in cement manufacturing, produces large volumes of CO_2 (Gibbs, Soyka and Coneely, 2000)). Therefore, since this CO_2 is not produced from fuel combustion, it is not covered by the BC carbon tax.

Canadian business tax data) by the average annual earnings per employee in the corresponding industry/province/firm-size (compiled from the *Canadian Survey of Employment, Payroll and Hours*). Summary statistics are presented in Table 2.

Between 2001-2013, the LEAP contains data on approximately 4 million firms; however, approximately 30% of these firms have zero employment throughout our period of analysis. After dropping these firms with zero employment and those with consecutive missing observations, there are approximately 2.1 million firms in Canada, which represents around 91% of employment in Canada.[9]

4. Methodology

I. Why the Synthetic Control Method?

To credibly estimate the employment effects using the difference-in-difference (DID) framework, the "parallel trends" assumption must be satisfied between the treated and control groups. It requires that the changes in employment for industries in BC (treated group) and rest of Canada (ROC) (control group) would follow the same time trend in the absence of the carbon tax. To test this assumption, we develop a test to succinctly display the support for or lack of parallel trends between employment in BC and ROC.

To start, for each industry we calculate a representative firm for ROC, and use the representative firm calculated for BC (based on our "all-firms" sample - see Section 4.II below). To test whether the pre-treatment trends are parallel between BC and ROC, we drop all data points from 2008 and

[9] After dropping the firms with no employment, there are still 40 million observations, consisting of 2.5 million firms. Among them, there are 437,780 firms in BC, which is 16% of the data. Among the 2.5 million firms, 11% of them have zero(s) that are surrounded by non-zeros. The breakdown is: 1 year: 6%, 2 years: 2%, 3 years: 1.2%, 4 years: 0.7%, 5 years: 0.5%, 6 years or more: 0.85%. For any single zero and double zero surrounded by non-zeros, we interpolated the employment data by the surrounding years employment data. Any firms reporting three or more of subsequent years of zeros are dropped from the dataset. These non-reports are likely due to late tax-filings or delays in the reporting system.

onwards, and fit the following equation to the data:

$$\ln \tilde{L}_{ipt} = \text{BC}_p + \beta(\text{BC}_p \times \text{Year}_t) + \text{ROC}_p + \alpha(\text{ROC}_p \times \text{Year}_t) + \epsilon_{ipt} \qquad (4.1)$$

where $\tilde{L}_{ipt}$ is the employment per capita, $L_{ipt}/\text{population}_{pt}$, letting $\ln \tilde{L}_{ipt}$ be the log of employment per capita for firm i in province p at time t.[10] BC_p is a dummy variable for BC and ROC_p is a dummy variable for the ROC. Year_t is the linear time trend variable. ϵ_{ipt} is the idiosyncratic error term. Finally, to test whether the trends in BC and ROC are parallel, we test the null hypothesis that the difference between β and α is zero. Rejecting the null hypothesis implies that the trends are not parallel between BC and ROC. We then apply the same test to check the parallel trends assumption between BC and synthetic BC (SC), substituting ROC with the SC data generated from the methodology described in Section 4.II.[11]

Table 3 displays the median p-value for the results of these tests across each representative firm for each industry. We see that for 12 out of the 24 industries, the ROC control group does not satisfy the parallel trends assumption. In comparison, when the SC is used as the control group, all industries show substantially higher p-values, failing to reject the null hypothesis. To supplement these tests, we also show Fig 1 and 2 to illustrate the correspondence between the tests and the visualization of the trends. Fig 1 shows the evolution of employment per capita in one representative firm for BC, ROC, and SC for the manufacturing (wood + plastic) sector.[12] Table A.1 in the Appendix gives the p-values for all five tests in each industry (it is from these p-values that the median p-value presented in Table 3 is calculated), and from this table we see that the corresponding p-value for ROC vs. BC is 0.000024 and the p-value for the SC vs. BC is 0.94. Clearly, the pre-treatment trends for ROC and BC are significantly different; however, when the SC is used as the control group, the trends are far from being significantly different.

Fig 2, on the other hand, illustrates a case where neither ROC or the SC satisfies the parallel

[10] See Section 4.II for why we use $\ln \tilde{L}_{ipt}$ as the dependent variable.

[11] For each industry this test is actually carried out 5 times, as we divide firms in each province into quintiles based on size, and then carry out the SC method on each size class (see Section 4.II). Hence, Table 3 presents the median p-value of these tests).

[12] See Section 4.II for the definition of a representative firm.

trends test well. In this case the p-value for ROC vs. BC is 0.014 and for the SC vs. BC is 0.84 for this particular representative firm. Clearly from these two figures we can see that p-values in 0.8-0.9 range do no necessarily indicate a good match between the SC and BC. Fortunately, Table 3 shows that the large majority of industries have median p-values that are over 0.95.

II. A Revised Approach to SCM

We implement the SCM according to how it is outlined in Abadie, Diamond and Hainmueller (2010). Let Y^I_{jpt} be employment in industry j in province p at time t which receives the policy intervention, and Y^N_{jpt} be the employment in that industry if it does not receive the intervention. Then we can write the effect of the intervention measured at time t as $\alpha_{jpt} = Y^I_{jpt} - Y^N_{jpt}$. In this study, the parameter of interest is $\alpha_{j,\mathrm{BC},2013}$, as BC is the province which implemented the carbon tax, and we are interested in the effect measured in the year 2013. We choose 2013 because the final increase of the BC carbon tax rate was completed in 2012, and so analyzing the policy's effect following this year ensures the analysis captures the total effect of the carbon tax. In addition, starting with 2013/14, the tax revenues were used more for targeted support subsidies of particular industries in BC (among others, most prominently the movie industry), and hence the tax lost its notion of being a "textbook" example of a revenue-neutral carbon tax. Abadie, Diamond and Hainmueller (2010) show that $\alpha_{j,\mathrm{BC},t}$ can be estimated by substituting $Y^N_{j,\mathrm{BC},t}$ for a synthetic control group which is defined as the inner product of a vector of weights and the vector of the outcome variable for the firms from ROC, where the vector of weights is such that the difference between the pre-treatment values of chosen variables of the treatment unit and the synthetic control group is minimized. See Abadie, Diamond and Hainmueller (2010) for a detailed discussion of the SCM.

Representative firm approach

Given that our primary interest is the industry-specific employment effect, the SCM is employed for each industry. This implies that the synthetic control group will be constructed out of

12 potential control units (9 non-BC provinces and 3 territories) from the donor pool if we are to use the industry-level data. However, the SCM tests the statistical significance of the estimates using placebo tests and the level of significance depends on the number of placebos available in the donor pool. Consequently, we require at least 9 control groups in the donor pool to obtain a significance level of 10%.[13] Nevertheless, due to data suppression and missing values in the publicly available Statistics Canada industry-level data, only 15 out of the 24 2-digit NAICS sectors have at least 9 control units. As these 15 sectors account only for about 60% of total employment in Canada, the SCM applied to this firm-level data would allow us to present results with a significance level of 10% for a limited fraction of Canadian employment. To increase the numbers of placebos, and therefore use a significance level of at most 10% for all industries, we use a revised approach to the SCM applied to firm-level data and test the validity of our method by Monte Carlo simulation.

For each sector (2-digit NAICS), we create five "representative firms" for each province delineated by firm size. Because our Monte Carlo simulations (presented below) show that each representative firm must include a "large number of firms," here equal to 100, for the results of our analysis to be consistent, the exact definition of this representative firm depends on the number of firms that exist in a given province's industry. Therefore, in all cases, the representative firm is the sum of at least 100 firms within one industry-province-size class combination. In particular, if there are 500 or more firms in a given industry-province pair, a representative firm is created for each quintile (i.e. each quintile contains the same number of firms, whereby the first (fifth) quintile is the quintile with the least (maximum) number of employees). If there are 400 to 499 firms in a given industry-province pair, a representative firm is created for each quartile. This same pattern is applied to industry-province pairs with 300 to 399 and 200 to 299 firms. If there are 100 to 199 firms in the industry-province pair then only one representative firm is created and if there are less than 100 firms in the industry-province pair, then the representative firm is dropped. The only

[13] We need at least 19 control groups to obtain a significance level of 5%, which is more than all the potential control units in Canada. This calculation of the significance level is based on the number of control units in the donor pool is the same as that used in Abadie, Diamond and Hainmueller (2010).

exception to this rule is made for the utilities industry, in which the number of firms is less than 100 for all provinces. In this case one representative firm is made for each province which has more than 40 firms. As a result of the above rules, BC has 5 representative firms in each industry except two: the utilities industry with one representative firm and the public administration industry with 4 representative firms.

The SCM is then run for each BC representative firm in each industry, with the firms in BC as the treatment group and using all representative firms outside BC as the donor pool. Depending on the particular industry, we obtain at minimum five donors (utilities sector) and up to 41 donors (accommodations and food services sector and retail trade (cars, furniture, groceries) sector). This methodology results in multiple employment effect estimates (one estimate per BC representative firm) and so to obtain one estimate, we take the average of the estimates weighted by the number of employees contained within each estimate's associated representative firm.

Placebo tests are then carried out on each representative firm to test for the "significance".[14] To do this we re-run the SCM, but where the treatment group is replaced by a representative firm from the donor pool, with the placebo donor pool being all representative firms in other provinces. If the estimated employment effect lies outside the range of the 90% of the estimates obtained by the placebos, then we say that the estimate is "significant at the 10% level."[15] Specifically, this "pseudo confidence interval" is constructed by taking the set of placebo estimates produced for each industry, dropping any outliers, dropping the top and bottom 5% of these estimates, and then taking the maximum and minimum of the left-over set.[16] Since each industry/province contains a different number of representative firms, the number of placebos available for each industry's estimation varies. In some cases, this leads to the significance level being higher than 10%. The figures in which the results are presented in Section 5, clearly show this when this is the case.

[14]Here and in the following we use the conventional terms of the "significance" and "confidence interval," although statistically the SCM produces pseudo-confidence intervals only. See Abadie, Diamond and Hainmueller (2010) regarding the interpretation of the placebo test inference methods.

[15]We call this 90% placebo range, a pseudo-confidence interval (pseudo-CI). For a discussion of the inference techniques used in this paper, see Abadie, Diamond and Hainmueller (2010).

[16]We define outliers by calculating the kernel density for each distribution of placebos and then storing the calculated density value for each placebo. We then drop any placebo that is assigned a density of less than 0.35.

We run the above-described analysis on the following sets of data samples: (a) all firms in our sample using 2 digit NAICS codes, (b) the smallest 33% of firms in the sample using 2 digit NAICS codes, (c) the largest 33% of firms in the sample using 2 digit NAICS codes, (d) a subset of firms in our sample using 3 digit NAICS codes.

We control for labor force changes due to migration and natural population growth over the time period from 2001 to 2013 by using log of employment per capita as our dependent variable rather than log of employment in levels.

As seen in Table 4, employment growth prior to the tax's implementation and after are notably different across provinces. For example, BC's employment growth prior to the carbon tax is similar to that of Québec's; however, in the post-tax period it drops to about one fifth of its employment growth in the previous period, whereas Québec's employment growth drops to about one half of what it was in the previous period. Unless this difference is entirely due to the carbon tax, this change proves problematic for running the SCM using employment in levels to isolate the effect of the tax on employment at the industry level. This is because the SCM implicitly assumes that the employment growth in each industry due to macroeconomic conditions stays the same, so if Québec is given a large weighting in the SC, the employment effect estimate will be biased by the higher aggregate employment growth rate in Québec, assuming that this higher rate of growth is not solely due to the carbon tax. We take the opinion that this change in the aggregate employment growth rate is primarily due to changes in migration patterns throughout Canada as well as the Great Recession, and not due to the carbon tax. To substantiate this claim, consider the employment growth in the two periods shown in the above table for PEI and Nova Scotia. Prior to the carbon tax being implemented they have similar rates of growth in employment; however, in the following period in which the Great Recession took place, their employment growth rate is substantially different. Hence, since a major policy change such as a carbon tax did not occur across either of these provinces during this time, this comparison suggests that this change in employment growth across provinces was largely influenced by the Great Recession. Further, Metcalf (2015) finds that the BC carbon tax did not have an economic impact at the aggregate level, corroborating our view that the large change in the employment growth rate in the period after 2008 is not likely due to the carbon tax. This assumption is contrary to the methods used in the previous literature, which could explain the large unemployment effect found in Yip (2018).

