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Do Carbon Taxes Kill Jobs? Evidence of Heterogeneous Impacts from British Columbia

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Abstract

Do carbon taxes kill jobs? With pricing at $30/tonne of carbon dioxide equivalent emissions, the BC policy is currently the most aggressive revenue-neutral carbon tax and serves as a role model for many jurisdictions world-wide. There are concerns, however, that this policy negatively impacts employment. This study uses firm-level synthetic control methods (SCM) to estimate employment effects of the BC carbon tax across industries. To take full advantage of the detailed firm-level data, we propose a revised SCM method, which we test in a Monte Carlo setting. Contrary to previous results, we find that BC employment was largely unaffected by the tax.

1. Introduction

In 2008 British Columbia (BC) became the first jurisdiction in North America to implement a revenue-neutral carbon tax. Today—pricing carbon at $30/tonne carbon dioxide equivalent emissions (CO_2e)[1] [2]—BC has the most aggressive revenue-neutral carbon tax worldwide. The lessons learned from BC will be instrumental to how other economies can manage carbon in the future.

For decades, there has been a consensus in the *theoretical* economics literature that carbon taxes are efficient, but the *empirical* evidence of the 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", as argued by Porter and van der Linde (1995). 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, in the case of BC, the policy is revenue-neutral by lowering business and personal income taxes[3]. Hence, it is not clear how these concerns play out empirically. This study estimates the causal effects of the BC carbon tax on employment using firm-level data and a synthetic control method (SCM) adapted to estimate the industry-level homogeneous effects and firm-level heterogenous effects.

Despite a large existing *theoretical* literature on carbon taxes (Nordhaus, 1993; Metcalf, 2009), the *empirical* literature is still small and inconclusive. To our knowledge, there are only few empirical papers to examine the effects of the BC carbon tax: Yamazaki (2017) finds that BC aggregate employment increased by 4.5% over the six years following the implementation of the policy, but that it had a negative effect on employment in carbon-intensive industries, while service industries received an increase in

[1] The tax rate was initially $10/tonne CO_2e when it was implemented in 2008, then increased $5/tonne annually until 2012.
[2] 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 CO_2. In 2013, CO_2 made up 78% of BC's GHG emissions methane made up 16%, while N2O made up 3% (measured in CO_2e) (Environment Canada, 2015).
[3] The personal income tax for the two lowest brackets was reduced by 2% in 2008 and 5% in 2009. In addition, the BC government provides a lump-sum credit to protect low-income households. A lump-sum of $100 per adult plus $30 per child is provided to single individuals whose income is below $30,000 or families whose income is below $35,000. Such lump-sum transfers are increased by 5% in 2009 and increased further by 10% in 2011.

employment. In comparison, Yip (2017) finds that the policy resulted in increased unemployment of 1.8%. Rivers and Schaufele (2014) focus on the tax's effect on the agricultural trade, finding that it did not adversely affect the sector's exports or imports.[4] 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.

The above discussion shows that the current empirical literature is inconclusive on the employment effects of the BC carbon tax, with one study finding the policy increased provincial employment, and another finding that it caused provincial employment to decrease. In addition, we identify a number of econometric challenges in the previous literature that could bias results. Empirically estimating the economic impact of the BC carbon tax is challenging due to a number of confounders. In particular, the BC carbon tax was implemented at a time of major macro-economic shifts. First, the great recession and subsequent recovery occurred simultaneously with the introduction and ramp-up of the carbon tax. Second, unlike other provinces in Canada, BC has been under special interest by foreign investors in the past decade(s), accelerating both migration and the steep increase of property values. Third, oil prices underwent drastic changes, especially during the time of our dataset from 2008 to 2013, and finally, other jurisdictions also have been implementing other environmental and energy policies[5]. Due to these confounders, it is crucial how the counterfactual is defined. We argue that new research is needed to guide policymakers on this important policy question.

[4] Thus far, only Martin et al. (2014a) 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 et al. 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 (2013), Martin et al. (2014b) investigate the effects of carbon pricing in the context of the European Trading Scheme.

[5] For example, in 2007 Alberta implemented emissions intensity reduction targets (Natural Resources Canada, 2013) and Quebec imposed a modest (not revenue-neutral) carbon tax (Sumner et al, 2011).

To analyze this question, we apply the SCM to a confidential firm-level data set. We prefer this confidential firm-level dataset over the publicly available aggregate data because employment data for certain industries is suppressed in the public aggregate dataset due to confidentiality concerns. A potential issue when applying the SCM to firm-level data is that it is possible that firms in the treatment province may be matched only to one firm from the donor pool due to the two firms simply sharing similar idiosyncratic variation in the pre-treatment period. Hence, in order to eliminate this possibility, we develop a revised SC estimation method. In brief, this method computes a representative firm from all individual firms in each province and runs the SCM using these representative firms. Thus, this technique results in all firm-level data being used and is more computationally efficient (this is because the optimization included in the SCM slows significantly when the number of units in the control donor pool is increased). We test this method in a Monte Carlo simulation to illustrate its validity. This technique results in an analysis similar to if aggregate data were to be used, however, using the firm-level data differs in that it overcomes the data availability issue present when using the public aggregate dataset.

As we wait for access to the firm-level data (our project just got approved with Statistic Canada in December 2017 and we hope to complete the analysis in the Spring 2018) we start by using the publicly available aggregate data for our analysis. In these preliminary results, our point estimates of the BC carbon tax employment effect suggest that the policy did not change employment trends at the industry-sectoral level in any substantial way; however, our results also show that there is great uncertainty in how the tax impacted employment in BC. The only industry found to have been impacted by the carbon tax at a level of statistical significance of 25% is the fabricated metal product manufacturing industry, with an employment loss of about 2700 workers by 2013, equivalent to approximately a 19.5% decrease in employment. Additionally, our point estimates from our total employment analysis indicate that aggregate provincial employment increased by 8552 jobs by 2013, an increase of less than 0.5% relative to the synthetic control counterfactual. This increase, however, is found to be insignificant at the 15% significance level. This result contrasts with the finding of Yamazaki (2017) that aggregate employment was 4.5% higher due to the carbon tax by 2013.

Finally, we ask the question whether, on average, employment losses were more likely in energy intensive industries. We find that the magnitudes of our point estimates of the employment effect are not correlated with the emissions intensity of the industry. In fact, if at all, our analysis shows that carbon intensive sectors in BC gained employment relative to the carbon non-intensive industries. This result casts doubt on the common assumption that carbon taxes disproportionately hurt carbon-intensive industries.

The rest of the paper is organized as follows. Section 2 provides background to the BC carbon policy and Section 3 describes the data. In Section 4 we describe our methodology and run Monte Carlo simulations to provide numerical support for the estimation strategy used with the firm-level data. Section 5 describes the results and we conclude in Section 6.

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 CO_2e, 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). 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.

Table 1: Tax rate for selected fuel types, BC, 2013

Fuel type	Units for tax	Tax rate (2013)	Tax % of final fuel price (2013)
Gasoline	¢ CAD/liter	6.67	5.10
Diesel	¢ CAD/liter	7.67	5.74
Natural Gas	¢ CAD/m^3	5.7	50.68
Propane	¢ CAD/liter	4.62	18.67

Note: Tax rate per unit volume for selected fuel types and the tax % of the final fuel price for 2013. This table was heavily-inspired by 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).

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). 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 (Rivers and Murray, 2015). Exemptions are made for methane fugitive emissions from oil and gas processing and extraction, fuel used by the agricultural industry, fuels exported from BC, all GHG emissions that are not directly produced from the combustion of fossil fuels (eg. methane produced from landfills), and all emissions produced outside BC's borders (Ministry of Finance, 2014). Thus, since many emissions produced by the oil and gas extraction industry are fugitive emissions (eg. methane leaked during extraction), the tax does not capture many of this industry's emissions. Additionally, 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[6].

3. Data

Our study will collect the most detailed firm-level dataset ever compiled to answer this question in Canada. We applied and obtained approval to work with the Longitudinal Employment Analysis Program (LEAP) from Statistics Canada's *Center for Data Development and Economic Research.* This dataset consists of the universe of employment data from all Canadian firms covering the time period from 2001 to 2015. 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 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*).

