Impact of the BC Carbon Tax on Sectoral GDP and Emissions

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Abstract

This paper develops a difference-in-difference model to quantify the sectoral impact of the implementation of the revenue neutral carbon tax in British Columbia, aimed solely at reducing carbon dioxide emissions in the province. The GDP analysis includes 119 sectors, sub sectors and special aggregates and finds a statistically significant impact for 58 sectors. The Emissions analysis includes 59 sectors and emissions categories and finds a statistically significant impact for 31 of them. Aggregate GDP is estimated to have declined by 1.25 billion dollars that is attributed to the carbon tax, in response an estimated emissions reduction of 2.451million tonnes of CO_2 is achieved in British Columbia. Another methodology employed to check for robustness is the construction of a counter factual using ARIMA modeling.

1. Introduction

Moving towards a low-carbon global economy is now widely recognized as one of the foremost challenges of our time. The Intergovernmental Panel on Climate Change (IPCC)'s Fifth Assessment Report, released in 2013, considers new evidence from multiple independent scientific analyses of the climate system and establishes that "*Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased*" (IPCC, 2013, pp. SPM-02)

The report states that the last three decades has been successively warmer at the Earth's surface than any of the preceding decade since 1850, and the atmospheric concentrations of Green House Gases (GHGs) as such carbon dioxide (CO_2), methane, and nitrous oxide have increased to the highest levels in at least the last 800,000 years, with CO_2 concentrations at a level 40 percent higher than the pre-industrial era (IPCC, 2013). These are staggering numbers and have led the IPCC to suggest, for the first time, the adoption of a global carbon budget of 1000 billion tonnes of CO_2 Equivalent (CO_2 Eq.) emissions in the atmosphere relative to pre-industrial levels, of which, a cumulative level of 531 billion tonnes has already been reached. GHGs other than $CO_{2,}$ such as Methane, CFCs, ozone, and nitrous oxide, also have a warming effect on the atmosphere and need to be accounted for in the remaining budget. Emission beyond this mark would likely risk global temperatures rising beyond the 2^{o}C target relative to 1990 levels and could lead to unpredictable and potentially hazardous consequences (IPCC, 2013)

Canada is the world's eighth largest emitter of GHGs, although its population is less than 0.5 percent of the world population (David Suzuki Foundation). As a country of massive land masses, with vast distances and frigid temperatures, Canada has a highly energy-intensive industrial base and energy consumption that ranks 7th in the World (Knoema, 2013). Energy consumption has grown about 22 percent and emissions by 19 percent since 1990 (David Suzuki Foundation). Although Canadian citizens largely rejected the idea of a nationwide carbon tax, as evident by the 2008 federal elections loss suffered by Dion and the Liberals who were proponents of a nationwide carbon tax (Yildiz, Barnes, & Yildiz, 2013), a few provinces in Canada have implemented carbon pricing policies to various extents. In October 2007, Quebec officially became the first North American state or province to implement a carbon tax on natural gas, coal and petroleum equal to $3 per tonne CO_2Eq. The level of the tax however is very small and applies only to energy producers, distributors and refiners (Carbontax Center, 2013); while Alberta imposes a carbon tax only on large scale emitters of the order greater than 100,000 Kt CO_2 equivalent emissions.

On July 1, 2008, British Columbia introduced North America's very first, broad-based, revenue-neutral carbon tax as part of its Climate Action plan, demonstrating a priority shift from short term economic gains to long term environmental sustainability. The plan aims for a 33 percent reduction in the province's emissions relative to 2007 levels by 2020. Starting at $10 per tonne of CO_2 Eq., the tax plan constituted scheduled increments of $5 per-tonne per year until the final increase took effect on July 1, 2012, fixing the tax rate at $30 per-tonne. The tax covers 70 percent of all reported emissions from fossil fuel combustion by industrial as well as business and household consumers in the province are rates are set in accordance with the carbon content of the fuel.

Economic activity in terms of both production and consumption affects GHG emissions. Although the carbon tax initiative in BC has largely been considered a success in terms of reducing emissions and has been deemed effective in the press and recent studies such as Schaufele and Rivers (2012) and Elgie and Mcclay (2013), there is a need for econometric analysis to determine how well the tax fared in terms of its impact on provincial GDP, and it's distributional impacts on individual sectors. In this paper, a difference in difference model is employed to investigate if there has been a significant impact on the British Columbia's Provincial GDP and GHG Emissions that can be attributed to the implementation of the carbon tax. In the first stage, a difference in difference estimate for GDP will be estimated for each of the industrial sectors classified under the North American Industrial Classification system using data from Statistics Canada for time frame 1997- 2011. In the second stage the same analysis will be conducted with Green House Gas Emissions using data from Environment Canada's National Inventory Reports from 1990-2011. In conclusion, an estimate for the cost of emissions reduction in terms of dollars of GDP forgone per each K-tonnes of Carbon equivalent emissions reduced will be established.

The paper is organized as follows: Section 2 gives a description of the two most internationally prevalent carbon pricing policies, section 3 presents a brief literature review on international experiences and research involving carbon tax and its impacts of GDP and emissions mitigation. Section 4 discusses the design and scope of the carbon tax effective in British Columbia. Section 5 presents the details of data and the empirical methodology used in the analysis. Section 6 presents and discusses results. Section 7 includes an alternate method for counterfactual construction to check for robustness. Finally section 8 presents the research conclusion.

2. Carbon pricing policies

Although GHG reduction is still a highly pressing international issue, efforts to mitigate GHGs emissions have been in practice in many parts of the world since the 1970s. Aldy and Stavins (2011) discuss three ways for curbing GHG emissions; (1) by mandating businesses and individuals to change their behavior regarding technology choices which translate into emissions; (2) by subsidizing businesses and individuals to invest in innovation and encourage use of cleaner goods and services; or (3) by putting a price on the greenhouse gas externality, to internalize the cost of the externality.

Of these three options, option (1) falls under command and control regulation, where firms are forced by governments to share the burden of the externality irrespective of its cost to them by setting technology or performance standards that the firms have to abide by. Although such standards may be effective in limiting emissions, the cost of compliance varies greatly from firm to firm based on its existing production processes and state of capital stock, leading to very expensive and inefficient processes to control emissions. Another disadvantage associated with command and control regulation is that it does not provide any incentives for innovation since the firm does not benefit from reducing emissions below what's mandated (Portney & Robert, 2000, p. 33).

Pricing carbon, on the other hand, is a market based instrument which can inherently influence behaviour through market signals and eliminate the need for mandated behaviour. A price measure puts a price on each tonne of CO_2 emitted and therefore provides a strong incentive for innovation to develop alternative, cheaper and cleaner technologies that lead to environmental and health benefits to the local economy while also generating revenue for the government that could further facilitate funding for research in clean technologies or rectify any distortions caused by the policy through revenue recycling mechanisms. The market based approach leads to the most efficient allocation of resources at the lowest cost to society since it is in the best interest of individuals and firms to opt for technology decisions and investments that reduce emissions at least cost to them (Stavins, 1998).

According to World Bank estimates, over 40 national and 20 sub-national jurisdictions, in both developed and developing countries have either adopted a carbon pricing scheme or are considering it (World Bank, 2013).Currently the cumulative impact for carbon mitigation policies in all these countries and regions only amounts to 7 percent of global emissions, however, World Bank estimates if domestic coverage of such mechanism in developed countries is extended to include a greater range of emission sources, and if emerging markets go ahead with the planned carbon mitigation initiatives, then almost half of global emissions could be priced (OECD, 2013, p. 11). A number of policy tools incorporate carbon pricing, such as carbon taxes, emissions trading systems or cap and trade, emission reduction credits, and fossil fuel subsidy reduction (Aldy & Stavins, 2011) along with a variety of hybrid combinations of these different alternatives which have also been employed in some cases. Of these, the most prevalent carbon pricing instruments are carbon taxes and cap and trade systems, which are discussed in further detail below.

2.1 Cap and Trade

Cap and Trade is a market-based instrument that controls environmental degradation by fixing the aggregate level of pollution and translating it into a limited number of tradable permits. The cumulative emissions allowance of the tradable permits corresponds to the emissions cap. This ensures that emissions do not exceed this maximum limit or cap. Distribution of permits can be done either through the process of auctioning, in which the government receives the revenue from the sale of permits, or through the process of free allocation of permits based on a firm's historical emissions, called grand fathering.

After the initial distribution of permits, a firm that emit beyond its allowance has to purchase additional permits to cover its emissions, whereas firms that emit below their allowance can sell their excess permits to others. This way, firms that face a lower cost of reducing emissions would have an incentive to take on added reductions, so that they can sell their excess permits to other firms that have a relatively higher control cost (Olmstead & Stavins, 2011). As each permit is tradable, it corresponds to a monetary value in the carbon market. In case of free allocation of permits, this is equivalent to a transfer of wealth amounting to the worth of the allocated permits to each firm, whereas in the case of auctioning, the government is the recipient of this wealth.

A cap can be designed on an annual basis or for a period of time. A cap extending to several time periods allows firms to save allowances for future use, rather than selling. This phenomenon is called allowance banking. A firm may also borrow from future allowances to cover current emissions, in cases where the cost of future abatement is lower relative to current cost. This mechanism of banking and borrowing leads to the most cost-effective allocation of allowances in the long run (Aldy & Stavins, 2011).

One disadvantage of the cap and trade system is cost uncertainty of the permits. Price uncertainty could jeopardize political support for environmental policies, therefore different cost containment tools are incorporated into the cap and trade system. These include offsets, allowance banking and borrowing, safety valves, and price collars. Offsets allow firms to write off some of their emissions if they undertake measures to mitigate some other pollutants not covered by the cap and trade system. Similar to banking and borrowing, offsets allow firms to reduce emissions at least cost by introducing this flexibility to reduce certain types of emissions, at the time when it is least costly to do so. Other cost containment methods such as safety valves and price collars bind the costs faced by a firm in meeting the emissions cap and reduces cost uncertainty of the permits, however, these measure also reduce the certainty of staying within the emissions cap. (Aldy & Stavins, 2011).