While our representative firm approach allows us to better utilize the firm-level data in employing the SCM, we also directly use the firm-level data to estimate the employment effect with a traditional DID approach. Following Bohn, Lofstrom and Raphael (2014) and Jones and Goodkind (2018), we augment the DID approach with the weights generated by our representative firm SCM approach. This allows us to construct the counterfactual more systematically by only using firms that are included in representative firms with the SCM weight. Each firm is given a weight such that the cumulative weight within the representative firm matches the SCM weight for this representative firm. With these weights, we estimate the following equation:

$$\ln L_{ipt} = \beta(\mathrm{BC}_p \times \mathrm{Post}_t) + X_{pt} + \phi_i + \lambda_t + \gamma_{jt} + \epsilon_{ipt} \tag{4.2}$$

where $\ln L_{it}$ is the log of employment for firm i in province p at time t. BC_p is a dummy variable for BC while Post_t is a dummy variable for the post-policy period (2008-2013). X_{it} is a vector of control variables at province by year level, such as population growth, oil price, and etc. ϕ_i and λ_t are firm and year fixed effects, respectively. γ_{jt} is (3-digit NAICS) sub-industry by time fixed effects. Finally, ϵ_{it} is an error term that captures idiosyncratic changes in employment. We estimate Eq.(4.2) for each industry at 2-digit NAICS level. The result is presented in Figure 7 and discussed in Section 5.

III. Monte Carlo Simulations

We run Monte Carlo (MC) simulations to demonstrate the characteristics of our representative firm approach to the synthetic control estimator. The primary goal of these simulations is to illustrate the fact that the synthetic control estimator in our revised approach is consistent. Hence, we use these MC simulations to show that the estimator in this technique converges to the true value of $\alpha_{j,2013,\mathrm{BC}}$ as the number of firms that are aggregated into the representative firm is increased. Similarly, we show that the probability of committing type 2 error decreases as the number of firms that are aggregated into the representative firm is increased. To show this, we run the following four sets of MC simulations.

The simulations are set up using a simple fake dataset with 100 provinces, each containing one industry, which contains n firms. The employment of each firm is randomly generated from a normal distribution. For simplicity, the standard deviation of this normal distribution is the same across all firms and provinces. Four years are included in the simulation, two before the imposed treatment and two after. In all simulations, the MSPE is minimized over the two years before the treatment. In each simulation, we run the SCM with BC as the treatment state, but also with all other 99 control states as placebo tests. We then rank the α_{jpT}'s (smallest $\alpha_{jpT} = 1$, highest $\alpha_{jpT} = 100$) that are produced by these 99 placebo units and 1 the one treatment unit, where T is the final year of the simulation. The alternate hypothesis is that the BC $\alpha_{j,\mathrm{BC},T}$ is different than zero, H_A: $\alpha_{j,\mathrm{BC},T} \neq 0$. The null hypothesis is that the BC $\alpha_{j,\mathrm{BC},T}$ is equal to zero, H_0: $\alpha_{j,\mathrm{BC},T} = 0$. If $\alpha_{j,\mathrm{BC},T}$ is ranked 1st, 2nd, 99th, or 100th, then at a significance level of 4% , the null hypothesis is rejected, and we conclude that the $\alpha_{j,\mathrm{BC},T}$ is significantly different from zero.[17]

In the first simulation, the mean of this normal distribution remains the same across all years and the number of firms in each province is one, $n_i = 1$ for all j. Thus, on average, employment in the treatment province, BC, should not be significantly different from employment in the synthetic control province. Additionally, in simulation 1, the normal distributions from which BC and the control's employment is drawn are equal. Thus, we expect that the null hypothesis gets rejected in only 4% of the simulations. This simulation is repeated 1000 times. Table 5 summarizes the defining parameters of each simulation.

The second, third, and fourth simulations differ from simulation 1 in that the mean of the normal distribution from which BC's employment is drawn changes in 2008 (i.e., when the carbon

[17] A significance level of 4% is used as, since we only have 100 units, it is not possible to determine the 2.5th and 97.5th percentiles, which is required to use a significance level of 5%. Using 1000 control units was attempted so that we could use the standard 5% significance level; however, these simulations demanded large computational power and were estimated to take approximately three months to complete.

tax is introduced). In these simulations, it drops by one standard deviation, which in this case is 2. In the second simulation $n_i = 1$ for all j, in the third simulation $n_i = 5$ for all j, and in the fourth simulation $n_i = 100$ for all j. Indeed, simulation 1 leads to the null hypothesis getting rejected in 3.2% of th simulations – close to the expected value of 4%.

In the simulations 2-4 the true treatment effect is a reduction of two units, $Y^I_{j,BC,T} - Y^N_{j,BC,T} = -2$. Fig.3 presents the distribution of treatment $\alpha_{j,\mathrm{BC},t}$'s for simulations 2–4. As expected, it shows, that as the number of firms per province increases, the $\alpha_{j,\mathrm{BC},T}$ estimate converges to the true value of -2.

Similarly, Fig.4 presents the distribution of the ranking of $\alpha_{iT,\mathrm{BC}}$'s for simulations 2–4 and demonstrates that as the number of firms per province increases, the probability that the $\alpha_{jT,\mathrm{BC}}$ will be found to be significant increases. Hence, we see that as the number of firms per province increases, the probability of committing type 2 error decreases.

5. Results

I. Heterogeneous Employment Effects Across Industries

Representative firm approach

Fig.5 presents the results of the industry-level analysis using our representative firm SCM approach. The figure displays $\alpha_{j,\mathrm{BC},2013}$, the treatment effect estimates for each industry j plotted along with a pseudo-confidence interval (CI). Fig.5 suggests that the carbon tax did have a significant effect on four industries.[18] The manufacturing (metal) industry saw the carbon tax result in a significant decrease of 15% in jobs per capita, equivalent to a loss of 5,700 jobs, while the information and cultural saw a significant decrease of 11% in jobs per capita, equivalent to a loss of 4,400 jobs. In contrast, Fig.5 shows that the carbon tax policy increased employment per capita

[18]The utility industry also shows a statistically significant employment effect, i.e., the point estimate is outside of the pseudo-CI. However, the significance level is much greater than 10% due to the insufficient number of placebos. Thus, we do not interpret the estimates to be statistically significant for the utility industry.

in the manufacturing (food + clothing) industry by 11.5%, equivalent to a gain of 2,300 jobs, and increased employment per capita in the transportation and warehousing (postal + warehousing) industry by 5.5%, equivalent to a gain of 1,100 jobs. The results in the rest of the industries are statistically insignificant at the 10% level.

Fig.6 shows the above results converted into employment change in units of persons employed. The point estimate with largest magnitude is a decrease in employment of 11,400 jobs in the health-care and social services industry. This is followed closely by the construction industry which saw a decrease in employment of 7,800 jobs. Offsetting these decreases are large increases in employment in the accommodations and food services sector and public administration. It should be noted that for all industries that see large changes in employment measured in jobs, except for manufacturing (metal), the corresponding estimate in percent change in employment per capita is insignificant. Hence, most of these large results in levels are also insignificant.

Despite the significance of the point estimates, this finding further provides a support of the "job-shifting hypothesis" in response to the revenue-neutral carbon tax. Similar to Yamazaki (2017), jobs mainly shift away from energy-intensive industries to clean service industries.

By taking the sum of the employment effect estimates presented in Fig.6, we can obtain an aggregate employment estimate. Further, by converting the pseudo-CI's presented in Fig.5 into employment in levels we can obtain a 90% pseudo-CI for this aggregate estimate.[19] The result is a decrease of aggregate employment of 0.86%, with an upper bound of an increase of 1.12% and a lower bound of a 2.42% decrease in employment. This -0.86% estimate is equivalent to a loss of 17,000 jobs, but is insignificant at the 10% significance level.

Fixed effects model with SCM-weights

In addition to our revised SCM method, we also estimate the industry-specific employment effects using the fixed effects model with SCM-weights. The results are presented in Fig.7. One of the advantages of this approach is that the precision of estimates improves relative to our revised

[19] We exclude the utilities sector in this calculation as it does not have a 90% pseudo-CI. Since the point estimate for the utilities industry is so small, this has a negligible effect on the aggregate estimate.

SCM approach. Despite the order of the employment effects across industries, this finding also suggests that jobs shift across industries. The employment effects range from -9% to 11%. Using employment share for each industry, the weighted average employment effect is -0.08%. This small employment effect is consistent with the results from the SCM approach.

To visually compare the employment effects between our revised SCM approach and fixed effect model, we plot one against another, presented in Fig.8. If the results perfectly match between our two approaches, the point estimates would be on the 45-degree dash line. There are several estimates that are closely on the 45-degree line. Although the match is not perfect, we do see a strong positive correlation between these approaches.

II. Small vs. Large Firms

Fig.9 and 10 present the employment effects on the smallest 33% and largest 33% of firms, respectively. A subtle, but clear difference is seen between the two figures, and is highlighted by the fact that the aggregate estimate generated by the bottom 33% of firms is above zero while the aggregate estimate generated by the top 33% is negative. This implies that the carbon tax appears to affect employment in the smallest 33% of firms more positively than employment in the largest 33% of firms.

In particular, employment in small businesses in the service industries such as healthcare and social assistance and retail trade (online, department stores, hobby) are significantly positively impacted by the policy. Small businesses in the healthcare and social assistance industry see a significant 24% increase in employment per capita while retail and trade (online, department stores, hobby) sees a significant 11% increase in employment per capita due to the carbon tax. Additionally, employment per capita among small firms in the manufacturing (food + clothing) industry increases significantly, by 27%.

On the other hand, employment per capita in the transportation and warehousing (air, rail, truck, pipeline) industry falls by 33% due to the policy. Fig.11 illustrates the difference between the estimates from the bottom 33% and top 33% of firms. Here we see that the negative result for the manufacturing (metal) industry in our estimations using all firms appears to be driven entirely by job losses in the sector's largest firms. Interestingly, we also see that while employment in small firms is significantly positively impacted by the policy, employment in large businesses in the healthcare and social assistance industry are significantly negatively impacted.

III. Sub-industries (3 Digit NAICS Industries)

Fig.12 and 13 present the percent change in employment per capita estimates for the manufacturing industries and selected other industries at the 3 digit level NAICS, respectively. This gives us insight into which sub-industries are driving the results seen in Fig.5.

In Fig.12, we see that while the point estimate for the primary metal manufacturing industry is not statistically significant, it is large and negative. This suggests that this sub-industry likely drives a large portion of the statistically significant and negative result seen in Fig.5 for the manufacturing (metal) industry. Further, we see that this overall result for the manufacturing (metal) sector is also largely contributed to by the transportation equipment manufacturing sub-industries, which sees a statistically significant -25% change in employment per capita, and the miscellaneous manufacturing sub-industries, which sees a significant -15% change in employment per capita. Together, the changes across these three sub-industries account for a total job loss of 10,800 jobs.

However, we also see that the overall result in the manufacturing (metal) industry is attenuated by statistically significant increases in the computer and electronic product manufacturing sub-industry and a large, but statistically insignificant, increase in employment per capita in the electrical equipment, appliance and component manufacturing sub-industry. We also see that the positive result in the manufacturing (food + clothing) industry is largely driven by positive changes in the leather and allied product manufacturing and clothing manufacturing sub-industries. Interestingly, employment per capita in chemical manufacturing increases by a significant 14%.

In Fig.13, we see which sub-industries are driving the results in the health-care and social assistance, accommodation and food services, and information and cultural services sectors. While no particular sub-industry seems to dominate the result of the health-care and social assistance sector, in the accommodation and food services industry we see that, while not statistically significant, the estimate for the food services and drinking places sub-industry, which accounts for a gain of 10,000 jobs, drives the positive point estimate for its parent industry in Fig.5. Fig.13 also illustrates that the large negative result seen in the information and cultural services sector is driven by a large negative employment effect seen in the broadcasting (except internet) sub-industry and the motion picture and sound recording industries.

IV. Correlation Between Employment Effect and GHG and Trade Intensity

Here we explore the question: are the changes in employment per capita related to the emissions and trade intensity of the industry. Fig.14 illustrates the relationship between the industry point estimates of the employment effect and the greenhouse gas (GHG) intensity of the industry.[20] As seen in the figure, there is a weak negative relationship between the two variables. The slope of the line is -1.04% per kilotonne CO_2e/\$1,000,000, with a standard error of 1.97% per kilotonne CO_2e/\$1,000,000, making the relationship insignificant.

However, it should be noted that because our analysis is conducted at the two-digit NAICS code industry level, many high-emitting industries such as the primary metal manufacturing industry are combined with low-emitting industries such as the computer and electronics manufacturing industry, leading to little variation in the GHG intensity amongst the industries and potentially masking a stronger relationship at the three-digit NAICS code level. Hence, we re-run this correlation on the estimates for the manufacturing industry at the three-digit NAICS code level and present this regression in Fig.15. In this figure we clearly see that that the negative relationship is stronger and, indeed, the regression results confirm this with a coefficient of -7.71% per kilotonne CO2e/\$1,000,000 with a standard error of 3.73% per kilotonne CO_2e/\$1,000,000. Hence, this correlation is statistically significant at the 5% level. Fig.16 shows that there is a weak negative

[20]GHG intensity is defined here as the GHGs emitted by an industry in a given year divided by the GDP produced by that industry in the same year. Emissions intensity is calculated using GHG data from CANSIM Table 153-0034 and GDP data from CANSIM Table 379-0029. Both of these datasets only include data for Canada, so an assumption implicit in this part of the analysis is that industries in BC have a similar GHG intensity as the Canadian average.

correlation between the employment effect estimates and the trade intensity of the industry.[21]

6. Discussion and Conclusion

Our analysis shows that the BC carbon tax led the energy-intensive manufacturing sectors, particularly these sectors' large companies, to contract while it boosted employment in smaller businesses in the service sectors and the manufacturing (food + clothing) sector (a non-energy-intensive manufacturing sector). These "job shifts" could be due to the recycling feature of the carbon tax, putting more money into the pockets of poorer households. This money might then subsequently be spent on smaller day-to-day purchases, such as massage services, chiropractic, and restaurants. Further, the reduction in the small business tax, funded by the carbon tax, also likely led to the positive employment effect we find in the small business sector.