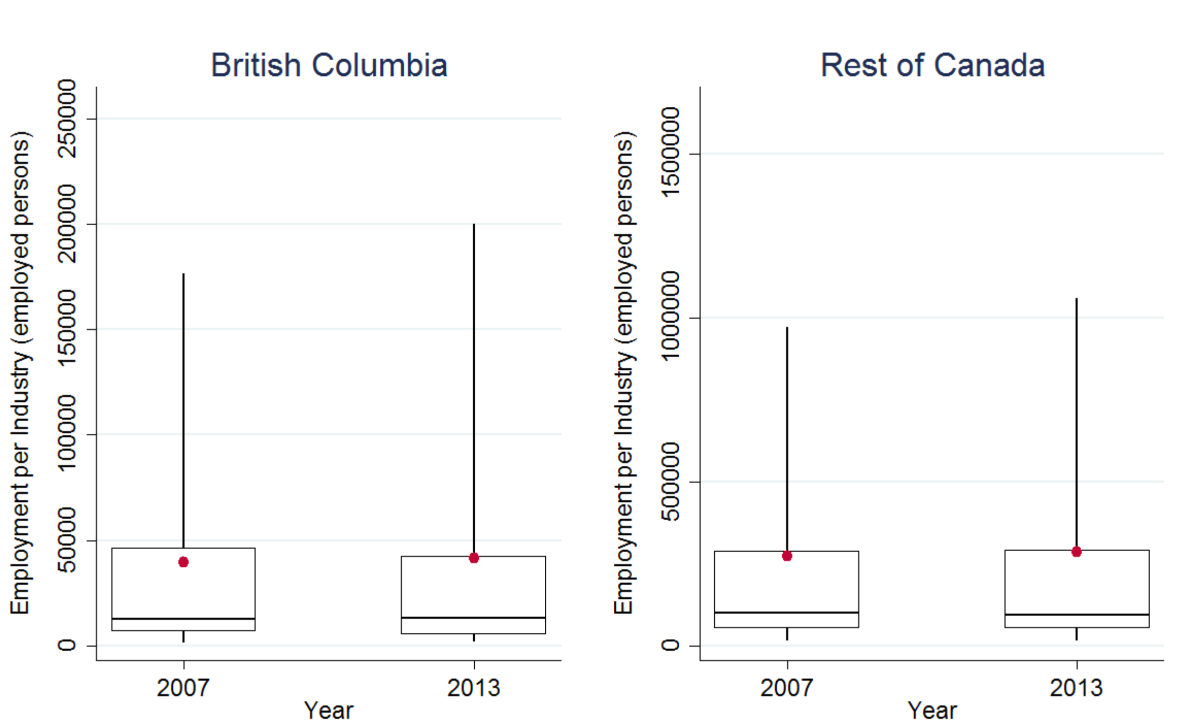
Unfortunately, we have yet to receive access to LEAP, so as a preliminary analysis we work with a publicly available employment dataset. The public data come from Statistics Canada's CANSIM Table 281-0023. This data is constructed from the Survey of Employment, Payrolls and Hours and is made up of monthly employment data, unadjusted for seasonality, covering the time period from 2002 to 2013. The employment measure used in this study is the number of persons paid (by salary or paid by the hour) and includes data for all 13 territories and provinces in Canada.

To provide a feel for the data, we include Figure 1, which summarizes employment across the 44 industries we analyze in our preliminary analysis. This figure shows that the median BC industry has about 13,000 workers in both 2007 and 2013 and that the mean employment across industries increases slightly between the two years, from approximately 40,000 workers to 41,500 workers. A similar change appears to occur

[6] 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 et al., 2000). Therefore, since this CO_2 is not produced from fuel combustion, it is not covered by the BC carbon tax.

in the Rest of Canada. Just from these raw statistics, it appears that the policy did not have a significant effect on employment in the province. The next Section describes the methodology that we will use to analyse the policy effect econometrically.

Figure 1: Boxplots of sectoral annual employment in BC and Rest of Canada in 2007 and 2013



Note: This figure presents boxplots of annual employment in BC and Rest of Canada in 2007 and 2013 across the 44 industries used in this preliminary analysis. The red dots indicate the mean while the whiskers are the 5th and 95th percentiles. The box represents the quartile range and the middle line is the median. This figure shows that there is no major change in the distribution of employment across the industries from before the carbon tax was implemented to five years later in either BC or the Rest of Canada.

4. Methodology

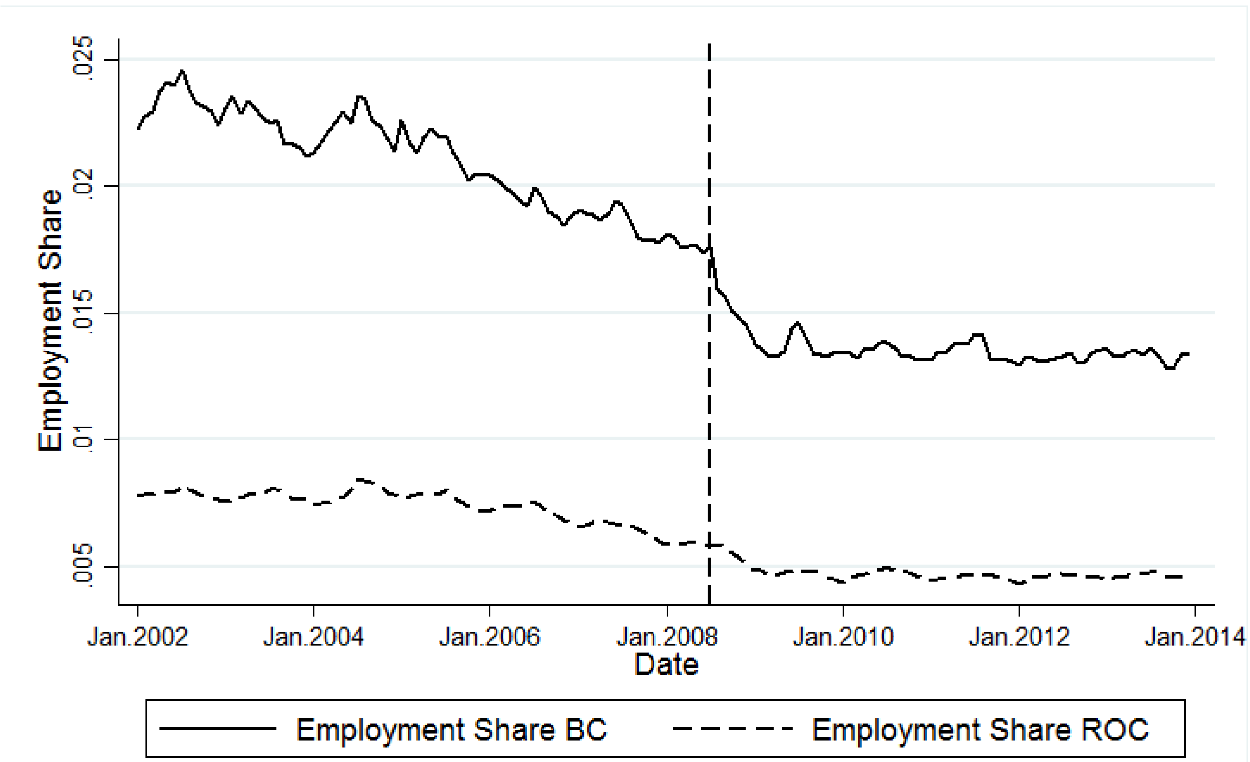
Analysis of the pre-treatment years (2001 to June 2008) in the public data shows that the "parallel trend" assumption of the Differences-in-Differences (DD) framework is violated for over 80% of BC industries if the Rest of Canada (ROC)[7] is defined as the control state. Thus, the traditional DD (as in Yamazaki, 2017) could produce biased results. As an example, Figure 2 shows BC employment data for the wood product manufacturing industry plotted alongside the data for the same industry for the ROC. Figure 2 clearly shows

[7] Defined as the sum of employment in all provinces and territories in Canada except for British Columbia.

that the parallel trend assumption does not hold in this industry when ROC is used as the control. Figure 3 shows, however, that a synthetic control constructed via the Abadie et al. (2010) SCM produces a control that does satisfy the parallel trend assumption. Therefore, in order to address this identification concern, our study develops industry-specific synthetic control groups. To our knowledge, SCM has yet to be applied to an analysis of the BC carbon tax.