2.2 Carbon Taxes

The theoretical basis behind using a carbon tax as a policy tool is that whenever the consumption of a certain good results in a negative externality whose cost is not internalized in the price of the good, than putting a tax on the good leads to improved social welfare as the resulting demand would then be responsive to the price inclusive of the cost of the externality. The optimal social welfare would be achieved at a tax level which would equate the marginal benefit provided by consumption of the good to the marginal cost of the good inclusive of the external damage it would result in. However, due to the considerable difficulty and lack of consensus in measurement of the marginal cost of damage, an alternative proposed by Baumol and Oats (1971) is to first develop standards to the acceptable limits of the externality and then implement policies to contain the damage within the pre-established limits. This have been shown as an effective means of reducing environmental externalities at least cost to the society and has become a standard approach in the design of environmental regulations enacted internationally (Ekins & Baker, 2002). The IPCC carbon budget of 1000 Giga Tonnes of GHG emissions, global temperature containment limit of within 2°C relative to 1990, and the international obligation for member countries to reduce emissions down to the 1990 levels are examples of such standards that serve as targets for policy performance.

A carbon tax could be set in terms of dollars per tonne of CO2 emissions (or CO2-equivalent of greenhouse gas emissions) by sources covered in the tax base, for example the Alberta carbon tax which applies only to big industrial emitters with emissions exceeding 100,000 Tonnes (CCEMC, 2013); it requires such big emitters to reduce emissions intensity by 12 percent below their 2004-2005 baseline or pay $15 per tonne of carbon equivalent emissions if firms exceed this target. Alternatively, the tax could be applied according to the carbon content of fuels used, with dirtier fuels like coal taxed at a higher rate relative to cleaner fuels like natural gas. It has been widely recognized that in order to be efficient, the carbon tax has to cover all possible sources, with the least number of exemptions. This would generate incentives that would move to equalize the marginal cost of abatement among all emitters (Ekins & Baker, 2002).

A carbon tax can be implemented either upstream, at the point of production/import, for example a tax on suppliers like coal mines and energy companies for each tonne of carbon equivalent emissions that they produce or import. The carbon tax in Quebec is an example of an upstream tax. As the production cost for the suppliers increases in response to the tax, the additional cost trickles down the supply chain to the consumers in the form of higher prices. This negatively effects demand and triggers fuel switching behavior on part of customers that in turn creates incentives for suppliers to invest in cleaner technologies. An advantage of upstream taxation is administrative ease, as it is collected from fewer entities, for instance, only suppliers, instead of every economic agent consuming fossil fuels. Also, it captures a majority of the emissions, since instead of accounting for emissions at the points of occurrence, which could be many thousands, it is easier to account for the amount of fuel produced at the source and estimate emissions from its known chemical composition and molecular breakdown during combustion. Alby and Stavins (2011) estimate an upstream carbon tax would be able to cover 98 percent of US emissions. The carbon tax can also be implemented downstream, or at the point of purchase or consumption. This has an equivalent effect of creating fuel switching incentives for consumers in favour of cleaner, low carbon fuels, in response to the higher fuel prices. The reduced demand of heavy fuels also incentivizes investment in clean alternatives on part of the suppliers, automakers, etc., that would serve to reduce future GHG emissions.

If the move towards a carbon tax is well planned and well-advertised, an economy with rational agents would adjust their expectations accordingly and as such, the carbon tax would serve to provide price certainty by fixing the cost of abatement and reinforces confidence in investment decisions. A carbon tax cannot however ensure a certain level of emissions, since that would depend of the consumers' respective price elasticity of demand, unlike emissions trading, which ensures an emissions cap, but provides no certainty about the price of carbon, allowing it to fluctuate in response to the economic climate. Since the environment is a shared resource and the emissions once released into the atmosphere, stay there for prolonged periods of time, this accumulation of the GHGs results in environmental damage that is increasing as a function of time, with each additional tonnes of emissions causing more damage than the last one. Thus, an efficient carbon tax needs to accommodate these changes by increasing the tax rate over time to cover the incrementally rising cost of abatement. (Zhanga & Baranzini, 2004).

Carbon tax is a revenue generating instrument and its impact on the economy largely depends on how this revenue is utilized. There are several research papers that report revenue recycling as a means to mitigate the tax burden resulting from the carbon tax itself, or to reduce other distortionary taxes on labor and capital, to compensate for any negative impacts on economic activity. The revenue can be used to compensate individuals or industries that are disproportionately impacted by the tax, such as low income households whose energy expenditure makes up for a relatively high percentage of disposable income, or energy-intensive sectors, whose production costs would rise substantially and negatively impact their regional competitiveness. The revenue could also be used to invest in cleaner technologies and R&D to ensure future emissions mitigation. (Goulder & Parry, 2008)

Theoretically, the two carbon containment methods are equivalent. Weitzman, (1971) argues that price and quantity can both be theoretically used as equivalent modes of control under full information and certainty, since incentives of profit maximization under a price control are essentially the same as those for cost minimization under a quantity control. However, under uncertainty, the price and quantity signals are transmitted in different ways, depending on the degree of uncertainty about marginal damage curves and their correlation with marginal abatement cost curves. Carbon taxes and auctioned permits can both achieve an efficient emissions target, with least cost to society and generate revenue for the government that could be used to compensate groups disadvantaged by the tax, correct distortions introduced by other labor or capital taxes, pay down deficits, or further invest in R&D to develop cleaner energy alternatives.

3. International Literature on Carbon tax research

Recognizing the immense threat posed by the effect of greenhouse gases on climate change in terms of rising ocean temperatures, habitat shrinkage and extreme whether events around the world, many countries have either implemented or are in the process of formulating price-based regulations and taxes to curb GHG emissions and to fulfill their Kyoto obligations. In countries that are yet to implement a containment policy, the research is based on simulations using a hypothetical carbon tax, while research from countries with greater experience with the tax evaluates its impact based on actual post carbon tax data.

Simulation based research

The Australian government introduced a carbon tax in July 2012 at a price of $10 per tonnes of CO, with plans to later convert into an emissions trading scheme. Since the tax is quite new, there is no data available at the Meng, Siriwardana and McNeill (2013)simulate the effects of a carbon tax of A$23 per tonne of carbon dioxide on the environment and on the economy using a Computed General Equilibrium (CGE) Model, as proposed by the government with, and without, a compensation policy. The simulation results show that a carbon tax of A$23 per tonne of CO_2-eq could reduce emissions effectively, but would result in a mild economic contraction, and that the proposed compensation plan would successfully mitigate the negative effects of a carbon tax on the economy. Emission reduction is estimated around 12 percent in the short-run. Since the tax does not cover land transport, agriculture and the household sectors, which are the biggest emitting sectors, the total emission reduction are achieved mainly through reductions in stationary emissions. However, the economy contracts mildly under a carbon tax as measured by real GDP (-0.59%) and real GNE (-0.09%).

Japan also introduced a carbon tax in October 2012 at a rate of 289JPY which applies to fossil fuels in accordance with their carbon content. We are unaware of any recent research conducted with one year of post carbon tax data, however in an earlier research paper Goto (1995) examines the macroeconomic costs and sectoral impacts of carbon taxation in a general equilibrium framework, showing that, if the economy adjusts efficiently, the macroeconomic costs are not very large. The simulation results estimate the abatement costs to stabilize annual CO_2 emissions at the 1990 level to be around 0.1 percent of GNP on average during the next 20 years. However, the carbon tax rate required to achieve this target is very high, nearly US$200/tonne C. The paper finds that carbon taxes might impose widely distributive economic burdens among industrial sectors or firms, due to one or more input not being substitutable in the short run, which adds to abatement costs. The numerical results illustrate sectoral impact ranging from nearly zero (construction) to more than 9 percent (steel) after-tax revenue losses relative to the baseline under the stated reduction target.

Wissema and Dellink (2007) use an applied CGE model to estimate the impact of a carbon tax on the economy, welfare and emissions in Ireland. They find that the cost of the carbon tax will be low in terms of welfare, a decline of less than 1 percent, even at a tax rate of 30 euro/tonne of CO_2 eq emissions. Sectors with a high CO_2 emission intensity are found to suffer substantially from cost increases and decreased demand, with the exception of Metal Products, Chemical and Textiles sectors. The macroeconomic impact of the carbon tax is not found to be very strong, while consumption pattern changes are clearly observed due to changes in relative prices as demand shifts from fuels with a high emission factor to energy sources with a lower carbon-intensity and from energy to other commodities.

Labandeira, Labeaga and Rodríguez, (2004) conducted a comprehensive analysis of the efficiency and distributive effects of green tax reforms (GRT) in Spain. A hypothetical revenue neutral GTR, in the form of a carbon tax on CO_2 emissions and a simultaneous reduction in payroll taxes by employers (social security contributions), is simulated to assess its environmental, economic and distributional consequences on the Spanish economy. The methodology combines the use of a static general equilibrium model, to capture the effects of tax on different economic sectors, with a microeconomic household energy demand model that assesses welfare implications. Reported results indicate a strong double dividend, with a GTR of 12.3 euro tax per tonne of CO_2 significantly reducing emissions of that pollutant in Spain alongside a reduction in the existing distortions created by the tax system. Employment and social welfare experience a slight increase. The effects of the GTR on production and prices are not homogenous, with activity in energy-intensive sectors being reduced while that in other sectors increases. Prices in energy-intensive sectors show a moderate rise, whereas other important goods for the household are slightly reduced. The paper concludes that it is possible to achieve a reduction in carbon dioxide emissions in Spain by means of a GTR, while simultaneously achieve an improvement of non-environmental social welfare at a rather low distributional cost.