Nevertheless, when the combined effect of this boost to employment in smaller firms and contraction in larger firms is considered, the results presented here suggest that the BC carbon tax had only a modest effect on employment in the provincial economy. For 20 out of 24 industries, placebo tests show that larger employment changes occurred in other provinces absent from the carbon tax, and so the null hypothesis of no employment effect cannot be rejected for most industries, nor on the aggregate. This may be an indication that most industries are able to switch to using lower carbon-emitting processes, the substitutability between labour and energy is high for many industries, and/or the reduction in corporate and income taxes increased the demand for and supply of labour to the point that it offset the negative employment effects of the BC carbon tax. Alternately, this result could suggest that there was an employment effect of the BC carbon tax but there were other economic factors following the implementation of the carbon tax which caused employment effects that were cumulatively larger than the employment effect from the carbon tax policy.[22]

[21] Trade intensity is defined as: (Import + Export)/(Total demand + Import) as in Yamazaki (2017).

[22] For example, consider the accommodations and food services industry. The $\alpha_{j,\mathrm{BC},2013}$ estimate measured in percent change in employment for this industry is large, at an increase of 11%. However, the span of placebo estimates is much larger, ranging from -8% to 18%. Hence, this suggests that at the same time as the carbon tax was implemented

We note that there were other economic events that occurred following the implementation of the carbon tax that may bias the estimator in certain industries. In the case of the Information and Cultural industry, in which our results show employment was worst hit, the estimate is likely biased by tax credits introduced in two other Canadian provinces, Ontario and Québec, which helped boost their film and, potentially, broadcasting industries. According to a BC film association report, these tax credits drew a significant amount of production away from BC and into Ontario and Québec, particularly in the years 2009 and 2010.[23] The report further states that action taken by the BC government in 2011 and 2012 helped stem the flow of production to Ontario and Québec but did not regain the productions that had initially left. Additionally, the construction industry is likely biased downwards by the high price of oil following 2008. This is because high oil prices led to an oil boom in the Alberta oil sands, which increased construction activity in Alberta.[24]

Since British Columbia's oil industry is much smaller than Alberta's, the effect of high oil prices on construction are likely much larger in Alberta than in BC. Therefore, since the SCM gave Alberta a positive weighting, high oil prices would disproportionately affect employment in Alberta's construction industry, biasing the synthetic control upwards and consequently biasing the employment effect estimate downwards.[25] In short, future research needs to investigate the employment effect in these particular sectors to obtain a clearer picture of the impact of the policy in these industries.

It should also be noted that while the BC carbon tax applies to the burning of all fossil fuels, a number of industries emit larger amounts of GHG not related to fossil combustion. For example,

in BC, employment in the management of companies and enterprises industry was also affected by other important factors.

[23] See Creative BC, 2011. https://www.creativebc.com/database/files/library/BCFM_ActivityReport_1011.pdf

[24] See Economic Commentary: Alberta's Oil and Gas Supply Chain Industry. Alberta Government. https://www.albertacanada.com/files/albertacanada/SP-Commentary_12-11-13.pdf

[25] Another major policy change which occurred around the same time as the implementation of the BC carbon tax was the creation (and destruction) of the Harmonized Sales Tax (HST) system in BC. In 2010, the BC government combined the Provincial and Goods and Services Tax into an HST, however, due to strong opposition, a referendum led to the repeal of the HST legislation on April 1st, 2013 . According to a 2012 manufacturing industry association report, the HST saved the manufacturing industry $140 million annually. Since the HST was in place for 4 months of the year in which we measure the effect of the carbon tax, it is possible that our manufacturing estimates were biased upwards, as the synthetic control was matched to BC during a period without the HST. However, the manufacturing industry report also estimated that the carbon tax had cost the industry over one billion dollars since being implemented, and so if there is a bias, it is likely small in comparison to the effect of the carbon tax.

Picard (2000) estimates that gas extraction leads to the creation of 3.1 tonnes of fugitive methane emissions per 106 m3 gas production. Using this estimate, and given that BC produces approximately 44 billion cubic metres of gas annually, we calculate that approximately 138,000 tonnes of methane are produced each year which are not captured by the BC carbon tax due to fugitive emissions being exempted from the tax.[26] Hence, the employment impact on the mining, quarrying, oil and gas extraction industry might have been notably different if the carbon tax did not exempt fugitive emissions. In addition, the air transportation industry does not have to pay the tax on any emissions outside of BC. For example, while an airplane from Vancouver, BC to Prince George, BC would pay the full tax, a plane from Vancouver to Calgary would only pay for the portion of emissions released in BC airspace. Thus, if the carbon tax policy were to be expanded to include these emissions, the impact on employment in the airline industry may be substantially different than found here.[27]

Our results differ from past studies (Yamazaki, 2017; Yip, 2018) which find a much larger and statistically significant distributional employment effect across industries and/or a significant total employment effect. This difference in results likely stems from a difference in methodology. Here, we use a revised approach to the synthetic control method to ensure that the parallel trends assumption at the industry-level is satisfied, whereas in these previous studies the parallel trend assumption was tested only at the aggregate level or tested on only a small number of years prior to the treatment. Our analysis shows that the parallel trends assumption for a traditional DID at the industry level does not hold, despite it holding at the provincial level. Hence, we argue that it is essential to use the SCM.

Our study re-examines the question of whether the BC carbon tax has had an effect on employment at the provincial and industry level. We investigate this question using confidential firm-level data. To overcome challenges unique to applying SCM to firm-level data, we use a revised method

[26] See Government of British Columbia. https://www2.gov.bc.ca/gov/content/industry/natural-gas-oil/statistics

[27] Yet another example of how exemptions may play a notable role in our results stems from the fact that the BC carbon tax does not cover emissions created from chemical processes. Hence, the non-metallic mineral manufacturing industry, which contains the large amounts of CO_2 emissions created as a by-product of the cement-making process, is not taxed on a large proportion of its emissions, and so, if the carbon tax were expanded to cover all GHGs, the employment effect estimate may be even more negative.

within the SCM framework and test it in a Monte Carlo simulation. We then applied the SCM to the confidential firm-level data. Our results show that the BC carbon tax overall did not have a significant effect on employment at the provincial level, and while it had an insignificant effect for most industries, it did significantly affect large metal manufacturing firms negatively, and in general boosted employment in small firms in the health, retail, and food and clothing manufacturing business sectors. By recycling the tax revenues from the carbon tax, jobs are likely to "shift" from energy-intensive industries to clean service industries.

References

Abadie, Alberto, Alexie Diamond, and Jens Hainmueller. 2010. "Synthetic control methods for comparative case studies: Estimating the effect of California's tobacco control program." *Journal of the American Statistical Association*, 105(490): 493–505.

Antweiler, Werner, and Sumeet Gulati. 2016. "Frugal cars or frugal drivers ? How carbon and fuel taxes influence the choice and use of cars." *Working Paper*.

Bohn, Sarah, Magnus Lofstrom, and Steven Raphael. 2014. "Did the 2007 Legal Arizona Workers Act Reduce the State's Unauthorized Immigrant Population?" *Review of Economics and Statistics*, 96(2): 258–269.

Environment Canada. 2015. "National Inventory Report: Greenhouse Gas Sources and Sinks in Canada."

Gibbs, M.J., P. Soyka, and D. Coneely. 2000. "CO$_2$ Emissions from Cement Production." In *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. , ed. Intergovernmental Panel on Climate Change.

Hafstead, Marc A.C., and Roberton C. Williams. 2018. "Unemployment and environmental regulation in general equilibrium." *Journal of Public Economics*, 160(November 2017): 50–65.

Harrison, Kathryn. 2013. "The Political Economy of British Columbia's Carbon Tax." *OECD Environment Working Papers*, 63.

Jones, Benjamin A., and Andrew Goodkind. 2018. "Urban Afforestation and Infant Health: Evidence from Million TreesNYC." *Working Paper*.

Martin, Ralf, Laure B de Preux, and Ulrich J Wagner. 2014. "The impact of a carbon tax on manufacturing: Evidence from microdata." *Journal of Public Economics*, 117: 1–14.

Martin, Ralf, Mirabelle Muûls, Laure B. de Preux, and Ulrich J. Wagner. 2014. "Industry Compensation under Relocation Risk : A Firm-Level Analysis of the EU Emissions Trading Scheme." *American Economic Review*, 104(8): 2482–2508.

Metcalf, Gilbert E. 2009. "Designing a carbon tax to reduce U.S. greenhouse gas emissions." *Review of Environmental Economics and Policy*, 3(1): 63–83.

Metcalf, Gilbert E. 2015. "A cpmceptual framework for measuring the effectiveness of green fiscal reforms."

Ministry of Finance. 2010. "Budget and Fiscal Plan 2010/11-2012/13." British Columbia.

Ministry of Finance. 2012. "Budget and Fiscal Plan 2012/13-2014/15." British Columbia.

Ministry of Finance. 2013. "Budget and Fiscal Plan 2013/14-2015/16." British Columbia.

Ministry of Finance. 2014. "Budget and Fiscal Plan 2014/15-2016/17." British Columbia.

Ministry of Finance. 2015. "Budget and Fiscal Plan 2015/16-2017/18." British Columbia.

Ministry of Finance. 2017. "Budget 2017 Update 2017/18 - 2019/20." British Columbia.

Murray, Brian, and Nicholas Rivers. 2015. "British Columbia's revenue-neutral carbon tax: A review of the latest "grand experiment" in environmental policy." *Energy Policy*, 86: 674–683.

National Energy Board. 2014. "Market Snapshot: The Canadian Propane Market's Recovery from the Polar Vortex."

Natural Resources Canada. 2015. *Energy Markets Fact Book.*

Nordhaus, By William D. 2016. "Optimal Greenhouse-Gas Reductions and Tax Policy in the "DICE" Model." *American Economic Review*, 83(2): 313–317.

Petrick, Sebastian, and Ulrich J Wagner. 2014. "The Impact of Carbon Trading on Industry : Evidence from German Manufacturing Firms." *Working Paper*.

Porter, Michael E. 1991. "America's Green Strategy." *Scientific America*, 264(4): 168.

Porter, Michael E., and Claas van der Linde. 1995. "Toward a new conception of the environment-competitiveness relationship." *Journal of Economic Perspectives*, 9(4): 97–118.

Rivers, Nicholas, and Brandon Schaufele. 2014. "The Effect of Carbon Taxes on Agricultural Trade." *Canadian Journal of Agricultural Economics*, 00: 1–23.

World Bank Group. 2018. "State and Trends of Carbon Pricing 2019."

Yamazaki, A. 2017. "Jobs and climate policy: Evidence from British Columbia's revenue-neutral carbon tax." *Journal of Environmental Economics and Management*, 83.

Yip, Chi Man. 2018. "On the labor market consequences of environmental taxes." *Journal of Environmental Economics and Management*, 89: 136–152.