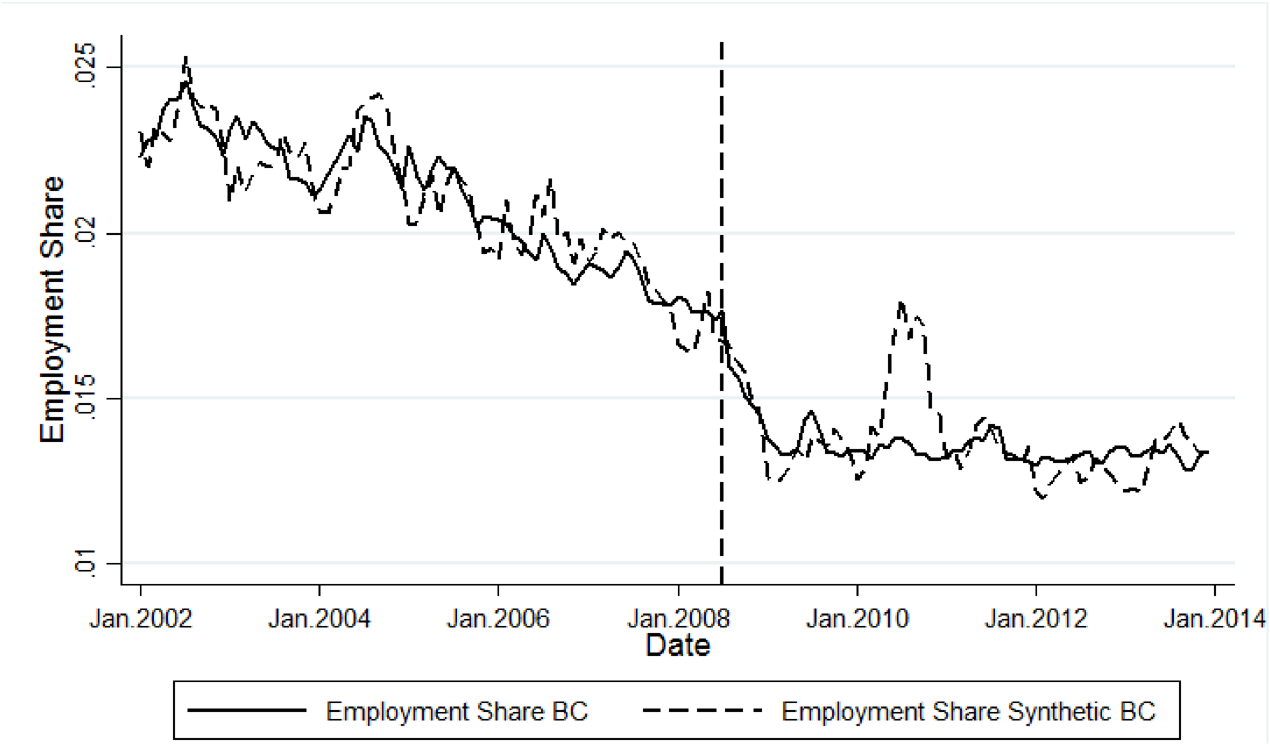
We apply the SCM to two different sets of BC data. First (because we have yet to receive access to the firm-level data) we use the public aggregate data from Statistics Canada to show preliminary results. Second, once we obtain access to the firm-level data, we will apply the SCM to confidential data to estimate a homogeneous treatment effect (the employment effect at the sectoral level) and heterogeneous treatment effects (the employment effects at the level of each BC firm) of the tax.

Figure 2: Employment share in the wood product manufacturing industry in BC vs. Rest of Canada



Note: This figure presents the wood product manufacturing industry employment share in BC compared to the employment share of this industry in the Rest of Canada. Notice that the pre-treatment trends, the trends prior to the vertical dashed line, are considerably different. Hence, the parallel trend assumption is violated if Rest of Canada is used as the control for this industry.

Figure 3: Employment share of the wood product manufacturing industry in BC vs. Synthetic BC



Note: This figure presents the wood product manufacturing industry employment share in BC compared to the employment share in synthetic BC. Notice that the pre-treatment trends, the trends prior to the vertical dashed line, are much better matched than in Figure 2. Hence, the parallel trend assumption appears much more likely to be satisfied using synthetic BC as the control rather than using ROC.

4.1 Estimation of Homogeneous Treatment Effect Using Aggregate Data

We implement the SCM according to how it is outlined in Abadie et al. (2010). Let Y_{itp}^{I} be employment in industry *i* at time *t* in province *p* which receives a policy intervention, and Y_{itp}^{N} 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 $\alpha_{itp} = Y_{itp}^{I} - Y_{itp}^{N}$. In this study, the parameter of interest is α_{itBC}, as BC is the province which implemented the carbon tax, i.e., the intervention. Abadie et al. (2010) show that α_{itBC} can be estimated by substituting Y_{itBC}^{N} 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 et al. (2010) for a detailed discussion of the SCM.

For certain industries in our analysis, the SCM creates a synthetic control which matches the trend of the treatment unit's pre-intervention period, but which has a magnitude over the pre-intervention period that does not match that of the treatment unit's. Thus, to correct for this, we subtract the average difference between the treatment unit and synthetic control unit in 2007 from our α_{itBC} estimate.

In this study, using the public aggregate data only, the above-described method is carried out on 44 industries. These 44 industries are made up of both 2 and 3-digit NAICS industries. The process used to decide which industries to include in our analysis started by considering all 3-digit NAICS industries. Since this would have led to 99 industries being included in our analysis, with many of them with insignificant employment levels, we then aggregated all industries not in the manufacturing, resource extraction, transportation, and construction industries to the 2-digit NAICS level. We kept a more detailed analysis of the manufacturing, resource extraction, transportation, and construction sectors because political discussions regarding the negative impacts of carbon taxes are often focused on these sectors. The public employment dataset does not include industries primarily involved in the agriculture, fishing and trapping, private household services, religious, and the military industries[8]. Additionally, certain industries are excluded due to employment data in these industries being suppressed from the public employment database due to confidentiality concerns. This leads to the employment data in the 44 industries we use covering 79% of total BC employment in 2013. These omitted industries will, however, be included in our analysis with the confidential firm-level data.

In our regression, the dependent variable is the industry's share of provincial employment. We choose the share (instead of level) because share data automatically controls for the large in-migration of workers to BC over the study period. To illustrate, the population of BC increased by 489,920 persons between 2002 and 2013, an 11.9% increase, and the province's labour force increased by 341,013, a 21% increase, in this

[8] There is another publicly available dataset (CANSIM table 282-007) which comes from Statistics Canada's Labour Force Survey which does capture all employment in BC, however, it does not include the same level of industry disaggregation as the dataset used here (CANSIM table 281-0023). Since we are interested in whether there is a distributional effect of the carbon tax we thus opted to use the data from CANSIM table 281-0023.

same time period. In contrast, the population and labour for other Canadian provinces did not increase at such a quick pace. For example, the province of Nova Scotia saw its population increase by only 7,894 persons, an increase of just 0.8%, and its labour force increased by only 27,992 persons, or 7.6%, in this time period[9]. Hence, the use of employment in levels (as the dependent variable) would clearly bias the results (unless one were to assume that the carbon tax itself were responsible for inter-state migration, an assumption we are not willing to make).

As in Yamazaki (2017), we are also interested in whether the BC carbon tax had an impact on provincial total employment. In order to estimate this, the SCM is applied to data including employment from all industries in BC. This data covers 86% of employment in the province as no data is suppressed at this level of aggregation, but the agriculture, fishing and trapping, religious, and military industries are still omitted from the dataset[10]. We denote the treatment effect parameter as α_{tBC}. In this case, employment growth relative to the base year of 2002 is used as the dependent variable. (Note that if employment measured in levels were used, then the SCM gives greater weight to those provinces which are similar in size to BC, even if the trend in employment growth between this province and BC are dissimilar. Thus, using employment growth as the dependent variable allows SCM to create a synthetic control that best matches the BC data's trend.)

In both cases, we consider the employment effect as of 2013. Hence, we focus our analysis on $\alpha_{i2013BC}$. 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. While data up until 2015 is available, we use data from 2013 to avoid additional confounding factors such as the oil price crash at the end of 2014. Since this section of the analysis is conducted using monthly

[9] Population and labour force data obtained from Statistics Canada CANSIM Table 051-0001 and 281-0024.
[10] As a check, we also applied this methodology to a dataset which does cover 100% of employment (CANSIM table 282-0007) and obtained qualitatively the same results.

data, $\alpha_{i2013BC}$ is calculated by taking the average of the estimated 2013 employment effect by month, $\alpha_{i2013BC} = 1/12 \sum_{m=1}^{12} \alpha_{i2013BCm}$.

For inference, placebo estimates on each industry are carried out. To do this, we use the SCM methodology as described above, but where the treatment group is replaced by a representative firm from the control group donor pool. This results in an estimate, α_{itC}, where C stands for "control", for each control unit. In accordance with Abadie et al. (2010), we call these other 12 cases placebo tests. If the estimated BC employment effect lies outside the range of 85%[11] of the estimates obtained by the placebo tests, we say that the estimate is significant at the 15% level.