Zhang (2008) uses a time-recursive dynamic CGE model for the Chinese economy, assuming a non-neutral carbon tax, to analyze the economic implications of a 20 percent and 30 percent reduction in China's CO_2 emissions in 2010 respectively, relative to the baseline. Under the two scenarios, China's

GNP in 2010 drops by 1.5 percent and 2.8 percent, with welfare decreasing by 1.1 and 1.8 percent, respectively, relative to the baseline. GNP is found to decline in nine of the ten sectors studied, the only exception being the services sector. Natural Gas and coal are the hardest hit sectors with gross output declining by 21 percent and 26 percent respectively. On average, all sectors experienced a drop of 1.5 percent and 1.9 percent under the two scenarios respectively. The study concludes that a greater reduction in CO_2, emissions will require a higher carbon tax, implying higher prices of fossil fuels, with the tax rate and consequently fuel prices, rising even higher as the emissions targets becomes more stringent, supporting other global studies that recognize China would be one of the regions hardest hit by carbon limits.

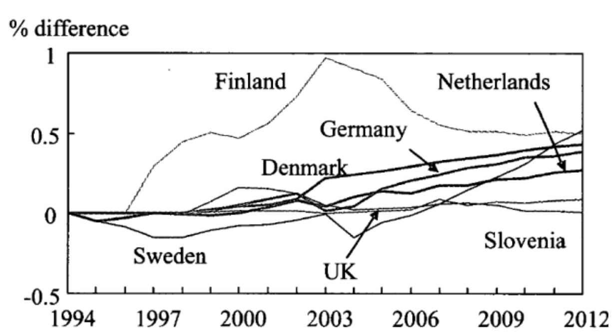
Experience based research

Bruvoll and Larsen (2004) apply a disaggregated applied general equilibrium model (AGE) model of the Norwegian economy to perform a counterfactual analysis and compare the model simulations for 1999 with and without carbon taxes, and further decompose the estimates obtained into explanatory factors such as policy measures, technological progress, fuel substitution and so on. The analysis finds the most contributive factors in emissions reduction are changes in energy intensity and energy mix, which collectively reduced emissions by 14 percent from 1990 to1999. Despite having one of the highest carbon tax rate in the world, the resulting emissions reduction in Norway attributed to the tax itself was very low. This is because the carbon tax rates applied to fuels and fuel extraction were high (10-51US$ per tonne), while on the other hand, several high emitting industries and sectors such as the metal and cement production processes were partly or fully exempt from the carbon tax, resulting in a carbon tax contributed reduction in emissions of merely 2.3 percent. The study therefore recommends that for a carbon tax to achieve emission reduction at least cost, it has to be broad-based and uniformly applied to all GHG emission sources.

Sweden was one of the first countries to implement a carbon tax in 1990. At the time the same tax rate applied to households and industries. Later the industrial tax was reduced due to competitiveness concerns and is currently about half of the household tax rate. Andersen (2004) found that CO_2 emissions in Sweden fell by just 0.8 million tonne from 1991-2000. He cites two studies by the Swedish energy agency. The first uses a MARKAL energy model to compute the impact of the carbon tax on CO_2 emissions and finds a 3-5 percent decline in emissions level from 1990-1994, relative to the scenario is which the carbon tax policy would not have been implemented. In a follow up study, which was designed to include all sectors, with the exception of transport, and was more inclusive in terms of greater field experts participation, the Swedish environmental protection agency found that an emissions reduction of 19 percent had been achieved between 1987-1994, of which about 10 percent were attributable to the implementation of the carbon tax in 1990. However, if the transport sector was also taken into account, the reductions attributed to the carbon tax were drastically reduced to about 3-5 percent.

In Denmark, the CO_2 tax was enforced in 1992; however, industrial processes were exempt for the first year. The timing of the decoupling of energy consumption and CO_2 emissions is noted to be the same as when industrial processes were included into the tax base (Enevoldsen M. , 1998). Denmark redistributes 20 percent of revenue generated by the carbon tax on industry to invest in technological and energy efficiency improvement initiatives. Enevoldsen (2000) found a strong decoupling of emissions and output growth in Denmark, reporting a 27 percent growth in output and 7 percent decline is emissions from 1991-1997. The Danish government estimates to have decreased emissions by about 12 percent, between 1990 and 2000, when corrected for electricity exports. Anderson (2004) cites a survey conducted by Shopley and Brasseur (1996) to access the impact of the tax on company management through interviews with a small sample of companies. Most companies reported a reduction in energy consumption of 20 percent or more with no effects on employment levels. The difference in the Danish experience with the carbon tax versus other Nordic countries could be due to its industrial energy consumption switching to cleaner technologies and the revenue redistribution components used to fund clean energy research (Andersen, 2004). In a broader analysis including seven European countries, Anderson (2008) finds that the countries included in the analysis (Sweden, Norway, Finland, Denmark, Slovenia, Germany and the UK) did not suffer from any harsh impact on GDP from the environmental tax, estimating the difference to be between -0.5 and 1 percent.

Figure 1 GDP Impact of the Carbon Tax in Europe



Note(s) : % difference is the difference between the base case and the cou nterfactual reference case.

Source: (Andersen, 2008, p. 75)

4. The BC Carbon Tax

The introduction of the carbon tax is part of British Columbia's Climate Action plan that aims for a 33 percent reduction in the province's emissions relative to 2007 levels by 2020. The province implemented its broad-based, revenue-neutral carbon tax on July 1, 2008, at a tax level of $10 per tonne of CO_2, with scheduled increments of $5 per-tonne, to follow each year until the final increase took effect on July 1, 2012, fixing the tax rate at $30 per-tonne. The gradual increments in the tax rate were introduced intentionally in order to give industry and household consumers enough time to adjust to the tax in terms of reduced consumption and explore fuel switching options (Ministry of Finance, British Columbia, 2012). The tax covers 70 percent of all emissions from fossil fuel combustion that are captured by the National Inventory Report. [1] All fossil fuels consumed by industrial as well as business and household consumers in the province are taxed according to the carbon content of the fuel. Table 1 presents details on the rates of selective fuels effective as of July 2012.

Table 1 Carbon tax rates for selected fuel types in BC

	Unit	Tax Rate Effective July 1, 2012
Gasoline	¢/litre	6.67
Diesel (light fuel oil)	¢/litre	7.67
Jet Fuel	¢/litre	7.83
Natural Gas	¢/cubic metre	5.70
Propane	¢/litre	4.62
Coal - high heat value	$/tonne	62.31
Coal - low heat value	$/tonne	53.31

Source: (Ministry of Finance, British Columbia, 2012)

The tax is designed with the sole purpose of reducing BC emissions by encouraging fuel consumers to use less fossil fuel and reduce their greenhouse gas emissions through providing a price incentive to opt for cleaner alternatives. Users who continue to use dirty fuels are made to pay a higher price for the fuel to incorporate for the amount of emissions their consumption would result in. The revenue neutral component of the tax means that all revenue collected under the carbon tax is redistributed to British Columbians through reductions in other taxes, with no net monetary gain for the BC government. The government is required by law, to show through a legislated three-year plan, how the carbon tax revenue flows back to individuals and businesses as tax reductions. Measures for revenue redistribution include income tax credits for low income individuals (Low Income Climate Action Tax Credit.), reducing

[1] Exceptions being emissions from: non-energy agricultural uses and waste (10%); fugitive emissions which cannot be measured accurately (10%); non-combustion industrial process emissions (6%); net deforestation(5%).

the personal income tax rates for the first two income brackets by 5 percent, providing remote and northern users benefits of up to $200 annually to account for their higher expenditure on transport and/or heating (Northern and Rural Area Homeowner Benefit), and reduction in business taxes (Government of British Columbia, 2008).

Carbon tax revenues for 2011/12 were $959 million, whereas revenue reduction due to redistribution measures was estimated to be 1141 million, resulting in a net tax benefit for 182 million to British Columbians. For the 2012/13 fiscal year, the tax reductions are expected to return $260 million more to taxpayers than the amount of carbon tax paid. (Government of British Columbia, 2013). In addition to the carbon tax, British Columbia is working with partners in the Western Climate Initiative (WCI) to develop a regional cap and trade system, which will work together with the carbon tax to reduce emissions and ensure BC's competiveness in the carbon trading marketplace, although the government has not yet outlined how the two systems will be coordinated.

Between 2007 and 2011, the province has experienced a 5.59 percent decline in total emissions, whereas on a per capita basis, the reduction has been much more substantial, at 11.1 percent. The government estimates that by 2020, the carbon tax will reduce British Columbia's CO_2 emissions by approximately 3 million tonnes annually (Government of British Columbia, 2008). Sustainable Prosperity (2012) reports that between 2008 and 2011, BC's GDP slightly outpaced growth in the rest of Canada, while its per capita emissions went down 5.3 percent more relative to the rest of Canada. However these statistics are based on simple calculations and cannot be used to establish causality with the carbon tax without a through econometric analysis which would control for other simultaneous event that also affected economic activity in the province, such as the financial crisis of 2008 and the Winter Olympics in 2010. In the following section, we apply a difference-in differences model to sectoral GDP and sectoral emissions in British Columbia, using the rest of Canada as a control group, in order to quantify the impact of the carbon tax on sectoral output and emissions.

5. Methodology and Data

5.1 Difference in Difference Analysis

Difference in difference analysis has been widely applied to what economists call "natural experiments" that examine the outcome of interest in response to an exogenous treatment (i.e. the source of variation in the explanatory variables is from an exogenous source), by comparing observations in groups exposed to the treatment, and comparison groups, which were left untreated. Opportunities for such natural experiments can arise in the aftermath of policy changes, government randomization or biological or physical events that affect some groups, and not others (Meyer, 1995). Since economics itself is not an experimental science, it seeks instances of random assignments in history to conduct these so called natural experiments (Whited, 2007). The BC carbon tax is another example of such an exogenous policy change since it was implemented fairly quickly and was largely unexpected by BC residents at the time it was implemented (Harrison, 2012).