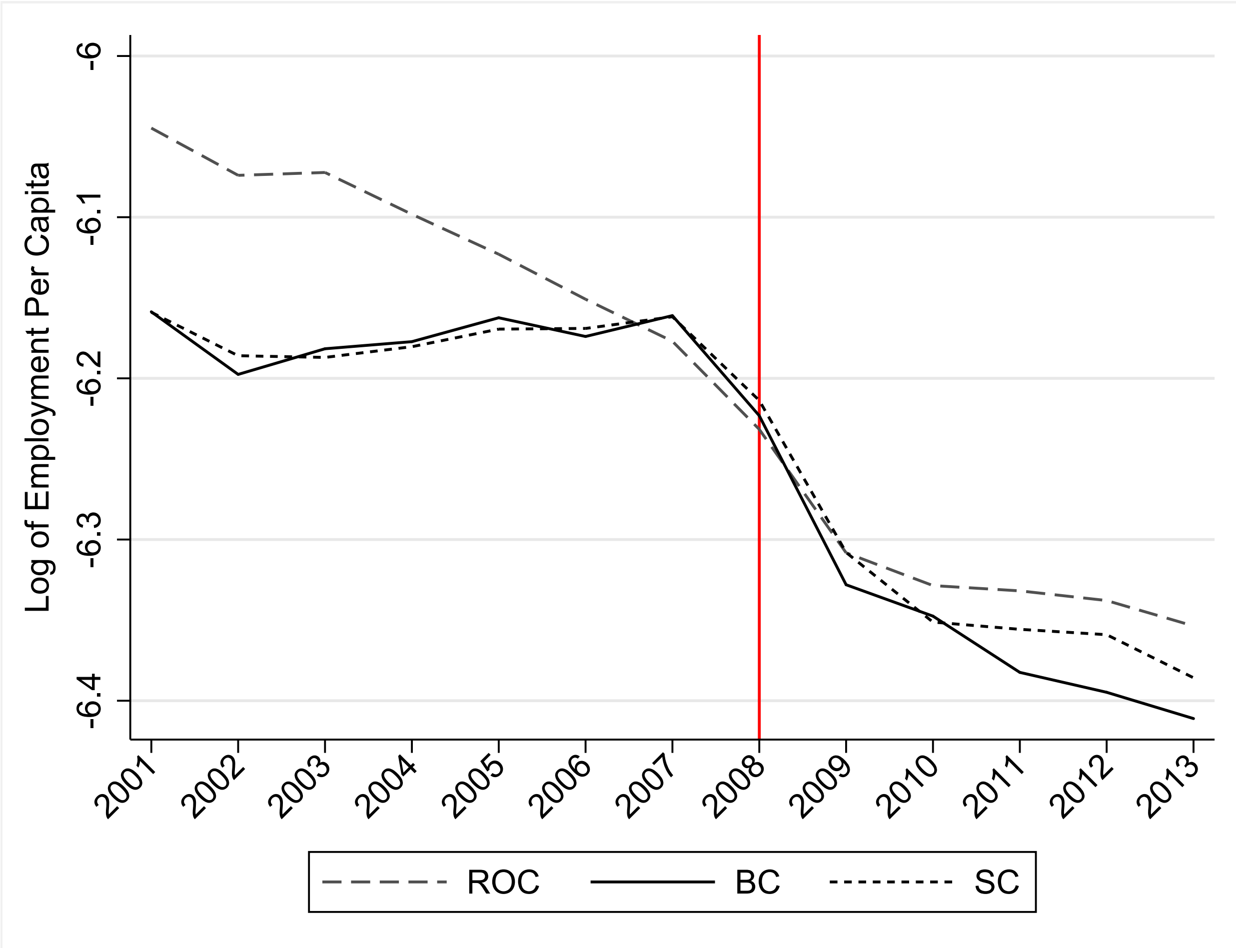

Figure 1: Employment per capita trends for BC, ROC, and SC

Note: This figure presents the evolution of one representative firm in the manufacturing (wood + plastic) industry log employment per capita in BC compared to the log employment per capita of the same quintile in this industry in the Rest of Canada and to the SC. Notice that the pre-treatment trends, the trends prior to the vertical dashed line, are considerably different between BC and ROC. Hence, the parallel trend assumption is violated if Rest of Canada is used as the control for this industry. However, when the SC is used as the control, it seems to be well satisfied. The p-value which corresponds to the test between BC and ROC for this figure is 0.000024 and between BC and the SC it is 0.94.
Source: Author's calculation.

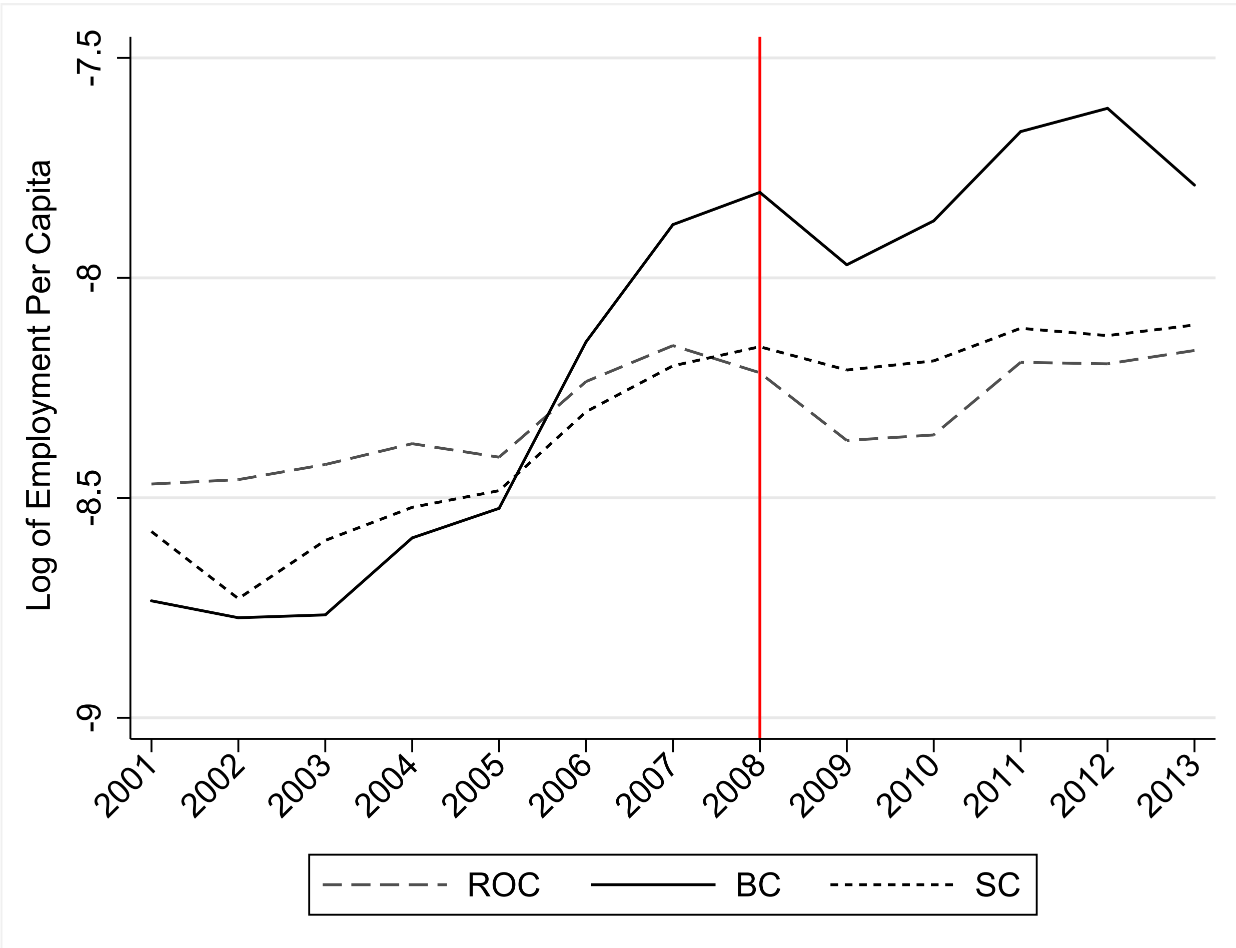

Figure 2: Employment per capita trends for BC, ROC, and SC

Note: This figure presents the evolution of one representative firm in the mining, quarrying, and oil and gas extraction industry log employment per capita in BC compared to the log employment per capita of the same quintile in this industry in the Rest of Canada and to the SC. Notice that the pre-treatment trends, the trends prior to the vertical dashed line, are considerably different between BC and ROC and BC and the SC. Hence, the parallel trend assumption is violated if Rest of Canada is used as the control for this industry and is only slightly better, but likely still violated when the SC is used as the control. The p-value which corresponds to the test between BC and ROC for this figure is 0.014 and for BC and the SC it is 0.83.
Source: Author's calculation.

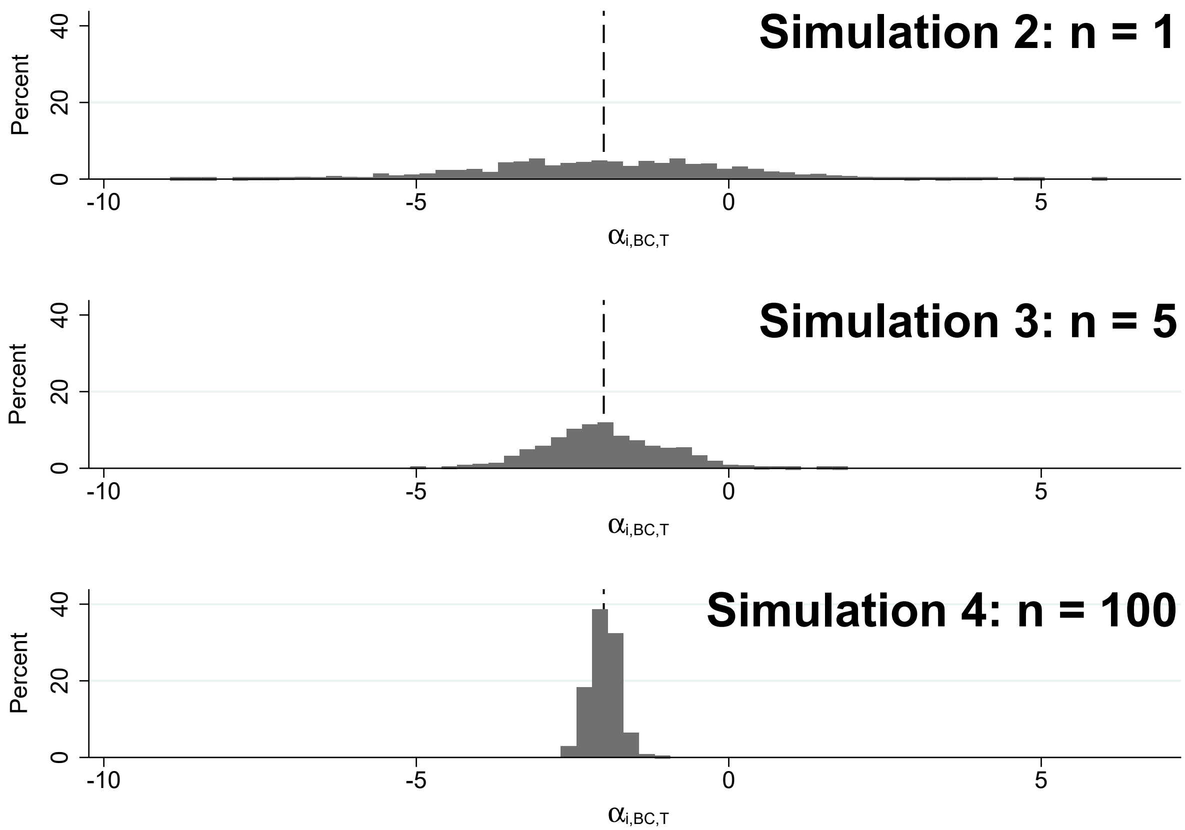

Figure 3: Results of Monte Carlo Simulations

Note: This figure demonstrates the convergence of the estimator to the true treatment effect as the number of firms used to calculate the representative firm increases. The top panel presents a histogram of the results of simulation 2, in which there is one firm per province; the middle panel shows a histogram of the results of simulation 3, where there is 5 firms per province; and the bottom panel gives a histogram of the results of simulation 4, in which there are 100 firms per province. The true treatment parameter is -2 and from this figure it is clear that, as the number of firms included in the representative firm increases, $\alpha_{jT,\mathrm{BC}}$ converges to the true value.
Source: Author's calculation.

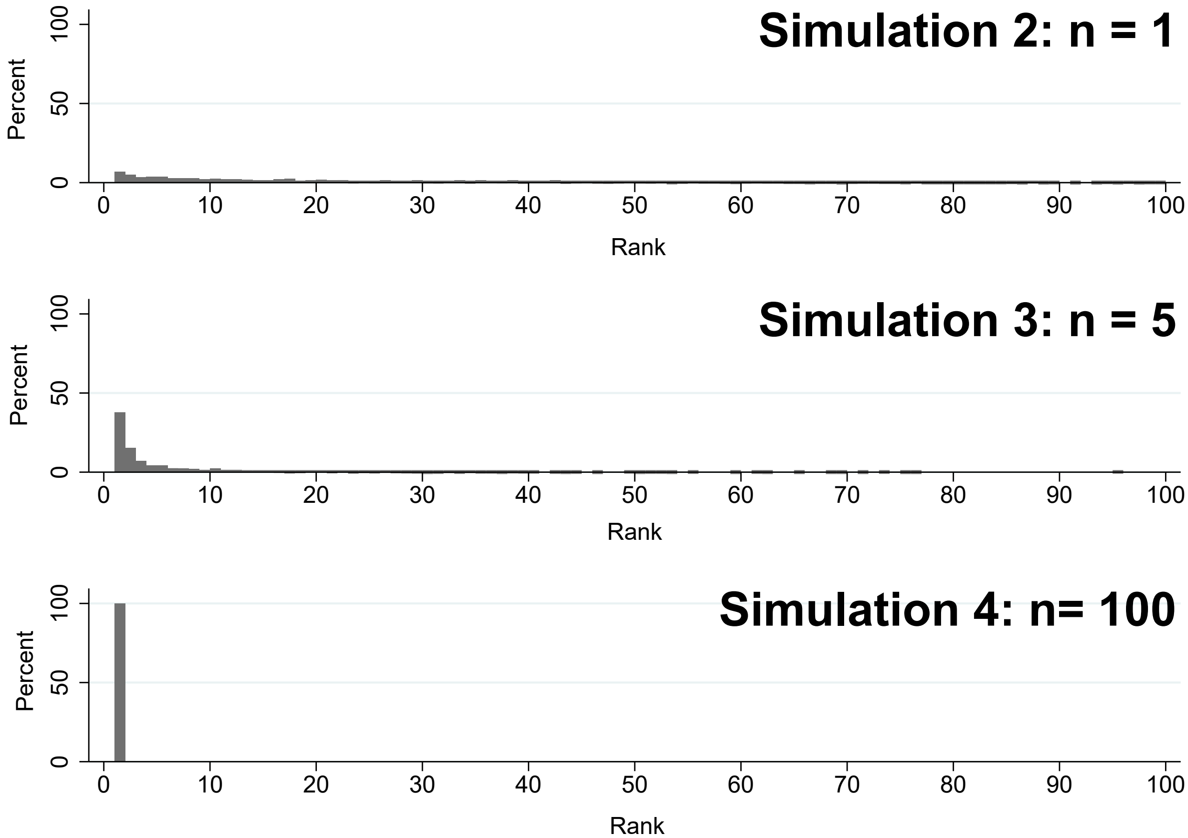

Figure 4: Results of Monte Carlo Simulations

Note: This figure shows that as the number of firms used to calculate the representative firm increases, the probability of committing type 2 error decreases. The top panel presents a histogram of the results of simulation 2, in which there is one firm per province; the middle panel shows a histogram of the results of simulation 3, where there is 5 firms per province; and the bottom panel gives a histogram of the results of simulation 4, in which there are 100 firms per province. Since the true treatment parameter in these simulations is -2, $\alpha_{jT,\mathrm{BC}}$ should be ranked 1st. Notice how, as the number of firms per province increases, the probability that, $\alpha_{jT,\mathrm{BC}}$ will be correctly ranked first increases. In other words, as the number of firms per province increases, the probability of committing type 2 error decreases.
Source: Author's calculation.