In all applications of the SCM in this paper, the mean square prediction error (MSPE) is minimized over the entire pre-treatment period.[12]

4.2 Estimation of Homogenous Treatment Effect Using Firm-Level Data

We label our estimation of the employment effect in each industry as the "estimation of the homogeneous treatment effect." This is because estimating the employment effect at the industry level implicitly assumes that the employment effect across firms within an industry is equal. We estimate the homogeneous treatment effect for each subsector (3-digit NAICS) by creating a representative firm for each province in the country. This representative firm is the "average firm," defined as the firm whose variables are the mean average of all those in a given province, in a particular subsector. Then, we use this representative firm as the treatment group in the SCM, using all other representative firms in the country other than BC as control groups. Thus, through the SCM, we obtain an employment effect estimate for each industry. Placebo tests are then carried out on each industry to test for significance. To do this we use the above methodology, but where the treatment group is replaced by a representative firm from the control group donor pool. If the

[11] A significance level of 15% is used because with only 13 provinces and territories in Canada, the smallest significance level for a two-sided hypothesis test that is possible is 2/13 ≈ 15%.
[12] As robustness tests, we minimised the MSPE over a range of different periods (from using just the 3 years prior to the treatment to using the 6 years prior). All these robustness tests yielded very similar results and are available from the authors upon request.

estimate estimated employment effect lies outside the range of 85% of the estimate obtained by the placebos, then the average estimate is significant. This analysis is conducted separating firms by firm size.

Similar to the method using aggregate data described in section 4.1, we control for labour force changes due to migration and natural population growth over the time period from 2001 to 2013 by using employment share as our dependent variable rather than employment in levels. Since employment in LEAP is measured by ALU, employment share will be the ALU of a given firm divided by the total ALU in the province's economy.

4.3 Estimation of Heterogenous Treatment Effects Using Firm-level Data

We label the estimation of the treatment effect across firms within an industry as the "estimation of heterogeneous treatment effects." This is because, in this method, we estimate the employment effect for each firm in BC, and so the heterogeneity in the employment effect within a given industry is apparent. The technique used to estimate the heterogeneous treatment effect is as follows. Suppose there are *n* firms in BC in subsector *i*. Then, the SCM (as described above) will be used *n* times, using each of these BC firms once as the treatment unit. Hence, a distribution of *n* estimates of the employment effect will be obtained (and from these *n* estimates summary statistics such as the average estimate for subsector *i* can be obtained). To test significance, a placebo test can be used again. By randomly selecting *s* number of firms from the donor pool and again running the SCM with these "placebos", the average estimate of $\alpha_{i2013BC}$ can be compared to estimates obtained using placebos, α_{i2013C}. If the average estimate lies outside the range of 95% of the placebos, then the average estimate is significant[13]. In addition, we can test for the difference between the distribution of the treatment to the placebo distribution using entropy methods (Kullback Leibler divergence statistics)**.** Through calculating the average estimate for a subsector *i*, this technique will also yield estimates at the subsector level (3 digit NAICS). This analysis is also separated by firm size.

[13] We expect to be able to use a significance level of 5% for this method since we assume that most industries at the 3-digit NAICS level will have over 100 firms across Canada.

Similar to the method using aggregate data described in section 4.1, in addition to employment in levels (to match similar type of firms), we can also control for labour force changes due to migration and natural population growth over the time period from 2001 to 2015 by using employment share[14] as our dependent variable.

4.4 Monte Carlo Simulations

We run Monte Carlo (MC) simulations to demonstrate the characteristics of the synthetic control estimator in our analysis of the homogeneous treatment effect using firm-level data. The primary goal of these simulations is to illustrate the fact that the synthetic control estimator in this technique is unbiased and consistent. Hence, we use these MC simulations to show that the estimator in this technique converges to the true value of $\alpha_{i2013BC}$ 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_{iTp}'s (smallest α_{iTp} = 1, highest α_{iTp} = 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 α_{iTBC} is different than zero, H_A: $\alpha_{iTBC} \neq 0$. The null hypothesis is that the BC α_{iTBC} is equal to zero, H_0: $\alpha_{iTBC} = 0$. If α_{itBC}

[14] In LEAP, employment is measured by ALU. Employment share will be then calculated by the ALU of a given firm divided by the total ALU in the province's economy.

is ranked 1st, 2nd, 99th, or 100th, then at a significance level of 4%[15], the null hypothesis is rejected, and we conclude that the α_{itBC} is significantly different from zero.

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 i. 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 2 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 (ie. when the carbon 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 i, in the third simulation n_i=5 for all i, and in the fourth simulation n_i=100 for all i. Table 2 summarizes the defining characteristics of each simulation.

Table 2: Parameters of the four Monte Carlo simulations

Simulation	**Mean of Control E(y_c)**	**Mean of Treatment y_{BC} Post 2008**	**Standard Deviation of y**	**Number 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.

Table 3 presents the results of simulation 1. It shows that the percentage of simulations that produces α_{iTBC} ranked 1st, 2nd, 98th, or 99th is close to the expected value of 4%.

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[15] 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.

Table 3: Results of Monte Carlo simulation 1

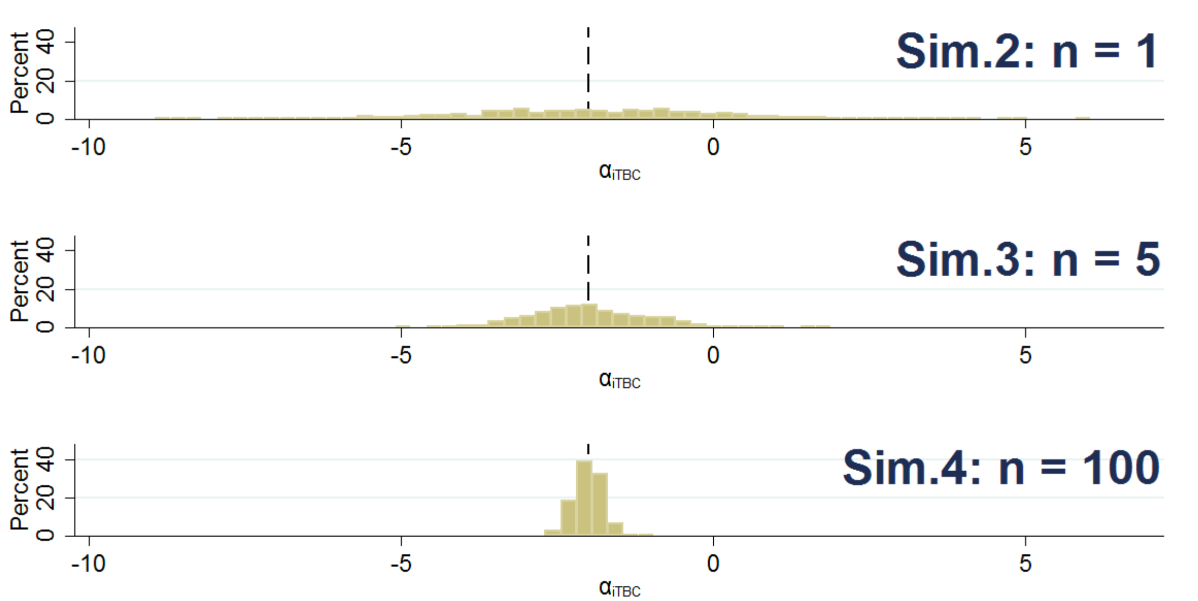
Method	Simulation	Expected percent of cases that α_{it} BC is significantly different than placebo	Percent of cases that α_{itBC} C is significantly different than placebo in simulation
A	1	4.0%	3.2%

Note: This table presents the main result of simulation 1. The result shows that the synthetic control estimator in our revised SCM technique rejects the Null numerically almost equivalent to what probability theory would predict.

In the simulations 2-4 the true treatment effect is a reduction of two units, Y_{BCT} - Y_c = -2. Figure 4 presents the distribution of treatment α_{it}BC's for simulations 2 – 4. As expected, it shows, that as the number of firms per province increases, the α_{iT}BC estimate converges to the true value of -2.