Difference in difference analysis is an empirical technique used to quantify the effect of a exogenous treatment, e.g. a certain policy change, by analysing the before and after trends in a group which receives the treatment and compared to trend observed in a "control" group, otherwise identical to the treatment group, except it did not receive the treatment. The underlying assumption being that of a "parallel trend" i.e. the treatment group would have continued on the same trend as the control group if it were not for the treatment effect (Meyer, 1995).

There are numerous studies by social, political and clinical scientists that employ this design framework for deriving causal inference for the treatment from a sharp, exogenous policy change. Examples include Li and Zhang (2011) who study the impact of China's one child policy on the gender ratio in the Han ethic group, Dale and Krueger (2002) investigate the effect of going to college on lifetime earnings, Slaughter, (1998) analyses the contribution of international trade on per capita income convergence across countries, (Alatas & Cameron, 2003) study the impact of increases in minimum wages on employment in Indonesia. Further examples can be found in Greene (2012) and Meyer (1995), a very famous one is Card and Krueger (1994) in which the authors examine the effects of an increase in the New Jersey state minimum wage on employment. Their sample consists of fast-food restaurants from four chains in New Jersey before (year = 0) and after (year = 1) the increase in the minimum wage. As a control group, they examined employment at a sample of similar restaurants in Pennsylvania over the same time period. The sample from Pennsylvania (treatment = 0) is assumed to follow the same set of changes over time as the sample for New Jersey, except that Pennsylvania did not receive the treatment, i.e. change in the minimum wage. The study found a positive, although not statistically significant difference in difference coefficient, suggesting for the first time that increase in minimum wage does not necessarily have an adverse effect on employment.

Difference in differences model can be estimated using regression analysis in the following basic equation:

$Y_{it} = \beta_0 + \beta_{1i} D_i + \beta_{2t} D_t + \beta_3 D_i{*}D_t + e_i$

Where Y_{it} is the dependent variable in group 'i' at time 't'. D_i is a dummy variable which assumes the value 1 for groups that undergo treatment, and zero for untreated groups. D_t is also a dummy variable which assumes a value of 1 for years after the treatment and zero for years prior to the treatment. Here e_i is white noise. If the treatment is exogenous, then e_i will be uncorrelated with D_i and D_t. Our coefficient of interest is the coefficient of the interaction term ($D_i{*}D_t$), β_3, as it uses the difference in means between treatment and control group, pre and post-treatment as the estimate of the treatment effect. The following table is generated by substituting ones and zeroes in the above equation and demonstrates what the difference-in-difference estimator β_3 captures.

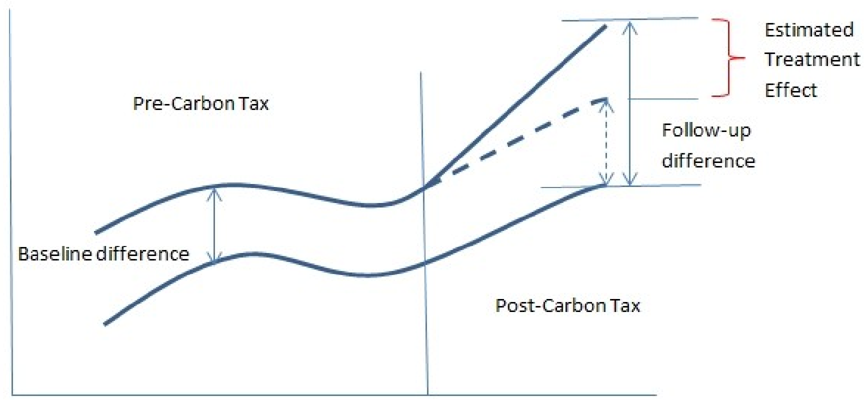
Table 2 Breakdown of the difference and difference analysis

	Expected Value Pre-treatment	**Expected Value Post-treatment**	**Difference**
Treatment group	$\beta_0 + \beta_1$	$\beta_0 + \beta_1 + \beta_2 + \beta_3$	$\beta_2 + \beta_3$
Control group	β_0	$\beta_0 + \beta_2$	β_2
	β_1 (Baseline difference)	$\beta_1 + \beta_3$ (Follow-up difference)	**β_3 (Difference-in-Differences)**

Here β_1 is the baseline gap between control and treatment groups, $\beta_1 + \beta_3$ is the follow up gap between the two groups. Hence the ratio β_3/β_1 measures the change in the gap between treatment and control groups resulting from the treatment. Since the control group is assumed to carry on the same pre-treatment path, an increase in the gap signifies a positive treatment effect for the treatment group, whereas a decrease in the gap means the treatment effect has been negative.

Graphical equivalent of the above is illustrated in Figure 2 below:

Figure 2 Illustration of the Treatment Effect using Diff-in-Diff Analysis



Adapted from: Angrist and Pischke, (2008, p. 172)

Suppose if we only considered the difference in the treatment group (β_2 +β_3), this would overestimate the treatment effect due to the presence of the time trend (β_2). Differencing with a control group therefore eliminates this time trend and allows for better isolation of the treatment effect (Albouy).

These differences can be calculated using observed data; however using regression allows us to add control variables that would help to control for other demographic, geographic, and socioeconomic characteristics and would result in a more efficient difference-in-difference estimators. Even if the added control variables do not lend much explanatory power to the model, they help to reduce the potential for omitted variables bias. A typical diff-in-diff model including control covariates is as follows:

$$Y_{it} = \beta_0 + \beta_{1i} D_i + \beta_{2t} D_t + \beta_3 D_i{*}D_t + \delta_1 X_1 + \delta_2 X_2 + \ldots.\delta_n X_n + e_i$$

where X_i are additional control variables; assumption being that their coefficients are similar for both treatment and control groups.

5.2 Data

GDP Analysis: The GDP data used in the analysis has been obtained from statistics Canada CANSIM Table 379-0025 and 379-0026 which reports Real GDP in millions of chained $2002, disaggregated by province and by Industrial NAICS nodes, covering 119 sectors, subsectors and special aggregates from 1997-2011.

Choice of control variables for GDP analysis: Since the same set of covariates is being applied to all 119 sectors, the choice has been restricted to general factors affecting the GDP, instead of sector specific choices. Provincial employment data has been obtained from statistics Canada CANSIM Table 281-0024 and reports number of persons with full-time or part-time employment in each province. Multifactor productivity at the provincial level has been obtained from statistics Canada CANSIM Table 383-0026 and reports the ratio of real GDP to combined labour and capital inputs, for each province from 1997-2011. It serves as a technological factor as it incorporates the effect of efficiency of input use on GDP and is a significant contributor to GDP growth. Consumption of fixed capital as measured by straight line depreciation has been obtained from Statistics Canada's CANSIM Table 031-0004. This control variable has been used following Bobinaite, Juozapaviciene & Konstantinaviciute, (2011) who found consumption of fixed capital to be a significant determinant of GDP. Investment is one of the basic components of GDP and is included as a control variable here following Josheski (2008) and Bobinaite, Juozapaviciene & Konstantinaviciute, (2011)

Emissions Analysis: GHG Emissions data has been obtained by the Environment Canada's National Inventory Reports, which include total GHG emissions by province in K-tonnes of CO_2equivalent units.

Choice of Control Variables for emissions analysis: The selection of control variables in this part of the analysis closely follows the approach by Lin & Li (2011). Energy intensity in the province (Energy use per unit of GDP) has been selected as a control variable following Wang et al. (2005) and Bruvoll & Larsen (2004) who found energy intensity to be a significant technological factor in emissions reduction. Robinson (1990) also argues that decreasing energy intensity offers the greatest potential for higher energy efficiency in Canada, and hence would play a crucial role in reducing CO_2 emissions. The variable has been compiled as a ratio of Provincial energy use in terajoules to the aggregate provincial GDP in million $. Energy use data has been compiled from the Stats Canada Reports on Energy Supply and Demand in Canada. A similar calculation has been employed by Nyboer & Kniewasser (2012). Energy Mix used in the province (Primary electricity, nuclear and hydro energy/ total energy use) is another variable included following Bruvoll & Larsen (2004)who found that the energy mix contributed to 5.1 percent reduction in CO_2 emissions in Norway. Since natural gas and petroleum products are used for electricity generation in many provinces, another control variable added to the analysis is electricity generated by fossil fuels in the province. Data source for these two variables is once again Stats Canada Reports on Energy Supply and Demand. Provincial GDP is another control added to the regression analysis following Bruvoll & Larsen (2004). Lane (2013) found that the intermediating link between total GDP and total emissions is energy consumption. Doda (2013) categorized Canada to the group of countries where relationship between emissions and GDP is stronger in periods of economic decline, similar to the financial crisis to 2008. Hence using GDP as a control will better help isolate the impact of the carbon tax which was implemented in a period of GDP decline. The Industry structure variable has been formulated by computing the proportion of provincial GDP that comes from the service industry. The reason this variable is included is based on the premise that as the service proportion of GDP rises, the goods and hence industrial proportion will fall, contributing to a decline is emissions that would have resulted from the industrial processes. Lin & Li, (2011) included this variable in their analysis of the impact of a carbon tax on emissions in the European countries and found it to be a significant contributor to emissions reduction in Netherland, Norway and Sweden. The paper also cites Joberta, Karanfil, & Tykhonenko (2010) to have found a significant impact of industry structure on per capita emissions.