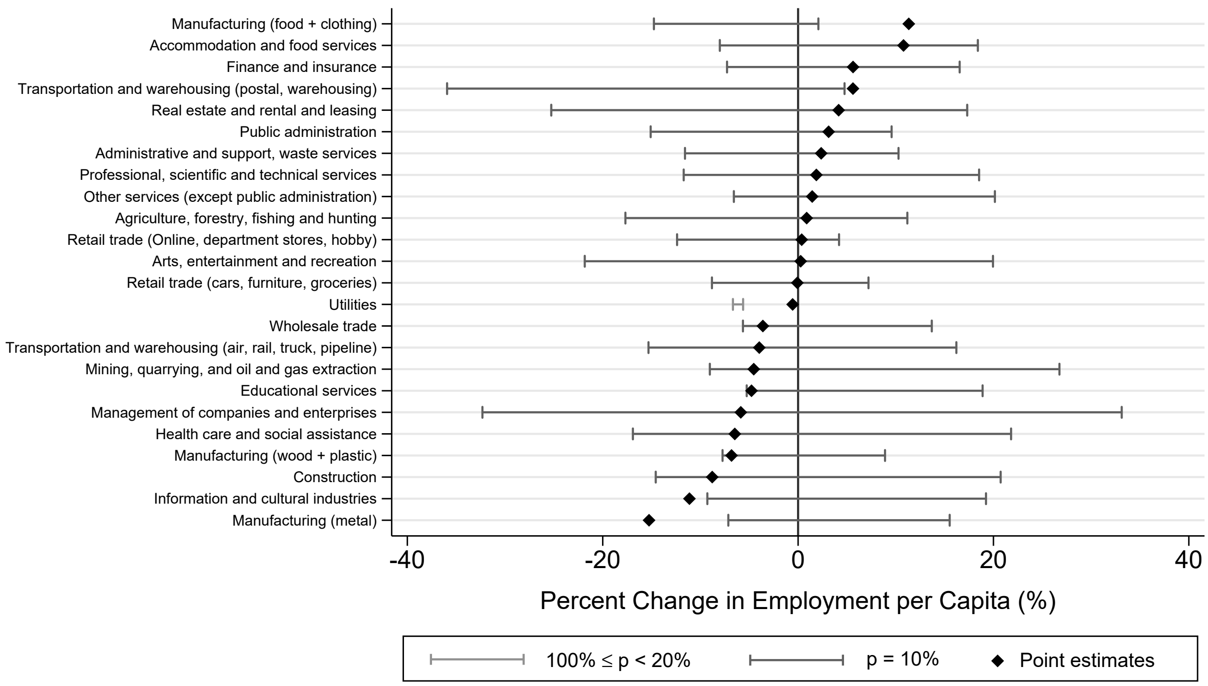

Figure 5: Percentage change in employment per capita, all firms

Note: This figure shows the estimated percent change in employment per capita for all industries. These results were produced using the synthetic control method (SCM) applied to confidential firm-level data. In order to apply the SCM to this firm-level dataset, firms are aggregated into "representative firms" which are then used as donor controls in the SCM. The results in this figure were produced using all firms in our cleaned dataset. The blue range presented for each industry is the pseudo confidence interval (pseudo-CI). If the estimate lies outside this pseudo-CI then the estimate is significant at the corresponding significance level, if the estimate lies within the pseudo-CI then the estimate is insignificant at the corresponding significance level.
Source: Author's calculation.

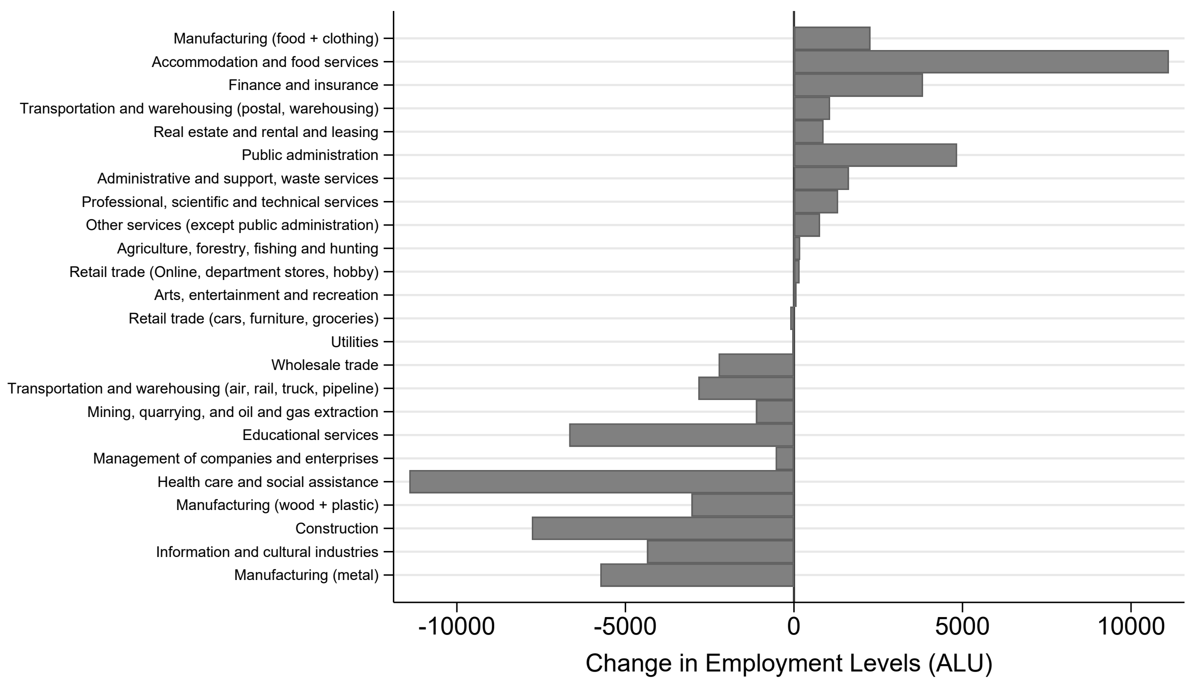

Figure 6: Change in level of employment, all firms

Note: Change in employment for all industries. These results were produced using the synthetic control method (SCM) applied to confidential firm-level data. In order to apply the SCM to this firm-level dataset, firms are aggregated into "representative firms" which are then used as donor controls in the SCM. The results in this figure were produced using all firms in our cleaned dataset.
Source: Author's calculation.

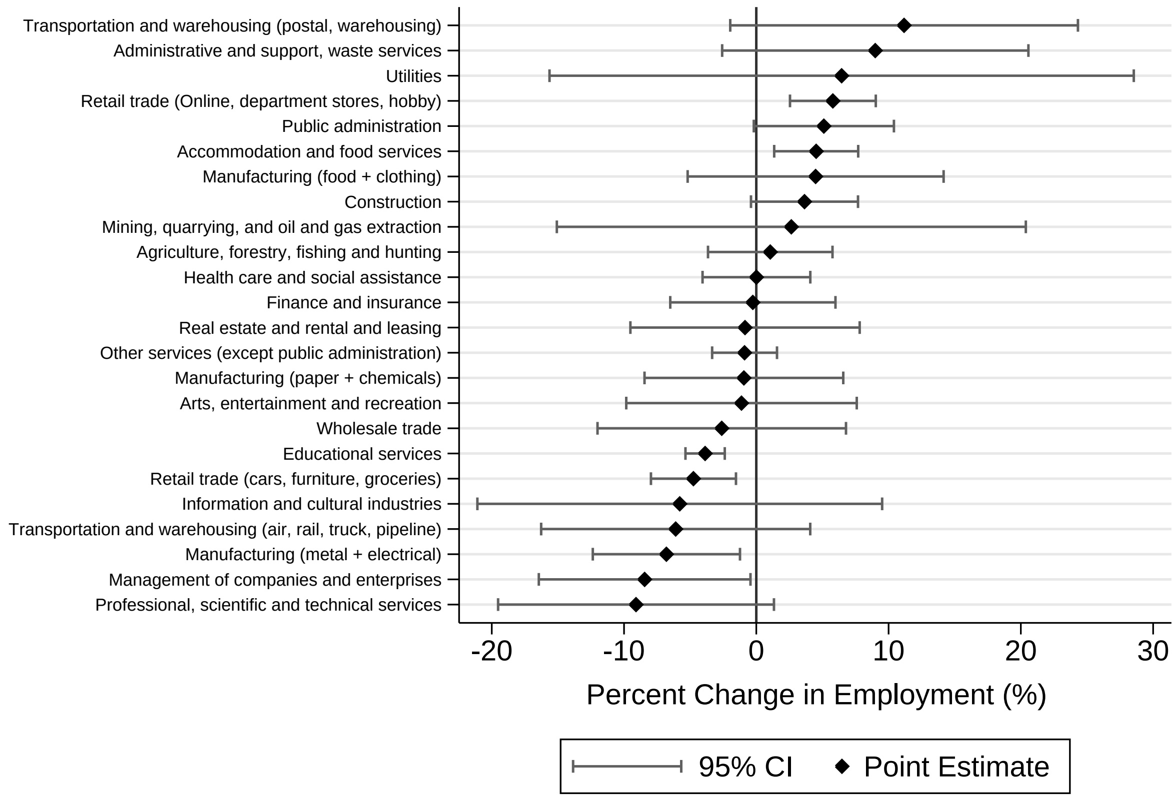

Figure 7: Percentage change in employment

Note: This figure plots the employment effects and the corresponding 95% confidence interval for all 2-digit NAICS industries. These employments are estimated using the SCM-weighted fixed effects methodology.
Source: Author's calculation.