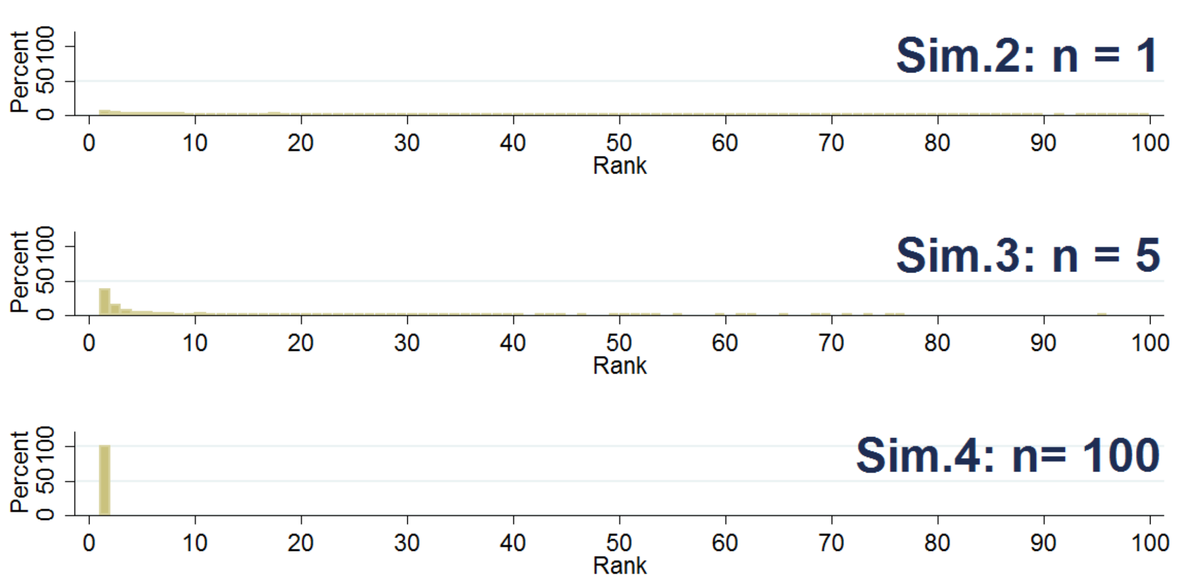
Similarly, Figure 5 presents the distribution of the ranking of α_{iTBC}'s for simulations 2 – 4 and demonstrates that as the number of firms per province increases, the probability that the α_{iTBC} will be found to be significant increases. Hence, we see that as the number of firms per province increases, the probability of committing type 2 error decreases.

Figure 4: Results of Monte Carlo Simulations 2 to 4, Distribution of Treatment Parameter Estimates



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, α_{iTBC} converges to the true value.

Figure 5: Results of Monte Carlo Simulations 2 to 4, Rank Statistics of Treatment Parameter Estimates



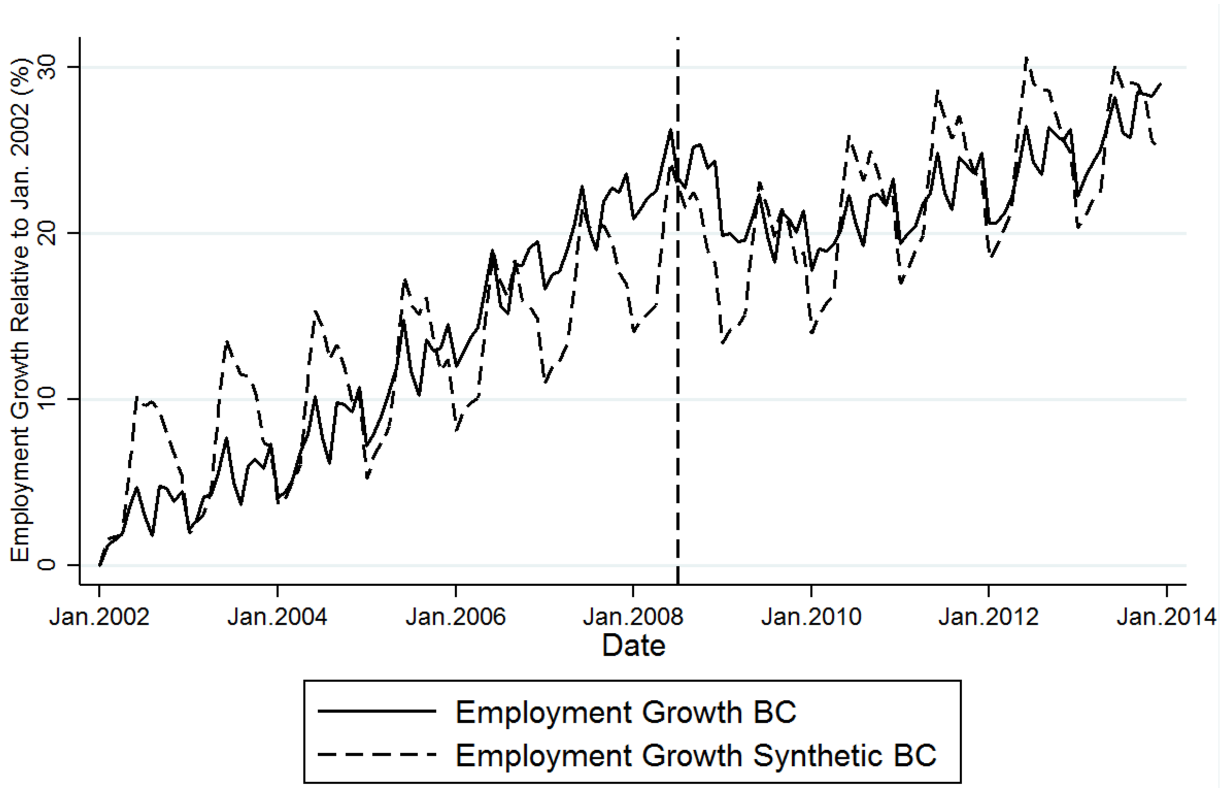
Note: This figure shows that as the number of firms used to calculate the representative firm increases, the probability of committing type 2 error decreases. The top panel presents a histogram of the results of simulation 2, in which there is one firm per province; the middle panel shows a histogram 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, α_{iTBC} should be ranked 1st. Notice how, as the number of firms per province increases, the probability that , α_{iTBC} 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.

5. Results

5.1 Total Employment Effect

Figure 6 and 7 present the results of applying the SCM to the public CANSIM data for the purpose of identifying the total employment effect of the carbon tax. Figure 6 displays the BC and synthetic BC employment trends and visually suggests that there is no discernible employment effect of the BC carbon tax at the aggregate level. The point estimate $\alpha_{2013BC,}$ in units of employed persons, is 8,552, which is relatively small. To put this in perspective, this is equivalent to an increase in total employment in BC by less than 0.5% relative to the synthetic BC counterfactual. While this result is in agreeance with our ad-hoc analysis presented in Figure 1, in order to statistically evaluate the effect of the post-treatment trends of BC and synthetic BC, we perform SCM placebo tests. Figure 7 presents the results of the placebo tests. Since many of the placebo tests yield α_{2013P}'s which have larger magnitudes than the α_{2013BC} estimate, it shows that the α_{2013BC} estimate is statistically insignificant.[16]

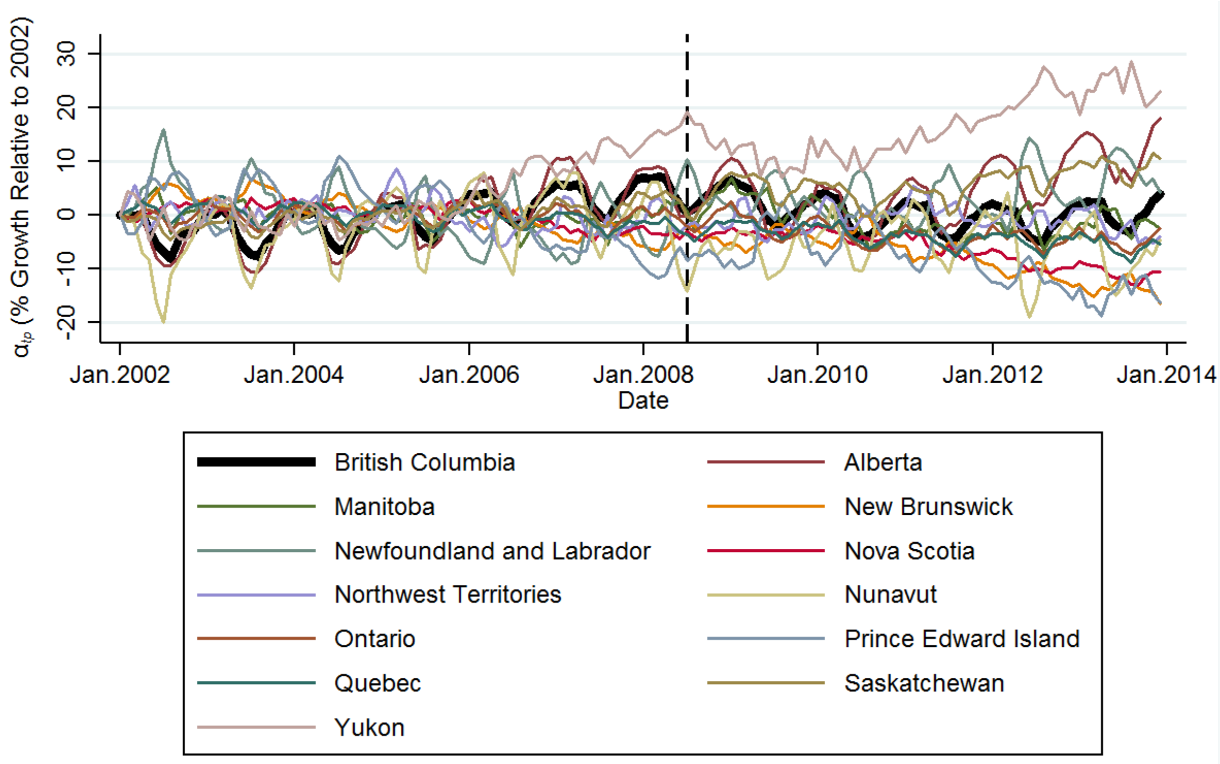
Figure 6: Total employment growth relative to January 2002 in BC and Synthetic BC



Note: Total employment growth relative to January 2002 in BC and Synthetic BC. The average α_{2013BC} estimate, in percent growth, is 0.54%, which is equivalent to an increase of 8552 employed persons

[16] Since there only exist 13 provinces and territories in Canada, the smallest significance level for a two-sided significance test that can be used is 2/13 = 15.3%.