5.3 Model

Estimation Equation for measuring the impact of the BC Carbon Tax on Sectoral GDP:

$$Y_{it} = \beta_0 + \beta_i d_i + \beta_t d_{year} + \delta_0\, d_{tax} + \delta_1\, X1_{it} + \delta_2\, X2_{it} + \delta_3\, X3_{it} + \delta_4\, X4_{it} + u_{it}$$

Where subscript *'i'* represent Canadian provinces and would vary from 1 to 13 and subscript *'t'* represents time in years and would vary from 1997 to 2011.

Y_{it} = Sectoral GDP

D_i= Represents a 13 dummy variables, one for each province and territory to account for province specific fixed effects.

d_{year}= Represents 15 dummy variable, one for each year from 1997-2011 to account for time specific fixed effects.

d_{tax} = is the interaction terms dummy with a value of 1 for BC, only in the post-carbon tax period 2008-2011. Its coefficient δ_0 is of interest to us as it estimates the average annual difference-in-difference between the sectoral GDP of BC and other Canadian Provinces before and after 2008.

$$\delta_0 = \underbrace{[E(Y|BC, Year>2007) - E(Y|RoC, Year>2007)}_{\text{Follow-up difference}} - \underbrace{E(Y|BC, Year<=2007) - E(Y|RoC, Year<=2007)]}_{\text{Baseline difference}}$$

Follow-up difference between BC's GDP and the Rest of Canada average GDP after 2008 (Carbon tax implementation year)

Baseline difference between BC's GDP and the Rest of Canada average GDP before 2008 (Carbon tax implementation year)

Additional Explanatory variables are added to increase the precision of the DD estimator as follows:

X1= Employment level in the province (number of persons employed)

X2= Investment in the province (Value of net capital stock using straight line depreciation)

X3= Multifactor productivity in the province (Ratio of real GDP to combined labour and capital inputs)

X4 = Consumption of fixed capital in the province (Straight line depreciation)

Estimation Equation for measuring the impact of the BC Carbon Tax on Sectoral GHG Emissions:

$GHG_{it} = Y_{it} = \beta_0 + \beta_i d_i + \beta_t d_{year} + \delta_0\, d_{tax} + \delta_1\, Z1_{it} + \delta_2\, Z2_{it} + \delta_3\, Z3_{it} + u_{it}$

Where subscript 'i' represent Canadian provinces and would vary from 1 to 12, (emissions data for Northwest Territories and Nunavut has been grouped), and subscript 't' represents time in years and would vary from 1990 to 2011.

GHG_{it} = Sectoral Emission, here the sectoral breakdown is not according to NAICS, rather follows the reporting structure for IPCC.

d_i= Represents a 12 dummy variables, one for each province and territory to account for province specific fixed effects.

d_{year}= Represents 21 dummy variable, one for each year from 1990-2011 to account for time specific fixed effects.

d_{tax} = is the interaction terms dummy with a value of 1 for BC, only in the post-carbon tax period 2008-2011. Its coefficient δ_0 is of interest to us as it estimates the average annual difference-in-difference between the sectoral GHG emissions of BC and other Canadian Provinces before and after 2008.

δ_0=[E(GHG|BC, Year>2007)-E(GHG|RoC, Year>2007)–E(GHG|BC, Year<=2007)- E(GHG|RoC,Year<=2007)]

Follow-up difference between BC's GHG emissions and the Rest of Canada average emissions after 2008 (Carbon tax implementation year)

Baseline difference between BC's GHG emissions and the Rest of Canada average emissions before 2008 (Carbon tax implementation year)

Additional Explanatory variables are added to increase the precision of the DD estimator as follows:

Z1 = Provincial GDP

Z2 = Electricity generated by fossil fuels in the province

Z3= Energy intensity in the province (Energy use per unit of GDP)

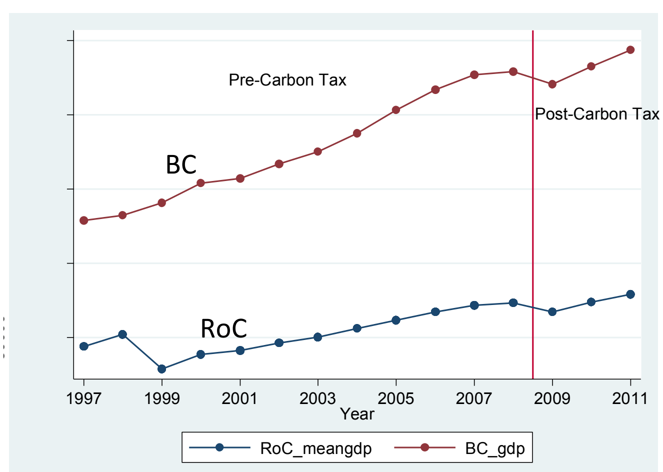
Z4= Energy Mix in the province (Electricity, nuclear and hydro energy/ Total energy use)

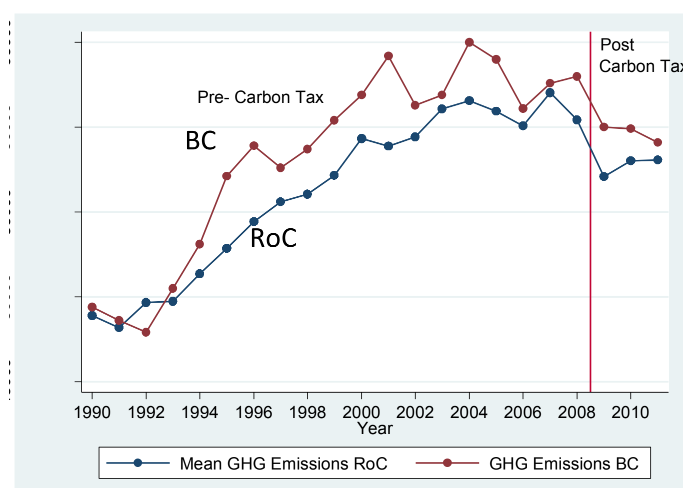
Z5= Industry Structure (GDP in Service Industry/GDP in All Industries)

Selection of Control group

A good counterfactual must satisfy the "Parallel trend assumption", i.e. the selection of control groups should be such that their pre-treatment trend is as similar as possible to the treatment group. Any difference in the trends gap after the treatment is then attributed to the treatment effect. If for example, the trend in the treatment group is more or less steep than the trend in the control group, this would lead to an over or under estimation of the DD estimator. In addition to the parallel trend condition, some other considerations in deciding on a good counterfactual for DD analysis are similarity in the underlying structure of the economies, culture, workforce etc. In our case, we have used all provinces other than British Columbia as controls, along with the three territories. The analysis will thus compare BC to the average of the thirteen control groups, pre and post treatment in order to estimate the treatment effect of the carbon tax. Figure 3 below compares the two Real GDP and GHG emissions trends. We observe that the two trends are similar before the treatment, although there is a slight difference in slopes. This is the case for aggregate GDP, however, our analysis involves 119 sectors and subsectors and the assumption of parallel trend may not be valid for all of them, in which case, difference-in difference will not be a suitable technique to measure the treatment effect. The same holds for the 59 sectors we observe in the GHG emissions analysis. Trend comparisons for individual sectors are included in the appendix.

Figure 3 Trend comparison between BC and Rest of Canada





5.4 Empirical analysis

Estimation using Stata can be conducted in two ways, one by using the Least squares Dummy Variable (LSDV) model and incorporating dummy variables to capture the two-way time and group fixed effects. The Fixed Effects design is a generalization of the Diff-in-Diff approach (Barry, 2011). Another is to use the in-built *diff* command which allows addition of two-way fixed effects as covariates and outputs differences for both treatment and control groups, along with the DD estimator. This facilitates the computation of relative changes before and after the treatment in the presence of covariates, which is not possible in LSDV, as it only reports a DD estimate. Group fixed effects filter out observed and unobserved variation within the provinces that is constant over time, or time-invariant. Similarly time fixed effects filter out all observed and unobserved variation over time which is common to all provinces. Employing two-way fixed effects greatly reduces the omitted variable bias that may be caused by unobserved time-invariant group variables or group-invariant time variables, leaving behind only the possibility of omitted variables that vary with time with in each province, which can be further reduced by adding covariates to the model (Z and X variables). The model includes dummy variables for each group and time period. For our analysis, this means a set of thirteen dummy variables, one each for the Canadian provinces and territories and an additional set of fifteen dummy variables for years 1997-2011. The unobserved individual effects are then captured in the coefficients on dummies for each province while the time effects are captured in the coefficients on time dummies (Angrist & Pischke, 2008). To avoid perfect multicollinearity or the "dummy variable trap", one dummy from both province and time sets is dropped. The regression controls for heteroskadasticity in standard errors by using the vce(robust) command in stata.