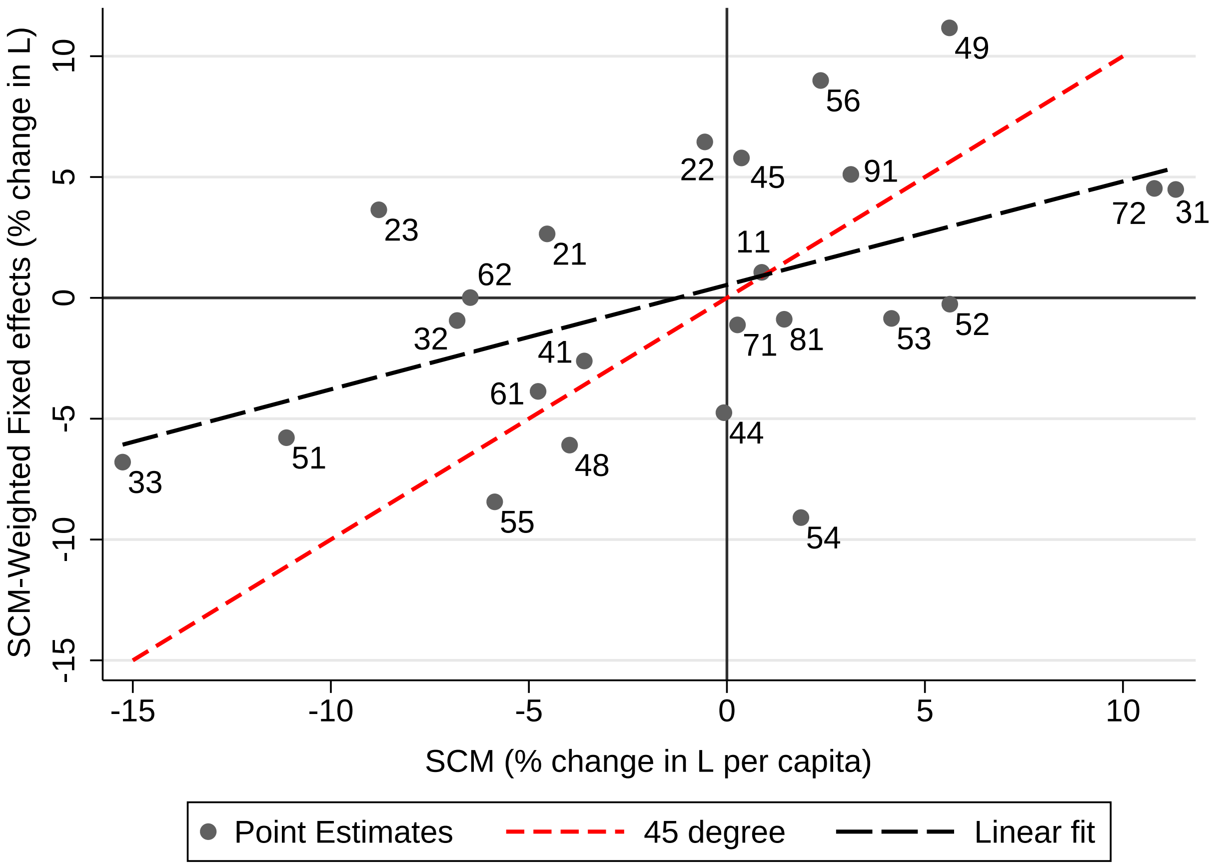

Figure 8: Comparison of estimates between the revised SCM and SCM-weighted fixed effect model

Note: This figure plots point estimates from the revised SCM approach and SCM-weighted fixed effect model. The red dash line is a 45 degree line, i.e., if point estimates are on this line, estimates perfectly matches. Black dash line is a linear-fitted line.
Source: Author's calculation.

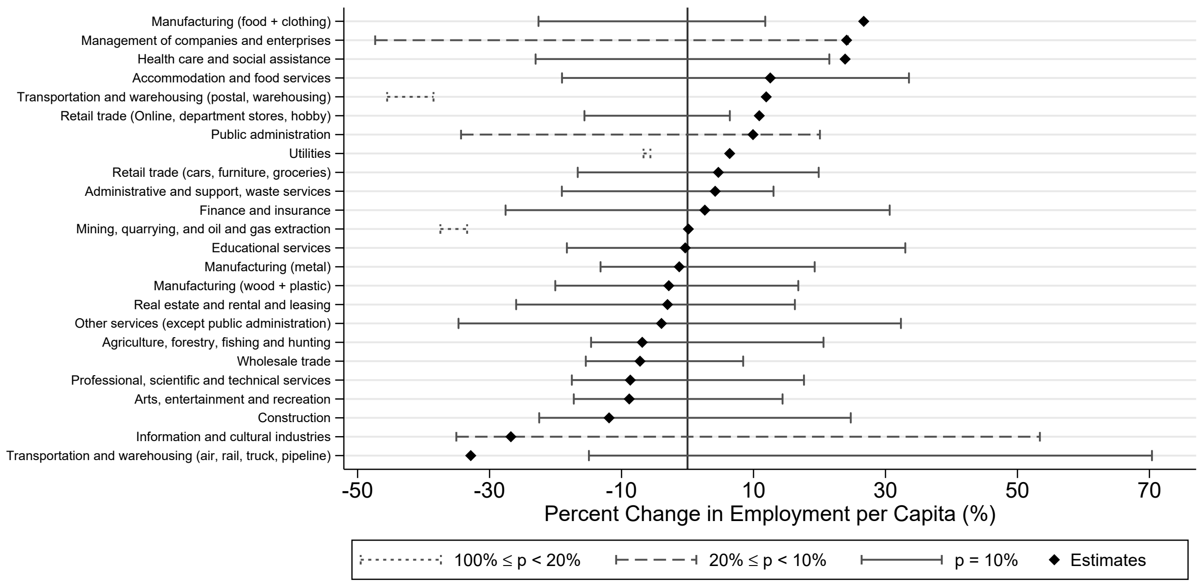

Figure 9: % change in employment per capita, bottom 33% of firms

Note: This figure shows the estimated percent change in employment per capita for all industries. These results were produced using the synthetic control method (SCM) applied to confidential firm-level data. In order to apply the SCM to this firm-level dataset, firms are aggregated into "representative firms" which are then used as donor controls in the SCM. The results in this figure were produced using the smallest 33% of firms in our cleaned dataset. The blue range presented for each industry is the pseudo confidence interval (pseudo-CI). If the estimate lies outside this pseudo-CI then the estimate is significant at the corresponding significance level, if the estimate lies within the pseudo-CI then the estimate is insignificant at the corresponding significance level.
Source: Author's calculation.

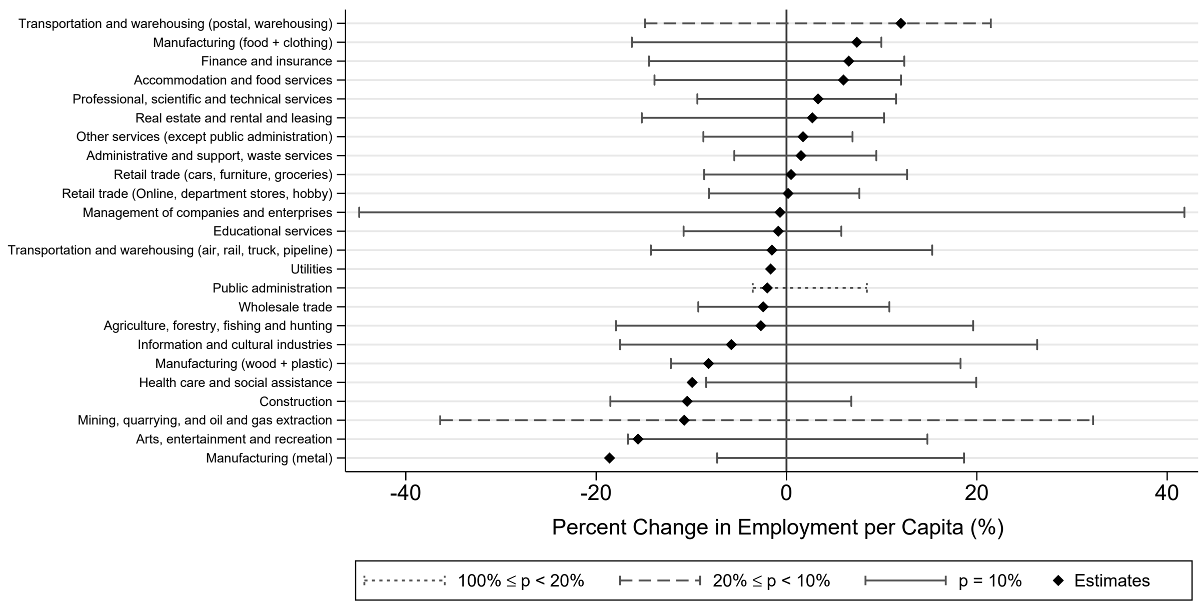

Figure 10: % change in employment per capita, top 33% of firms

Note: This figure shows the estimated percent change in employment per capita for all industries. These results were produced using the synthetic control method (SCM) applied to confidential firm-level data. In order to apply the SCM to this firm-level dataset, firms are aggregated into "representative firms" which are then used as donor controls in the SCM. The results in this figure were produced using the largest 33% of firms in our cleaned dataset. The blue range presented for each industry is the pseudo confidence interval (pseudo-CI). If the estimate lies outside this pseudo-CI then the estimate is significant at the corresponding significance level, if the estimate lies within the pseudo-CI then the estimate is insignificant at the corresponding significance level.
Source: Author's calculation.

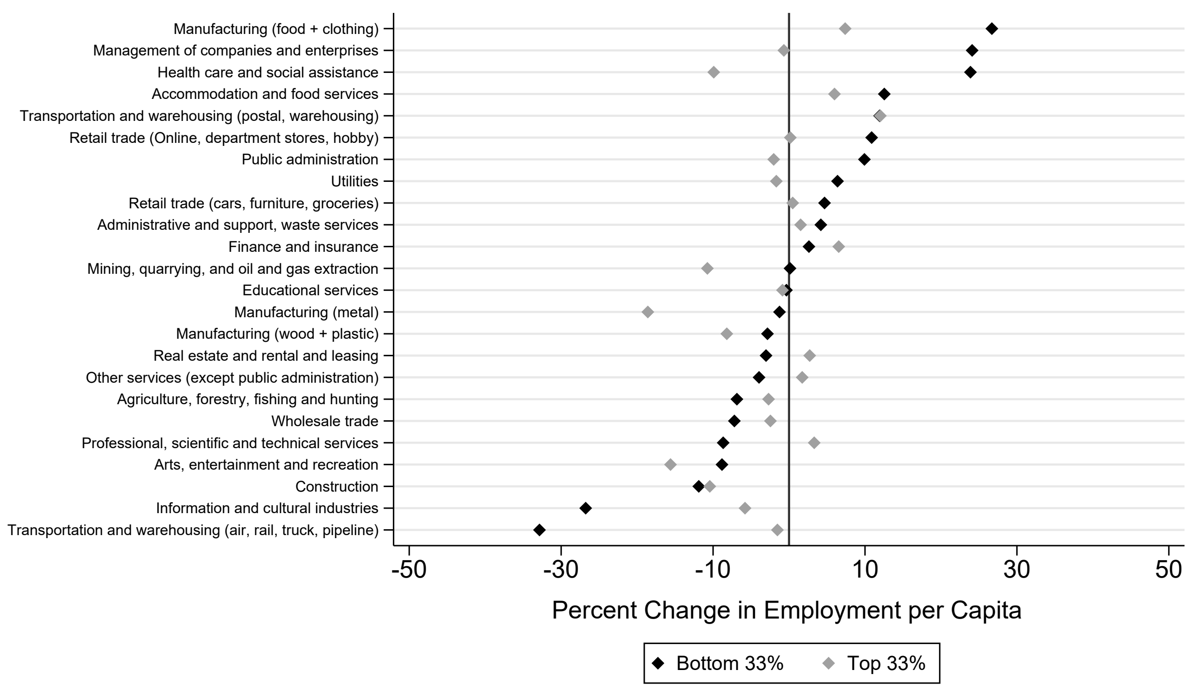

Figure 11: Top and bottom 33% comparison

Note: This figure presents the point estimates from figures 9 and 10 in one graph. This is done to illustrate the differential impact the carbon tax had on the largest 33% of firms compared to its effect on employment in the smallest 33% of firms.
Source: Author's calculation.

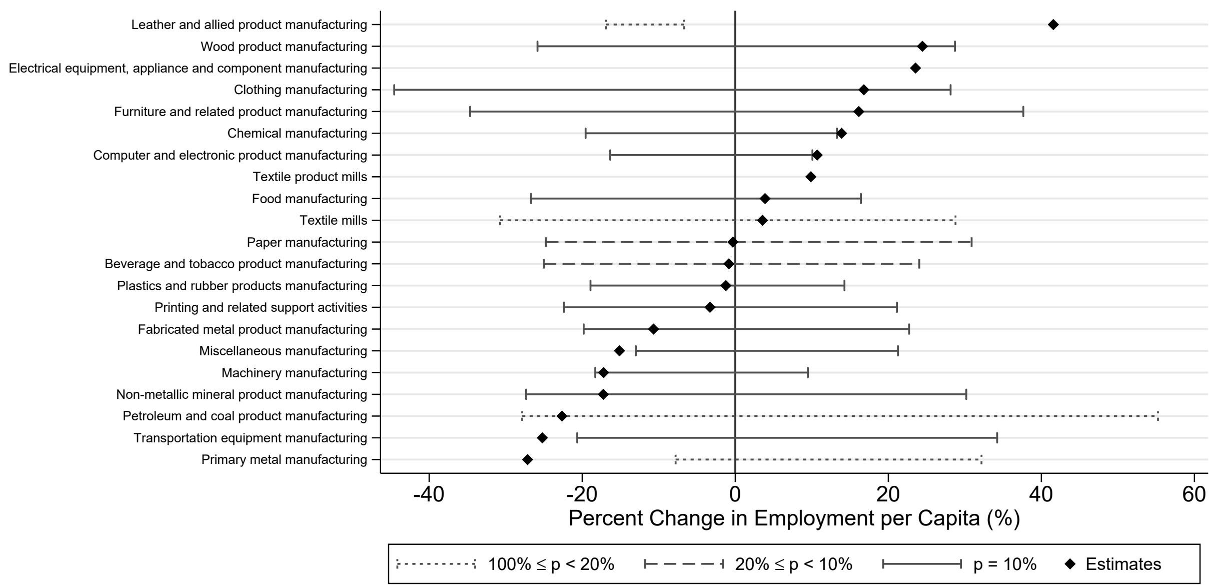

Figure 12: % change in employment per capita for the Manufacturing sub-industries (3-digit NAICS)

Note: This figure shows the estimated percent change in employment per capita for manufacturing 3-digit subsectors. These results were produced using the synthetic control method (SCM) applied to confidential firm-level data. In order to apply the SCM to this firm-level dataset, firms are aggregated into "representative firms" which are then used as donor controls in the SCM. The blue range presented for each industry is the pseudo confidence interval (pseudo-CI). If the estimate lies outside this pseudo-CI then the estimate is significant at the corresponding significance level, if the estimate lies within the pseudo-CI then the estimate is insignificant at the corresponding significance level.
Source: Author's calculation.