Figure 7: Treatment and placebo parameter estimates for all months



Note: This figure presents the α_{tp} estimates for all placebo tests and BC across all years of the analysis. α_{tBC} is the estimated change in employment growth in BC due to the carbon tax in year *t*. The figure shows that the α_{2013BC} estimates of many other provinces are larger than that of BC's, indicating that the BC estimate is insignificant at a significance level of 15.3%.

5.2 Sectoral Employment Effect

While the results show that there is no statistically significant employment effect at the level of provincial total employment, it is still possible that there is a significant distributional impact across industries. Figure 8 presents the results of the sectoral analysis conducted at the industry level using the public aggregate data. The figure displays $\alpha_{i2013BC}$, the treatment effect, estimates for each of the industries plotted along with a pseudo-confidence interval (CI). This "confidence interval" is constructed by taking the range of the placebo estimates, α_{i2013C}, and centring it at the $\alpha_{i2013BC}$ estimate. For some industries the Figure does not provide pseudo-CI's. This is because those industries have only one placebo, and so there is no *range* of α_{i2013C} estimates. Figure 8 shows that for nearly all industries (for which a test of significance is possible) the treatment effects $\alpha_{i2013BC}$ are insignificant.

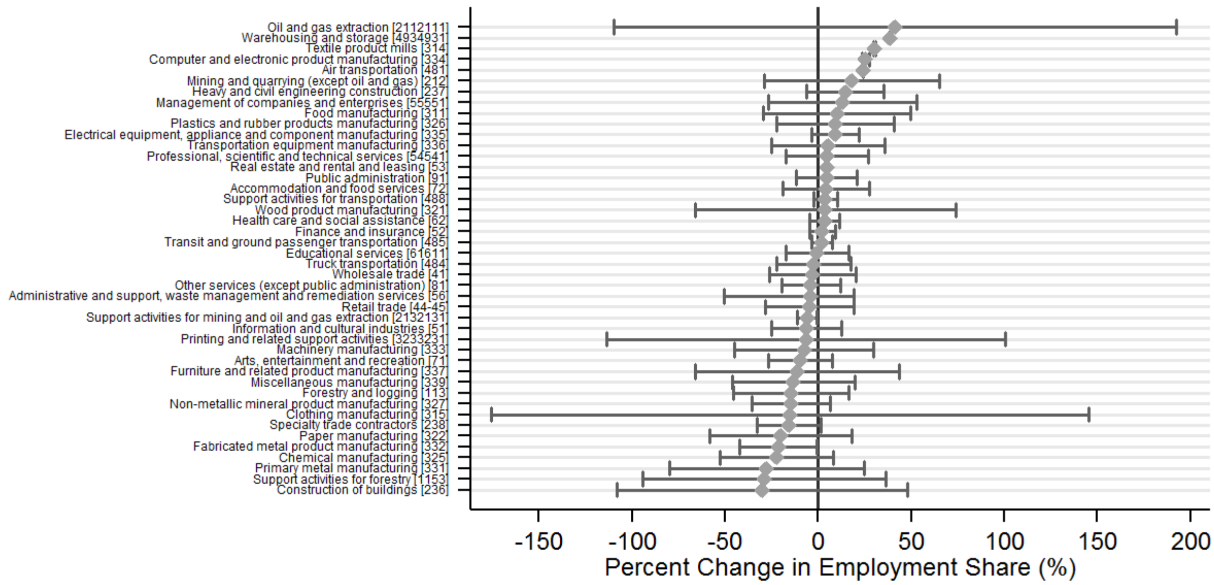
Some further notes are in order: The textile product mills and computer and electronic product manufacturing industries both have very small pseudo-CI's, which appear to indicate that the point estimate for these industries is significant. However, due to data suppression in the public-use files, there exists data for only two control states for each of these industries, so these point estimates are only significant at the 66.6% significance level. The only industry which does have more than 2 placebo units and whose pseudo-CI indicates a significant employment effect is the fabricated metal product manufacturing industry. This industry has a point estimate of -21.4% change in employment share. The data allow for 7 provinces to be in the control group donor pool, and so this estimate is significant at the 25% significance level.

It should be noted, however, that although the vast majority of point estimates are insignificant, these results should not be interpreted as evidence that the BC carbon tax had no effect on employment. Rather, due to the size of the pseudo-CI's, we can only conclude that if there was an employment effect, there were also other economic factors which caused equal, if not greater, employment effects during this same time period.

Figure 9 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 13,600 jobs in the construction of buildings industry. However, as can be seen in the figure, the placebo runs for the industries which lost or gained large amounts of employees produced also large range of estimates, suggesting that the estimates in these industries are insignificant. The only "significant at the 25% level" estimate is the loss of employment in the fabricated metal product manufacturing industry. This industry saw a decrease in employment of 2,708 jobs due to the carbon tax, equivalent to a 19.5% decrease in employment in this industry.

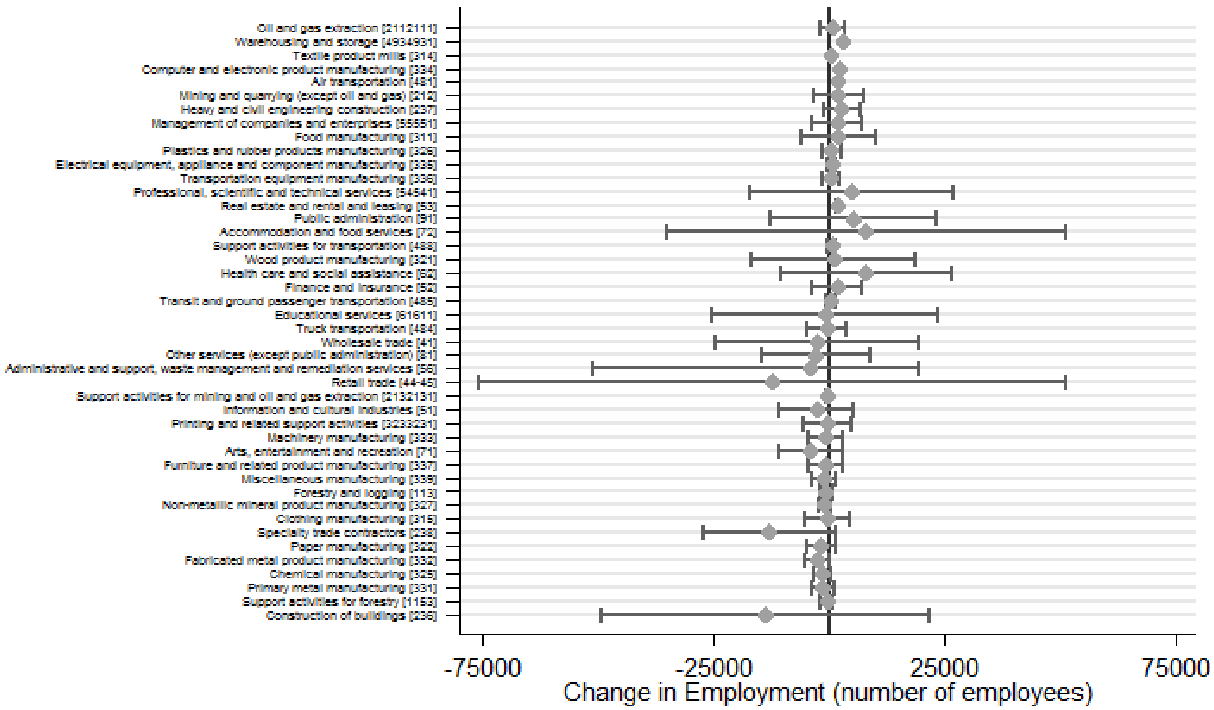
For comparison to the BC employment effect estimate presented in section 5.1, we sum the $\alpha_{i2013BC}$ measured in employed persons to calculate a second estimate of $\alpha_{2013\text{BC}}$. This method leads to a total employment effect of -18,768 employees. This represents a drop of 0.95% in BC's total employment. In comparison, the method of section 5.1 led to an increase of 0.5% in employment. However, it should be noted again that using this method of calculating the total employment effect we do not observe the entire universe of workers, but 79% only.