6. Results and Discussion

6.1 GDP

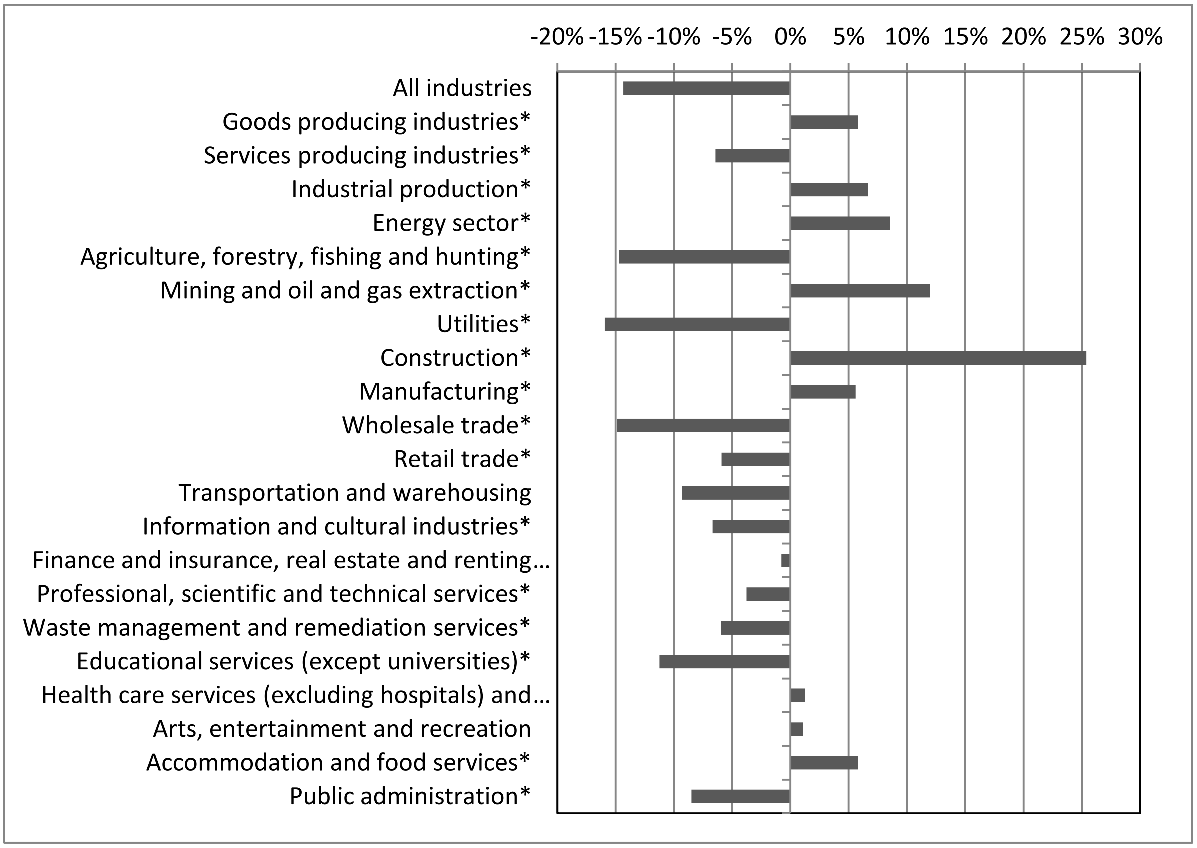
The GDP regression results indicate a statistically significant impact on 58 of the 119 sectors analyzed. Table 4 illustrates the difference in difference estimator coefficients as a percent change from the baseline difference[2] between BC and the rest of Canada, for major NAICS sectors. Aggregate GDP is seen to have declined by CAD $1.25 Billion or 14 percent relative to the baseline[3]; however the coefficient is not statistically significant. This is not to say that the GDP in BC declined by 14 percent relative to the pre carbon tax level, rather, the average gap between the GDP of BC and the rest of Canada mean shrank by 14 percent post carbon tax. The number is not huge in absolute terms, as it makes up about 0.8 percent of BC's GDP in 2007 ($150.9 billion) , but the percent change from baseline seems rather large. The negative sign of the carbon tax effect is also as expected and aligns with international experiences. The motivation behind enforcing a carbon tax is to encourage businesses to modify their energy inputs and production processes towards cleaner technologies. However, such a transition is often difficult to perform in the short run due to lack of cost-effective alternatives. Hence businesses find it more feasible to reduce output in the short run, or relocate production facilities to lower tax jurisdictions, resulting in a lower GDP at the provincial level.

At the sectoral level, the largest declines relative to baseline are observed in agriculture, forestry, fishing and hunting, utilities, wholesale trade, transportation and warehousing and public administration. The factors behind the decline experienced by these sectors could stem from reduced competitiveness and profitability as costs of production rises due to higher energy prices. Sectors experiencing the highest gains include construction, mining and oil and gas extraction and manufacturing.

[2] i.e. the pre-carbon tax gap between rest of Canada and British Columbia

[3] The calculation is made by taking the ratio of the DD coefficient to the pre carbon tax difference in GDP between BC and the Rest of Canada average.(i.e. treatment effect/ pre-treatment difference between treatment and control group)

Figure 4 Treatment effect in Sectoral GDP as % change relative to baseline difference



Note: Indicates the carbon tax effect is significant at 10%*

Sectoral GDP Analysis

6.1.1 Agriculture, forestry, fishing and hunting

The estimates obtained for agriculture, forestry, fishing and hunting sector shows one of the most severe negative impacts from the carbon tax at -15 percent and is highly statistically significant at a 90 percent confidence interval.

Table 3 Diff-in-Diff Analysis for the Agriculture, Forestry, Fishing and Hunting Sector

Sector/Sub sector	Diff-in-Diff (Million $)	% change from baseline
Agriculture, forestry, fishing and hunting	-924.716*** (127.4)	-15%
Crop and animal production	-421.5762***(117.6)	-19%
Forestry and logging	-396.5371***(120.2)	-11%
Fishing, hunting and trapping	-32.68813***(8.195)	-34%
Support activities for agriculture and forestry	-128.0481***(14.9)	-24%

*Note 1: *** p<0.01; ** p<0.05; * p<0.1*
Note 2: Robust standard errors are reported in parenthesis

The size of the agriculture sector in BC at the beginning of 2008 was $4.62 billion, therefore an annual decline of 0.9 billion is massive and likely points to an over estimation. The agriculture sector has a high energy requirement as inputs for maintenance of greenhouse temperatures and use of motorized farm equipment, tube wells etc. Since harvesting is highly time sensitive, it is very difficult for the sector to adjust its energy options in the short run. Therefore the negative coefficient estimates from the analysis make sense in terms of incurred losses due to reduced production in response to high energy costs. To compensate for some of the loss, the BC government has initiated a greenhouse carbon tax relief grant program in 2013, following a similar temporary carbon tax rebate in 2012. The grant reimburses 80 percent of the carbon tax paid on natural gas and propane used for greenhouse heating and CO_2 production in commercial greenhouses (Ministry of Agriculture, BC, 2013). Since our analysis is limited to data up till 2011, the effect of these programs has not been captured.

Crop and animal production lost $421.5 million on average; bringing its GDP down 19 percent relative to baseline. Forestry and logging also experienced a 396 million drop in GDP. Fishing, hunting and trapping is also associated with very high energy costs due to consumption of heavy marine fuels, which are more carbon intensive. In addition, transport and storage of crop and animal products including fish and game requires refrigerated means of transportation and warehouses and hence suffer a significant increase in production costs as a consequence of the carbon tax.

6.1.2 Utilities

The Utilities sector also indicates a statistically significant GDP decline of $441 million or 16 percent relative to baseline. The utilities sector reported a GDP of $3.27 billion in 2007, which indicates a decline of 12 percent relative to the pre-tax level. This is expected as electricity generation is highly energy intensive and large quantities of electricity are produced by burning fossil fuels such as coal and natural gas.

Table 4 Diff-in-Diff Analysis for the Utilities Sector

Sector/Sub sector	Diff-in-Diff (Million $)	% change from baseline
Utilities[4]	-441.0079***(106.6)	-16%
Electric power generation, transmission	-504.6049***(117.6)	-14%

*Note 1: *** p<0.01; ** p<0.05; * p<0.1*
Note 2: Robust standard errors are reported in parenthesis

[4] No data available for Natural gas distribution and Water, sewage and other systems for BC

Due to the imposition of the carbon tax, a higher cost of production would induce firms to limit production in the short run and move towards cleaner technologies in the medium to long run. A change in natural gas distribution would also be expected, as firms using heavier fossil fuels would substitute towards natural gas which is relatively cleaner than other fossil fuels. However, Statistics Canada supresses GDP data for natural gas due to confidentially reasons, therefore this expectation cannot be verified.

6.1.3 Construction

The regression results show the largest positive impact of the carbon tax in the construction sector at $323.3 million, which is a 25 percent increase from baseline. The construction sector reported a GDP of 9.1 billion in 2007. A DD coefficient measuring $323.3 million therefore represents a moderate 3.5% annual decline relative to the pre-tax level, which presents a sharp contrast compared to the 25 percent decline measured against the baseline. This result is statistically significant at a 10 percent confidence interval. Looking at the subsectors, positive and significant coefficient is obtained for non-residential construction, whereas negative and significant results are seen for repair construction and engineering construction. The sign of the coefficient for non-residential construction is unexpected since all three of these sectors use large amounts of cement, which is known to be a highly carbon intensive product, since its production involves burning tires and other fossil fuels.

Table 5 Diff-in-Diff Analysis for the Construction Sector

Sector/Sub sector	Diff-in-Diff (Million $)	% change from baseline
Construction	323.3081* (176.3)	25%
Residential building construction	87.04738 (125.3)	4%
Non-residential building construction	348.7471***(96.96)	14%
Transportation engineering construction	-140.6254 (84.71)	-15%
Oil and gas engineering construction	364.4545 (302.5)	9%
Electric power engineering construction	79.75772 (92.84)	5%
Communication engineering construction	28.58922 (15.61)	36%
Other engineering construction	-267.9806* (141.2)	-20%
Repair construction	-169.5481***(24.04)	-43%

*Note 1: *** p<0.01; ** p<0.05; * p<0.1*
Note 2: Robust standard errors are reported in parenthesis

A carbon tax should therefore have had a negative impact on the non-residential construction. One explanation for this could be an estimate bias as the regression did not control for the effects of the BC

Winter Olympics in 2010, massive construction activities for which were initiated around the same time as the imposition of the carbon tax. The other significant treatment effects as seen in engineering construction and repair construction can be explained by their use of inputs such as bitumen, cement, steel and hydrated lime etc… (Brown) , whose production is highly carbon intensive and likely experienced a decline is GDP due to a rise in input costs since the carbon tax came into effect.