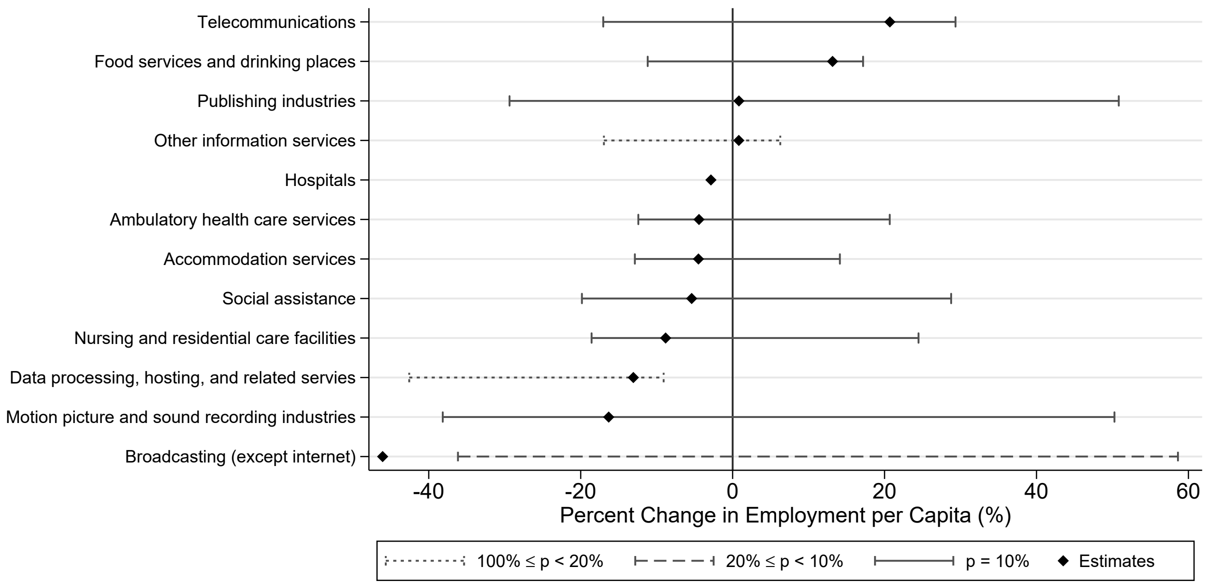

Figure 13: % change in employment per capita for selected other sub-industries (3-digit NAICS)

Note: This figure shows the estimated percent change in employment per capita for 3-digit subsectors of the accommodation and food services sector, the healthcare and social assistance sector, and the information and cultural services sector. These results were produced using the synthetic control method (SCM) applied to confidential firm-level data. In order to apply the SCM to this firm-level dataset, firms are aggregated into "representative firms" which are then used as donor controls in the SCM. The blue range presented for each industry is the pseudo confidence interval (pseudo-CI). If the estimate lies outside this pseudo-CI then the estimate is significant at the corresponding significance level, if the estimate lies within the pseudo-CI then the estimate is insignificant at the corresponding significance level.
Source: Author's calculation.

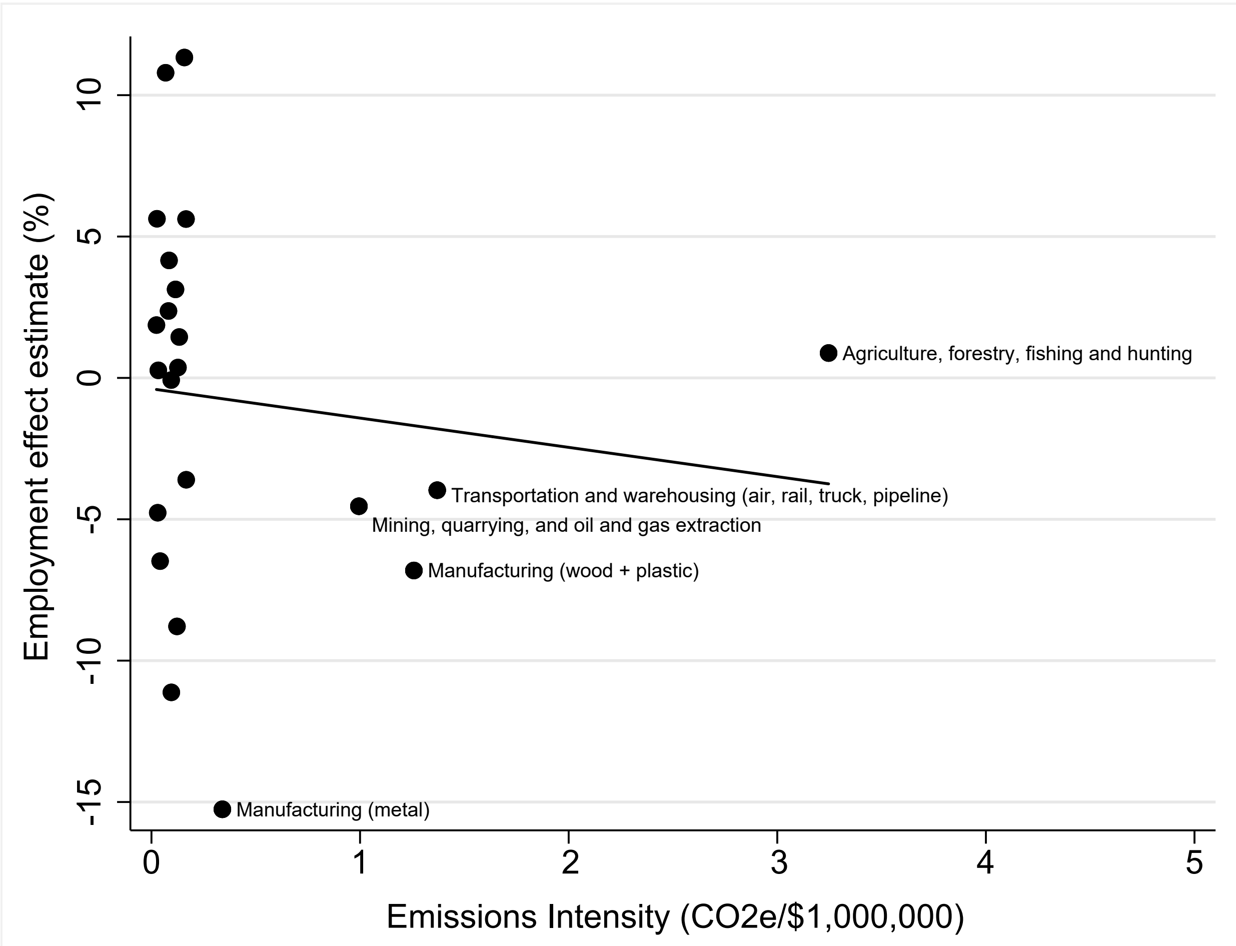

Figure 14: Correlation of employment effects with emission intensity at 2-digit NAICS industries

Note: This plot illustrates how the industry point estimates are correlated with emissions intensity. Due to the high level of aggregation used in this study, many high emitting subindustries (e.g., the primary metal manufacturing industry) are combined with low-emitting subindustries (e.g., computer manufacturing), resulting in small variation in emission intensity amongst the 24 industries. The utilities industry is not included in this graph as the GHG data used here are Canada-wide data, and since BC's electricity is primarily generated from hydroelectricity, while most other provinces rely much more heavily on fossil fuels, the emissions intensity data for the utilities industry was misleading. The fitted line has a slope of -1.04% per kilotonne CO_2e/\$1,000,000, with a standard error of 1.97% per kilotonne CO_2e/\$1,000,000. Hence, the relationship is negative but insignificant.
Source: Author's calculation.

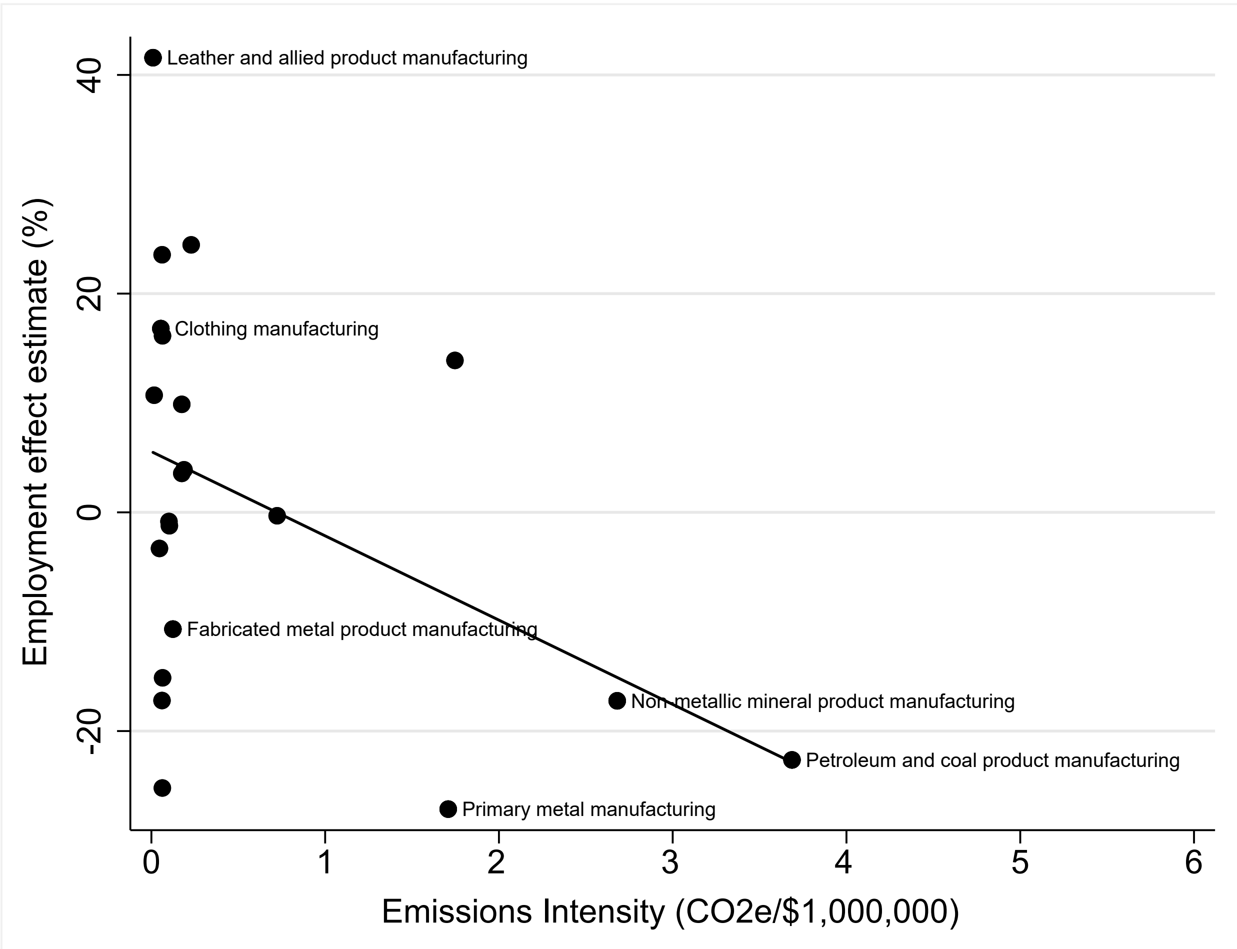

Figure 15: Correlation of employment effects with emission intensity at 3-digit NAICS industries

Note: This plot illustrates how the industry point estimates, generated from the 3-digit NAICS industry level analysis presented in Fig.12 and 13, are correlated with emissions intensity. The fitted line has a slope of -7.71% per kilotonne CO_2e/$1,000,000 with a standard error of 3.73% per kilotonne CO_2e/$1,000,000. Hence, the relationship is negative and significant at the 5% level.
Source: Author's calculation.