Figure 8: Percent change in employment share, all industries



Note: This figure shows the estimated percent change in employment share for all industries. These results were produced using monthly aggregate data. In the vast majority of industries, where it is possible to construct a pseudo-confidence interval, the $\alpha_{i2013BC}$ is insignificant. In all cases except the fabricated metal product manufacturing industry, where the estimate does appear to be significant, the number of provinces available to be used as placebos is very small and so the estimate is only significant at a very high significance level. The point estimates in this figure are the $\alpha_{i2013BC}$ estimates while the intervals are the range of α_{i2013p} estimates obtained from the placebo tests centred at the $\alpha_{i2013BC}$ estimate.

Figure 9: Change in level of employment, all industries



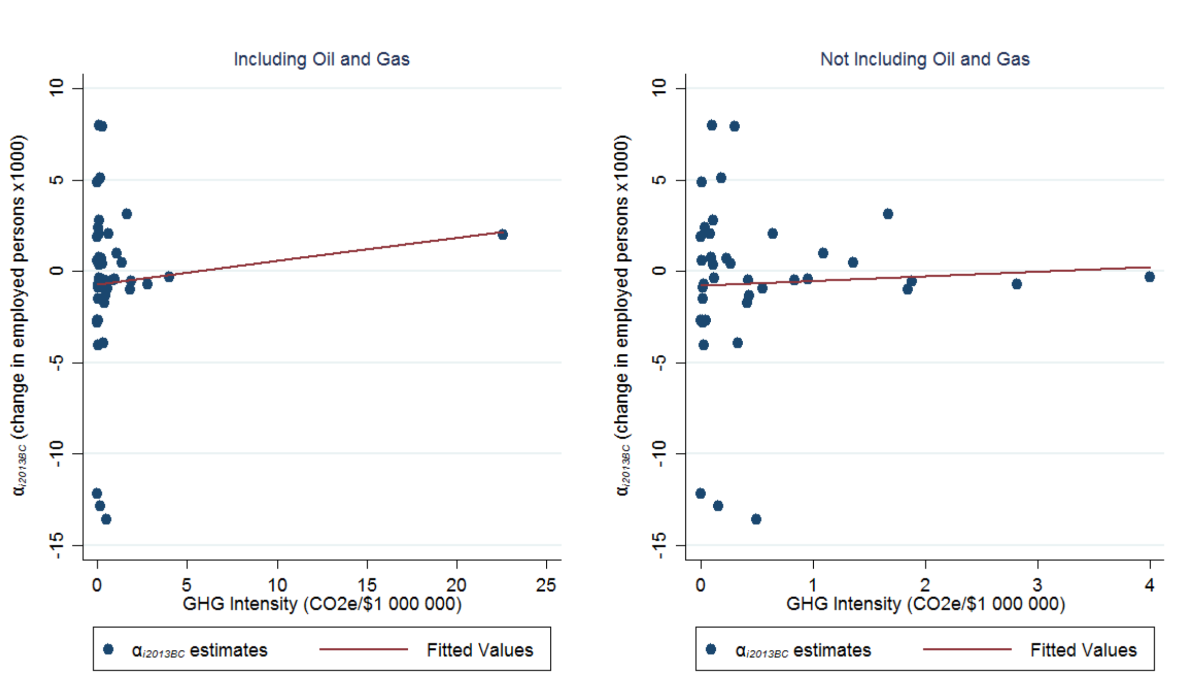
Note: Change in employment measured in persons employed for all industries. These results were produced using monthly aggregate data. The total employment effect in levels produced by summing up the industry-level changes displayed in this graph is a drop of 18 768 employed persons.

A question we are also interested in is: are the changes in employment related to the energy intensity of the industry? Figure 10 illustrates the relationship between the industry point estimates of the employment effect and the greenhouse gas (GHG) intensity[17] of the industry. The left panel of Figure 10 shows that there is a weak, positive relationship between the industries' point estimates and their GHG intensity. However, there is a clear outlier, the oil and gas extraction industry. The right panel removes this outlier and re-plots the results. Again, there is a weak, positive relationship. Overall, it hence seems that our result contradicts the common concern that jobs in carbon-intensive industries are lost by a carbon tax. We should note however, that this relationship, is again statistically speaking insignificant: while the line's slope in

[17] 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.

the right panel is 255 employed persons per kilotonne CO_2e/$1,000,000, its standard error is 843 employed persons per kilotonne CO_2e/$1,000,000 which implies a positive but statistically insignificant relationship.

Figure 10: Correlation of estimated industry treatment effects with emissions intensity



Note: These plots illustrate how the industry point estimates are correlated with emissions intensity. The left panel shows this relationship including the Oil and Gas Extraction industry, while the right panel shows the relationship with this outlier removed. In both cases it can be seen that the correlation is weak and slightly positive. The slope estimate for the regression line in the right panel is 255 employed persons per kilotonne CO_2e/$1 000 000 with a standard error of 843 employed persons per kilotonne CO_2e/$1 000 000. Hence, the relationship is positive and insignificant. This result contradicts the common assumption that employment in carbon-intensive industries would be worst hit by a carbon tax.

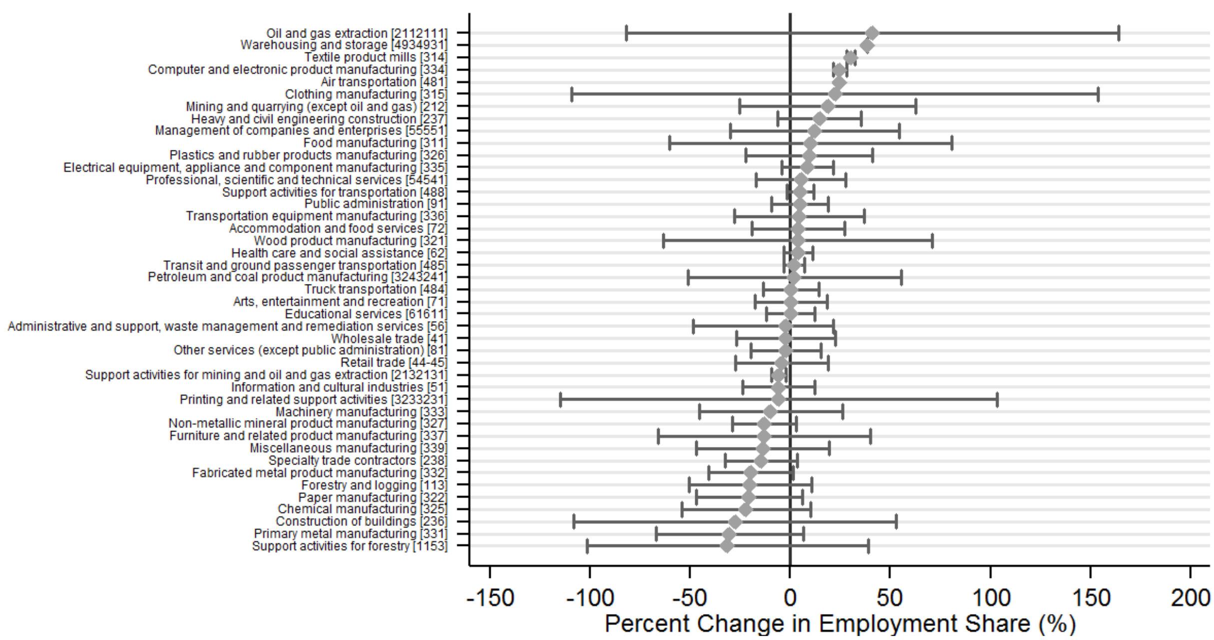
So far, our analysis has used monthly data. Using the SCM with monthly data raises the concern, however, that the synthetic control will be matched to the treatment unit based on seasonal patterns, rather than the overall trend in employment (so putting more weight on provinces with the same seasonality pattern, rather the same overall trend over years). As a robustness check for the sectoral analysis we rerun the regressions using annual aggregate data.