6.1.4 Mining, Oil and Gas Extraction

Mining, oil and gas is another carbon intensive sector showing a positive GDP impact, which goes against initial expectation that a reduction is demand due to the carbon tax would lead to lower levels of production. However, since the extracted resources are one of BC's biggest exports, it would make sense if the production is not negatively impacted by the carbon tax, which is specific to BC. The sector shows a 12 percent growth relative to baseline, which is statistically significant and amount to $883.5 million dollars. Compared to the pre-tax level of GDP, the increase measures almost 20 percent. However, looking at the trend comparison for the sector between BC and the rest of Canada on page (i) in the Appendix, we observe that the rest of Canada is not a suitable counterfactual for this sector since the trends are going in opposite directions. Hence the diff-in-diff approach with rest of Canada as a counter factual is not a suitable technique for isolating the carbon tax impact for this sector, hence the results can be disregarded. The only subsector indicating a negative impact is coal mining, experiencing a decline of $17.6 million. However, this result is not significant.

Table 6 Diff-in-Diff Analysis for the Mining, Oil and Gas Extraction Sector

Sector/Sub sector	Diff-in-Diff (Million $)	% change from baseline
Mining and oil and gas extraction	883.4995***(156.4)	12%
Oil and gas extraction	249.3458** (98.42)	6%
Coal mining	-17.6135 (53.13)	-3%
Metal ore mining	206.6092***(45.63)	11%
Non-metallic mineral mining and quarrying	70.1811 (60.97)	21%
Support activities for mining and oil and gas	297.2821** (111.9)	4%

*Note 1: *** p<0.01; ** p<0.05; * p<0.1*
Note 2: Robust standard errors are reported in parenthesis

6.1.5 Manufacturing

Manufacturing consists of 44 sub-sectors, and makes it hard to comment of the changes experienced by each one of them, however, at an aggregate level; DD coefficient for manufacturing came out positive. The regression results in a positive GDP impact of about $3.3 billion, or a 6 percent increase from baseline. Compared to the pre-tax GDP level in 2007, the increase measures almost 20 percent; a figure that seems highly implausible. Durable and non-durable good, both show a GDP increase of 5 percent and 7 percent respectively, however, the coefficient for durable goods is not statistically significant. Once again, this is unexpected since manufacturing requires massive energy inputs, especially electricity, and one would expect a carbon tax to limit production in response to higher production costs. This result also goes against industry experts who claim that the BC carbon tax is harming businesses (Finlayson, 2013). Analysing the trend comparison for the manufacturing sector, between BC and the rest of Canada on page (i) in the appendix, we observe that similar to the mining sector, the rest of Canada is not a suitable counterfactual for manufacturing since the trends are going in opposite directions. Therefore a positive treatment effect in response to the carbon tax for the manufacturing sector can be disregarded in the context of this analysis.

Table 7 Diff-in-Diff Analysis for the Manufacturing Sector

Sector/Sub sector	Diff-in-Diff (Million $)	% change from baseline
Manufacturing[5]	3298.11* (1509)	6%
Durable goods manufacturing	1630.805 (999.4)	5%
Non-durable goods manufacturing	1833.952** (564.8)	7%

*Note 1: *** p<0.01; ** p<0.05; * p<0.1*
Note 2: Robust standard errors are reported in parenthesis

6.1.6 Transportation

Transport is one of the sectors most directly impacted by the carbon tax due to its consumption of motor fuels such as gasoline, diesel, marine gas oil, aviation fuel, jet fuel and propane which are taxed according to their individual carbon content and resulting emissions upon combustion.

Table 8 Diff-in-Diff Analysis for the Transportation Sector

Sector/Sub sector	Diff-in-Diff (Million $)	% change from baseline
Transportation and warehousing	-242.1113 (143.92)	-9%
Truck transportation	20.23336 (47.56)	6%
Transit and ground passenger transportation	-71.0912 (75.16)	-5%
Pipeline transportation	46.02174 (28.85)	2%
Air, rail, water, scenic and sightseeing & other	-292.417*** (57.64)	-111%
Postal service and couriers and messengers	-0.51747 (15.94)	-1%
Warehousing and storage	-15.6353 (17.04)	-3%

*Note 1: *** p<0.01; ** p<0.05; * p<0.1*

[5] Appendix includes the complete table, with all 44 manufacturing sub-sectors

Note 2: Robust standard errors are reported in parenthesis

The transportation and warehousing sector reported a pre-tax GDP of $9.4 billion. The regression results indicate that at an aggregate level, the sector experienced a 9 percent decline is GDP relative to baseline, which amounts to $242 million, but is not statistically significant. Compared to the pre-tax level, the decline measures a mere 2.5 percent. Truck transportation is seen to have a positive impact from the carbon tax. This could be due to a shift in freight being transported through trucks rather than by rail or air, since aviation and marine fuels are taxed at a higher rate relative to diesel, which is the predominate fuel used in trucking. Transit and ground passenger transportation declined by 5 percent, which is easy to explain in terms of commuters opting for public transit and cleaner modes of travel in response to the higher fuel prices. However both these results are not significant. Data on air and water transportation GDP was either not available or hidden due to confidentiality reasons.

6.1.7 Wholesale trade and Retail

Table 9 Diff-in-Diff Analysis for the Wholesale and Retail Sectors

Sector/Sub sector	Diff-in-Diff (Million $)	% change from baseline
Wholesale trade	-1350.114*** (231.96)	-15%
Retail trade	-381.5933*** (89.13)	-6%

*Note 1: *** p<0.01; ** p<0.05; * p<0.1*
Note 2: Robust standard errors are reported in parenthesis

Wholesale has registered a highly significant decline of 15 percent relative to baseline and amounts to a loss of $1.3billion in dollar terms. Compared to the pre-tax level in 2007 ($7.5 billion), decline measures over 17 percent. The negative impact of the carbon tax on wholesale could be explained through expenses incurred in transportation and storage of whole sale goods. Transportation either by truck or rail would be more expensive after the imposition of the carbon tax. In addition, storage and warehousing required for wholesale are highly energy intensive since it requires large amounts of electricity, especially for goods requiring heating, cooling or refrigeration. Retail trade also reports a significant negative coefficient for carbon tax impact though of a much lessor magnitude than whole sale. Reasons explaining this decline could be higher logistical costs for businesses and consumers reducing their number of shopping trips in order to minimize fuel costs.

6.1.8 Public Administration

The results obtained indicate a negative impact of the carbon tax on public administration GDP in BC. The effect is a highly significant 8 percent decline at the federal level. The decline is more severe at the provincial level, at negative 15 percent. Compared to the pre-tax level in 2007, the decline in the provincial public administration sector measures much less (2.5 percent). One reason to explain the decline in provincial GDP could be the revenue neutrality of the carbon tax and claims that the BC government gave back more transfers than the revenue it collected from the carbon tax, resulting in a net decrease in provincial revenues and hence a decline in its ability to fund programs and services generating GDP. Another explanation for the decline observed in the provincial public administration GDP is likely the fact that the BC government legislates complete carbon neutrality, i.e. a complete offset of GHG emissions for all publically funded entities for each subsequent year after the tax came into effect in 2008 (Government of British Columbia, 2013), resulting in a more stringent effective tax burden on public administration than a $30/tonne carbon tax. The result however is not statistically significant. The decline at the federal level and in defence services cannot be explained through the carbon tax, however could be the result of the federal government's austerity measures to balance the budget deficits and debt reduction plans. Since the regression does not explicitly control for such sector specific effects, the DD coefficient shows an overestimate of the carbon impact for these sectors.

Table 10 Diff-in-Diff Analysis for the Public Administration Sector

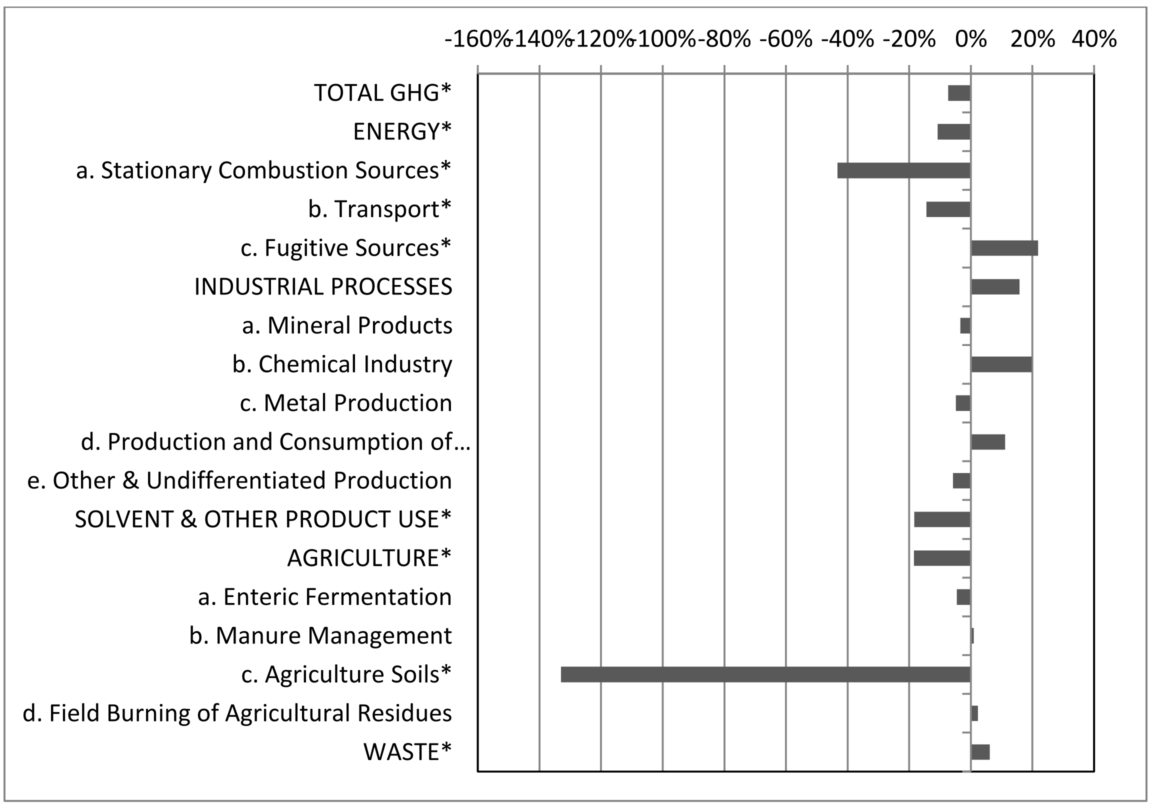
Sector/Sub sector	Diff-in-Diff (Million $)	% change from baseline
Public administration	-645.1167** (274.78)	-8%
Defence services	-185.2725*** (46.86)	-20%
Federal government public administration	-290.4848** (112.9)	-8%
Provincial and territorial public administration	-58.9011 (67.55)	-15%
Local, municipal and regional public administration	-100.866 (65.0)	-4%