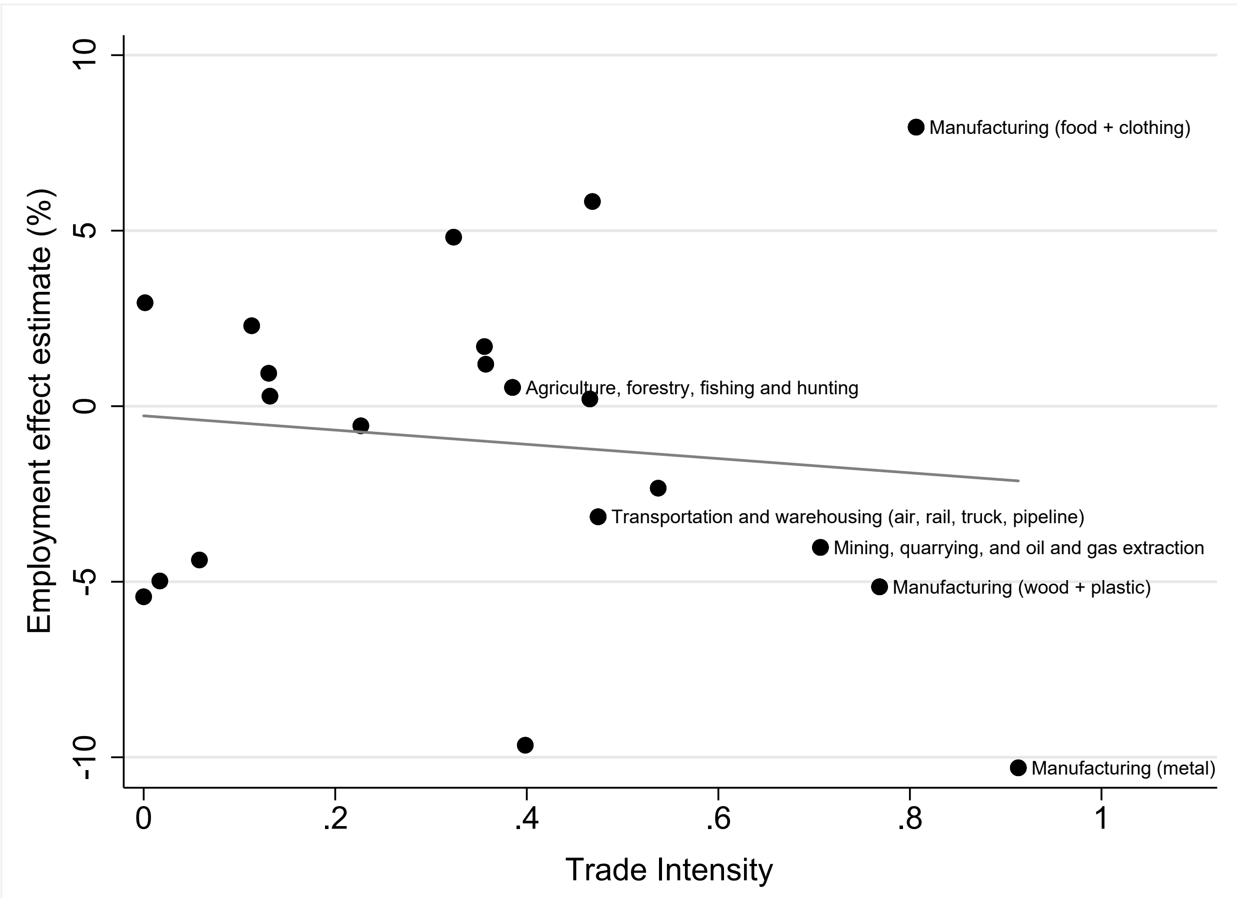

Figure 16: Correlation of employment effects with trade intensity at 2-digit NAICS industries

Note: This plot illustrates how the industry point estimates, generated from the 2-digit NAICS industry level analysis presented in Fig.5, are correlated with trade intensity. The fitted line has a slope of -2.03% change in employment per unit change in trade intensity with a standard error of 3.93% change in employment per unit change in trade intensity. Hence, the relationship is negative and insignificant at the 5% level.
Source: Author's calculation.

Table 1: Tax rate for selected fuel type

Fuel type	**Tax rate (2013)**	**Tax % of final fuel price (2013)**
Gasoline (cents/liter)	6.67	5.10
Diesel (cents/liter)	7.67	5.74
Natural Gas (cents/m$\hat{3}$)	5.7	50.68
Propane (cents/liter)	4.62	18.67

Notes: Tax rate per unit volume for selected fuel types and the tax % of the final fuel price for 2013. This table is adapted from Table 2 in Murray and Rivers (2015). Gasoline and diesel data were obtained from CANSIM Table 326-0009, natural gas data were obtained from Natural Resources Canada (2015), and propane data were obtained from National Energy Board (2014).

Table 2: Summary Statistics

NAICS	British Columbia				Rest of Canada			
			Total L				Total L	
	Mean	SD	Pre	Post	Mean	SD	Pre	Post
11	5.22	15.62	30,595	29,239	3.27	18.33	115,543	122,826
21	18.66	-	25,402	40,775	27.69	245.33	125,877	179,614
22	68.75	-	1,294	1,635	179.87	1370.34	19,977	27,425
23	5.53	23.10	91,489	113,620	6.68	53.32	516,218	723,231
31	20.79	70.16	23,263	26,392	33.86	198.65	211,212	197,074
32	25.23	141.99	52,550	54,927	31.84	148.84	344,754	345,000
33	12.76	48.74	43,089	48,545	25.05	230.97	602,897	631,101
41	10.09	37.07	69,471	81,752	12.84	93.05	535,652	614,343
44	17.75	218.56	143,503	175,640	17.88	278.31	885,210	1,081,246
45	13.44	183.97	41,963	49,217	17.82	324.29	296,783	348,931
48	11.79	159.54	57,447	72,668	9.59	155.51	325,924	406,895
49	31.32	-	16,174	19,653	34.54	569.36	93,882	103,672
51	14.86	151.21	33,280	40,070	27.10	315.33	198,645	244,495
52	13.89	156.55	56,091	69,475	21.42	403.24	439,983	538,234
53	3.52	16.36	28,382	34,458	4.90	34.44	165,734	197,179
54	4.53	30.23	71,405	92,548	5.46	61.17	486,856	614,043
55	5.21	25.79	9,981	10,627	7.08	40.82	56,480	65,838
56	10.79	122.26	66,259	83,235	13.83	110.16	485,919	565,055
61	54.04	478.11	99,976	121,372	96.86	755.32	639,043	812,763
62	13.13	268.28	149,775	191,785	17.95	241.79	971,494	1,254,037
71	11.70	90.13	27,779	33,841	12.58	121.26	144,774	181,798
72	17.03	86.51	127,069	168,206	15.65	87.23	622,783	816,831
81	4.97	22.76	56,656	69,398	4.95	29.92	362,257	442,777
91	328.98	-	92,778	118,109	304.74	4872.45	779,074	982,460

Notes: SD stands for standard deviation. Pre means 2001-2007 while Post means 2008-2013. L means average labour unit (ALU).

Table 3: Median p-value from parallel trend test for each industry

NAICS	ROC	BC
Agriculture, forestry, fishing and hunting	0.25	0.98
Mining, quarrying, and oil and gas extraction	0.03**	0.87
Utilities	0.51	0.71
Construction	0.00***	0.91
Manufacturing (food + clothing)	0.01***	0.95
Manufacturing (wood + plastic)	0.03**	0.98
Manufacturing (metal)	0.04**	0.98
Wholesale trade	0.00***	0.94
Retail trade (cars, furniture, groceries)	0.06*	0.97
Retail trade (Online, department stores, hobby)	0.10	0.97
Transportation and warehousing (air, rail, truck, pipeline)	0.05*	0.98
Transportation and warehousing (postal, warehousing)	0.70	0.99
Information and cultural industries	0.23	0.97
Finance and insurance	0.71	0.96
Real estate and rental and leasing	0.36	0.99
Professional, scientific and technical services	0.18	0.95
Management of companies and enterprises	0.49	0.93
Administrative and support, waste services	0.10*	0.96
Educational services	0.01***	0.96
Health care and social assistance	0.01**	0.92
Arts, entertainment and recreation	0.02**	0.98
Accommodation and food services	0.26	0.96
Other services (except public administration)	0.28	0.96
Public administration	0.29	0.99

Notes: This table presents the main result of our parallel trend test. The median p-value for each industry presented in this table is calculated from the p-values generated for the parallel trend test for each representative firm within each industry, which are presented in Table 5 in the Appendix. ROC stands for rest of Canada and SC stands for synthetic-BC.
*** Significant at the 1 percent level, ** Significant at the 5 percent level, * Significant at the 10 percent level.

Table 4: Employment growth rate (%)

Province	2001-2007	2007-2013
Newfoundland and Labrador	7	12
Prince Edward Island	7	8
Nova Scotia	8	1
New Brunswick	8	-1
Québec	12	6
Ontario	11	4
Manitoba	8	6
Saskatchewan	10	12
Alberta	22	12
British Columbia	15	3

Notes: This table presents employment growth rate (%) in the period before and after the implementation of the carbon tax in BC.
Source: CANSIM Table 282-0008

Table 5: Parameters of the four Monte Carlo simulations

Simulation	Mean of Control $E(yc)$	Mean($y_{\text{BC, Post}}$)	SD(y)	# of Firms per province
1	20	20	2	1
2	20	18	2	1
3	20	18	2	5
4	20	18	2	100

Note: Four Monte Carlo simulations were run to demonstrate the characteristics of the synthetic control estimator in our analysis of the homogeneous treatment effect using firm-level data. Specifically, the first simulation is designed to test whether the estimator rejects the null hypothesis consistent with basic probability theory, while the second, third, and fourth simulations illustrate the fact that the synthetic control estimator is consistent as the number of firms increases. This table summarizes the parameters of each simulation.

Appendices

Appendix A   Additional Table

Table A.1: Parallel trends test by firm size

NAICS	Size 1		Size 2		Size 3		Size 4		Size 5	
	ROC	SC	ROC	SC	ROC	SC	ROC	SC	ROC	SC
Agriculture, forestry, fishing and hunting (11)	0.76	0.90	0.45	0.98	0.10*	0.99	0.00	0.99	0.25	0.91
Mining, quarrying, and oil and gas extraction (21)	0.79	0.98	0.03**	0.87	0.02**	0.84	0.01**	0.83	0.20	0.92
Utilities (22)	0.51	0.71								
Construction(23)	0.09*	0.97	0.00***	0.91	0.00***	0.86	0.00***	0.86	0.01***	0.92
Manufacturing										
food + clothing (31)	0.03**	0.95	0.01***	0.98	0.00***	0.99	0.00***	0.94	0.02**	0.93
wood + plastic (32)	0.03**	0.98	0.08*	1.00	0.01**	0.96	0.00***	0.94	0.71	0.98
metal (33)	0.12	0.95	0.23	0.98	0.00***	0.98	0.04**	0.98	0.00***	0.97
Wholesale trade (41)	0.42	0.94	0.01***	0.95	0.00***	0.94	0.00***	0.94	0.00***	0.91
Retail trade										
cars, furniture, groceries (44)	0.13	0.94	0.06*	0.99	0.00***	0.97	0.42	0.98	0.01***	0.92
online, department stores, hobby (45)	0.52	0.92	0.02**	0.97	0.04**	0.99	0.71	0.98	0.10	0.90
Transportation and warehousing										
air, rail, truck, pipeline (48)	0.36	0.98	0.01**	0.99	0.85	0.98	0.01***	0.98	0.05*	0.99
postal, warehousing (49)	0.05*	0.97	0.60	0.99	0.70	0.98	0.91	0.99	0.96	1.00
Information and cultural industries (51)	0.51	0.97	0.20	0.98	0.04**	0.95	0.23	0.95	0.60	0.98
Finance and insurance (52)	0.71	0.93	0.36	0.96	0.91	0.96	0.83	0.97	0.04**	0.97
Real estate and rental and leasing (53)	0.43	0.92	0.24	1.00	0.50	0.99	0.09*	1.00	0.36	0.96
Professional, scientific and technical services (54)	0.69	0.91	0.12	0.95	0.16	0.97	0.18	0.95	0.49	0.94
Management of companies and enterprises (55)	0.60	0.89	0.51	0.99	0.22	0.93	0.49	0.92	0.23	0.99
Administrative and support, waste services (56)	0.90	0.89	0.20	0.98	0.10*	0.99	0.03**	0.96	0.01***	0.88
Educational services (61)	0.03**	0.99	0.01***	0.96	0.00***	0.93	0.00***	0.93	0.13	0.96
Health care and social assistance (62)	0.00***	0.90	0.00***	0.96	0.01**	0.90	0.47	0.92	0.34	0.93
Arts, entertainment and recreation (71)	0.02**	1.00	0.09*	0.99	0.36	0.98	0.02**	0.92	0.01***	0.93
Accommodation and food services (72)	0.41	0.90	0.61	0.97	0.01**	0.99	0.26	0.96	0.02**	0.86
Other services (except public administration) (81)	0.01***	0.87	0.76	0.95	0.10	0.96	0.28	0.96	0.74	0.99
Public administration (91)	0.93	1.00	0.06*	0.96	0.53	0.99	0.00***	0.99		

Note: This table presents the p-values generated by the Wald test between α and β in Eq.(4.1) for each representative firm in each industry. Notice that for many industries the p-value for the Rest of Canada (ROC) representative firms is less than 0.05, indicating that it does not satisfy the parallel trend assumption, whereas the p-value for the synthetic control (SC) is always greater than 0.7, indicating that it does not have a significantly different trend compared to the trend of the BC representative firm. *** Significant at the 1 percent level, ** Significant at the 5 percent level, * Significant at the 10 percent level.