The results of the annual analysis are very similar to when monthly data is used. Figure 11 shows the $\alpha_{i2013BC}$ estimates measured in percent change in employment share and it can be seen that with the exception of the clothing manufacturing industry, there is very little change in the magnitude or sign of the point estimates for each industry. The clothing manufacturing industry's $\alpha_{i2013BC}$ estimate is relatively large and negative in the monthly analysis, however, in Figure 11 it is large and positive.

A total employment effect estimate is also derived from the industry employment effect estimates. In this case, the total employment effect estimate obtained is a drop of 6,409 employed persons, equivalent to a decrease of 0.33%.

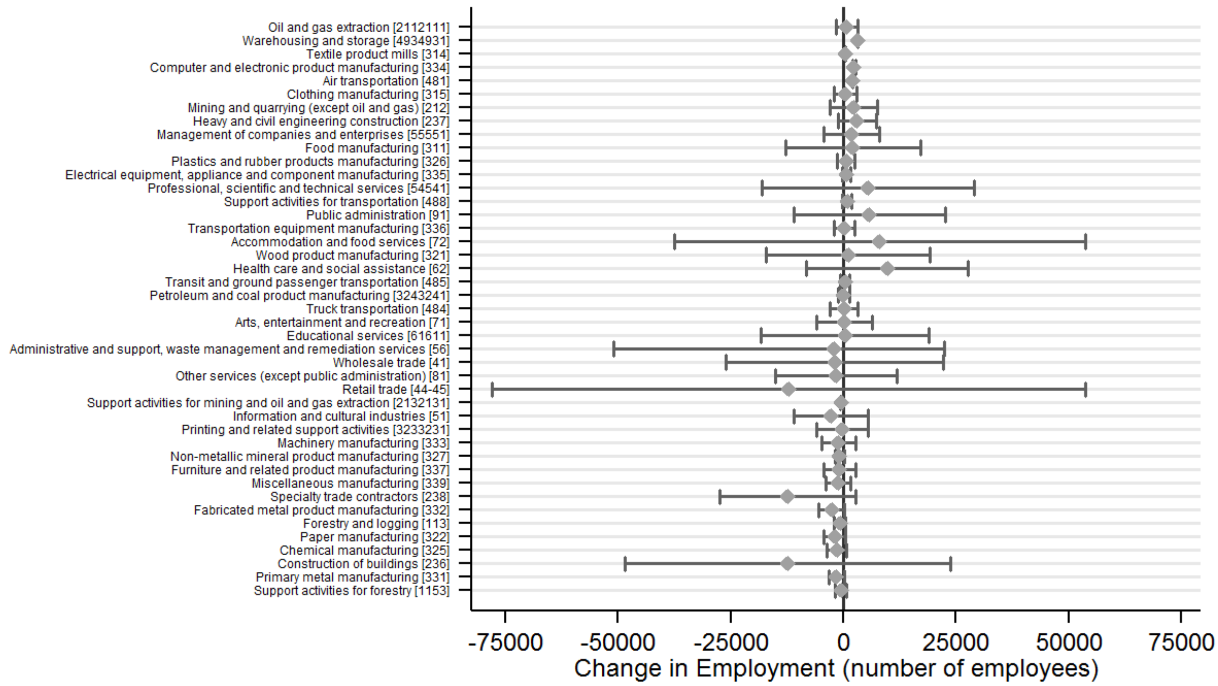
However, it should be noted that using annual data has the disadvantage of only providing the SCM with seven pre-treatment data points for which to construct a synthetic control. Abadie et al. (2010) show that the SCM estimates become consistent as the number of pre-treatment units go to infinity.

Figure 11: Percent change in employment share, all industries, annual data



Note: Percent change in employment share for all industries. These results were produced using annual aggregate data. Notice how the magnitude and sign of most industries are very similar between the results presented in this figure and those presented in Figure 7. One exception to this is the clothing manufacturing sector which has a large negative point estimate in the monthly analysis but has a large positive point estimate in the annual analysis presented here.

Figure 12: Change in level of employment, all industries, annual data



Note: This figure presents the change in employment for all industries. These results were produced using annual aggregate data. The magnitude of the change in levels is very similar using the monthly data (Figure 8) as when using the annual data (this figure). The total employment effect in levels produced by summing up the industry-level changes presented in this figure is a drop of 6409 employed persons.

5.3 Firm-Level Analysis Results

This analysis is not done yet as the authors have not yet been granted access to use the confidential data in Ottawa. We expect to have access to this data by Spring 2018.

6. Discussion and Conclusion

Overall, the results presented here suggest that the BC carbon tax had only a small effect on employment in the provincial economy. While some point estimates presented in this study are large, placebo tests show that larger employment changes occurred in other provinces absent from the carbon tax, and the null hypothesis cannot be rejected. If our main estimates hold with the firm-level data, then 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. For example, consider the oil and gas extraction industry. The $\alpha_{i2013\,\mathrm{BC}}$ estimate measured in percent change employment share for this industry is large, at an increase of 41%. However, the span of placebo estimates is much larger, ranging from -68% to 110%. Hence, this suggests that at the same time as the carbon tax was implemented in BC, employment in the oil and gas extraction industry was also affected by other important factors.

Further, we note that for a number of industries there were other economic events that occurred following the implementation of the carbon tax that may bias the estimator. In the case of the oil and gas industry, the past decade has seen billions of dollars being invested into BC to exploit the province's reserves of natural gas through hydraulic fracturing[18]. However, in our analysis, the SCM gave a weighting of 42% to Ontario, which has received no investment in the hydraulic fracturing industry. Hence, it is likely that the large and positive point estimate obtained for the oil and gas industry is biased upwards by the large recent investment in this industry in BC. Additionally, the construction of buildings 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.[19] Since British Columbia's oil industry is much smaller than Alberta's, the effect of high oil prices on construction are larger in Alberta than in BC. Therefore, since the SCM method gave Alberta a 27% weighting in the creation of BC's synthetic control in this industry, high oil prices would disproportionately affect employment in Alberta's construction of buildings industry, biasing the synthetic control upwards and consequently biasing the employment effect estimate downwards.

[18] British Columbia's Natural Gas Strategy. Ministry of Energy and Mines. http://www.gov.bc.ca/ener/popt/down/natural_gas_strategy.pdf
[19] Economic Commentary: Alberta's Oil and Gas Supply Chain Industry. Alberta Government. https://www.albertacanada.com/files/albertacanada/SP-Commentary_12-11-13.pdf

We also found that the industry point estimates were not significantly correlated with the emissions-intensity of the industry. One may cautiously argue that this result strengthens the finding that the BC carbon tax had no discernible effect on employment in the province.

It should also be noted that a number of industries obtained exemptions provided by the BC carbon tax policy. For example, Picard (2000) estimates that gas extraction leads to the creation of 3.1 tonnes of fugitive methane emissions per 10^6 m^3 gas production. Using this estimate, and given that BC produces approximately 44 billion cubic metres of gas annually[20], 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. Hence, the employment impact on the oil and gas industry might have been notably different if the carbon tax did not exempt fugitive emissions. Similarly, employment in both the air transportation and non-metallic mineral product manufacturing industries is found here to not be impacted by the tax, despite both being high-emitting industries. However, each industry also benefits from the exemptions provided by the BC carbon tax. The air transportation industry does not have to pay the tax on any emissions outside of BC and the non-metallic mineral product manufacturing industry does not get charged for any emissions not produced from the burning of fossil fuels[21]. Thus, if the carbon tax policy were to be expanded to include these emissions, the impact on employment in these industries may be substantially different than found here.

Our results differ from past studies (Yamazaki, 2017; Yip, 2017) which found a significant distributional employment effect across industries and a significant total employment effect. This difference in results likely stems from a difference in methodology. Here, synthetic controls were developed to ensure that the parallel trend assumption at the industry-level is satisfied, whereas in these previous studies the parallel trend assumption was tested only at the provincial level. Our analysis shows that the parallel trend

[20] Government of British Columbia. https://www2.gov.bc.ca/gov/content/industry/natural-gas-oil/statistics
[21] CO_2 is a by-product of the cement-making process, making this industry a high-emitter, but exempt from the carbon tax since this CO_2 is not generated from the combustion of fossil fuels.

assumption for a traditional DD 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-examined 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 two different datasets, one consisting of aggregated employment data and the second will use confidential firm-level data. To overcome challenges unique to applying SCM to firm-level data, we use a revised method within the SCM framework and tested it in a Monte Carlo simulation. We then applied the SCM to the aggregated data and will soon repeat this with confidential firm-level data. Our preliminary results show that the BC carbon tax did not have a significant effect on employment at the provincial or industry level.

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