*Note 1: *** p<0.01; ** p<0.05; * p<0.1*
Note 2: Robust standard errors are reported in parenthesis

6.2 GHG Emissions

The GHG Emissions regression results indicated a statistically significant impact on 31 out of 59 emissions categories and sub categories analyzed. Figure 5 illustrates the difference in difference estimator coefficients of major categories sectors as a percentage change from the baseline, (i.e. the pre-carbon tax gap between GHG emissions from rest of Canada and British Columbia). Total GHG emissions are seen to have declined by 7 percent relative to the baseline. The largest emissions reductions relative to baseline are observed in agriculture, metal production, transport and stationary combustion sources. The reduction in overall GHG emissions is as expected, since the BC carbon tax is a very broad based tax and applies to an estimated 70 percent of all fossil fuel emissions in the province captured by the National Inventory Reports. Higher prices of fossil fuels resulting from the carbon tax gives incentives to businesses and individual users to switch to less carbon intensive fuel choice and modifies consumption patterns.

Figure 5 GHG Emissions Diff in Diff as % change relative to baseline



Note: Indicates the carbon tax effect is significant at 10%*

River and Schaufele (2012) estimated that this response of consumption demand to the carbon tax is almost 5 times larger than an equivalent price change in gasoline, since fuel price fluctuations are regular and short-term, so they do not modify consumption behavior to the extent that a permanent or increasing carbon tax does, as people expect it to stay and account for it in their long-term consumption plans.

Table 11 Diff-in-Diff Analysis for Major Emissions Categories

Emission Categories	Diff-in-Diff (Kt CO_2)	% change relative to baseline
Total GHG	-2451.641** (1104.26)	-7%
Energy	-2761.965*** (922.55)	-11%
Industrial Processes	432.2726 (478.18)	16%
Solvent and Other Product Use	-8.28** (3.17)	-18%
Agriculture	-285.06*** (87)	-18%
Waste	175.33 (42.64)	6%

*Note 1: *** p<0.01; ** p<0.05; * p<0.1*
Note 2: Robust standard errors are reported in parenthesis

Of the five major emissions categories, energy and agriculture and solvents use show the largest reduction in emission, the former two statistically different from zero with a 99 percent confidence interval. Energy related emissions show a decline of 11 percent relative to the pre-carbon tax baseline difference between emissions in BC and those in the rest of Canada on average, with its coefficient measuring a reduction of 2762 Kt.in CO_2 equivalent units. The decline in agriculture is smaller in magnitude at about 248 Kt in CO_2 eq, however, relative to the baseline difference, the change measures a decline of 1.3 times. The negative sign of the coefficient would be expected if we were to believe the GDP losses in agriculture in the previous section, however, the percentage change seems rather high. Industrial processes indicates an increase in GHG emissions of 16 percent, however this result is not statistically significant. Analysing the trend comparison for the sector on page iv in the appendix, we see that the parallel trend assumption does not hold and hence the coefficient is clearly biased.

Sectoral Emissions Analysis:

6.2.1 Energy

Energy emissions are further sub categorized into Stationary Combustion Sources, Transport and Fugitive Sources:

6.2.1.1 Stationary Combustion Sources

Table 12 Diff-in-Diff Analysis for Emissions in the Energy Sector

Energy sub-categories	Diff-in-Diff (Kt CO_2)	% change relative to baseline
Stationary Combustion Sources	-2317.64*** (733.98)	-43%
Electricity and Heat Generation	10.30117 (558.52)	1%
Fossil Fuel Production and Refining	1035.925** (381)	50%
Mining & Oil and Gas Extraction	-917.1312 (332.98)	-7%
Manufacturing Industries	-1713.719*** (283.15)	-15%
Construction	-27.31971* (14.55)	-36%
Commercial & Institutional	-467.1398** (179.62)	-30%
Residential	-140.3673 (217.87)	-5%
Agriculture & Forestry	-20.50822 (74.86)	-17%

*Note 1: *** p<0.01; ** p<0.05; * p<0.1*
Note 2: Robust standard errors are reported in parenthesis

Emissions from Stationary combustion sources indicate a statistically significant decline of 43 percent relative to the pre-carbon tax baseline. The largest emissions reductions were experienced in construction and commercial & institutional sectors at -36 percent and -30 percent relative to the baseline respectively, followed by reductions in stationary combustion emissions in the Agriculture and Forestry sector at -17 percent, however this result is not statistically significant. The results report a 50 percent increase in GHG emissions in the fossil fuel production and refining sector. This is a highly energy intensive sector and one would have expected a decline in emissions since the carbon tax came into effect, instead this estimate seems to suggest that the carbon tax did not have the desired impact on the sector. Mining, oil & gas extraction reports a 7 percent decline is emissions. The manufacturing and construction sectors also show substantial reduction in emissions relative to baseline, both sectors showing coefficients that are statistically significant.

6.2.1.2 Transport

The Transportation sector is most directly impacted by the carbon tax since the tax makes fossil based motor fuels more expensive. Emissions from the sector are seen to decrease by 14 percent relative to the baseline, with a reduction of 1.9 Mt CO_2 eq in GHG emissions. Looking at individual modes, almost all modes show a negative coefficient for the difference-in differences estimator, with railway showing a decline in emissions of over 4 times, and its coefficient is significant at a 90 percent confidence interval. Emissions from road transportation report a statistically significant decline of 11 percent. Among its sub categorizations, the highest emissions reduction is experienced by light duty gasoline truck, at over 12 times relative to baseline. One explanation could be that light duty trucks are mostly used for domestic purposes and families owning a truck usually have a second car, since the trucks are not as fuel efficient. With the carbon tax coming into effect, households find it more feasible to purchase and drive vehicles of higher fuel efficiency, or opt for alternative modes of commute such as carpooling and local transit, resulting in lower emissions from road transportation. Emissions from domestic marine transport seem to have significantly increased by 59 percent. This finding is unexpected since marine transportation fuels are also covered in the carbon tax base, even after considering the marine industry to have an inelastic fuel demand, the increase in emissions of this scale seems too large and perhaps suggests a modal switching in the logistics supply chain in favor of Marine transport that is difficult to justify.

Table 13 Diff-in-Diff Analysis for Emissions in the Transport Sector

Energy sub-categories	Diff-in-Diff (Kt CO_2)	% change relative to baseline
Transport	-1942.131*** (610.455)	-14%
Civil Aviation (Domestic Aviation)	-197.1371*** (27.24)	-15%
Road Transportation	-605.7042*** (181.14)	-11%
Light Duty Gasoline Vehicles	-106.4134* (59.09)	-2%
Light Duty Gasoline Trucks	-575.2751*** (129.48)	-1291%
Heavy Duty Gasoline Vehicles	-110.4043** (41.98)	-10%
Motorcycles	-1.033311 (0.76)	-6%
Light Duty Diesel Vehicles	1.626634 (2.98)	5%
Light Duty Diesel Trucks	-36.94714*** (7.92)	-23%
Heavy Duty Diesel Vehicles	213.5466 (155.48)	63%
Propane & Natural Gas Vehicles	-12.74778 (20.38)	-2%
Railways	-240.5959* (126.83)	-412%
Navigation (Domestic Marine)	684.2004** (248.14)	59%
Other Transportation	-1386.766* (668.45)	-26%
Off Road Gasoline	-82.05901 (63.76)	-7%
Off Road Diesel	-1367.25* (671.73)	-266%
Pipelines	53.90253 (86.85)	2%

*Note 1: *** p<0.01; ** p<0.05; * p<0.1*
Note 2: Robust standard errors are reported in parenthesis

6.2.1.3 Fugitive Sources

Emissions from fugitive sources are hard to measure accurately and therefore cannot be taxed under the current system, given existing technologies in place. The analysis shows an increase in fugitive emissions by 22 percent relative to baseline. This could be simply due to increased activity in the BC mining and exploration sector (Ministry of Energy and Mines, BC, 2012). The significant increase for fugitive emissions from oil and natural gas may be indicative of an increased demand for natural gas as a transition fuel towards a cleaner environment, since natural gas produces relatively lower emissions and is a good substitute to coal and other heavier fossils for electricity and heat generation, as well as for transportation in the form of Liquefied Natural Gas (LNG).

Table 14 Diff-in-Diff Analysis for Emissions from Fugitive Sources

Energy Emission sub-categories	Diff-in-Diff (Kt CO_2)	% change relative to baseline
c. Fugitive Sources	1451.402***(186.08)	22%
Coal Mining	26.80673 (48.32)	4%
Oil and Natural Gas	1447.156***(164.4)	24%

*Note 1: *** p<0.01; ** p<0.05; * p<0.1*
Note 2: Robust standard errors are reported in parenthesis

6.2.2 Industrial Processes

The BC carbon tax directly impacts the energy- related costs of Industries since it applies to the purchase and use of all fossil fuels within BC, along with peat and tires, if used for energy or heat generation. The analysis shows a negative coefficient for all the sub categories of industrial processes with the exception of chemical industry. Natural resources Canada identifies cement, iron and steel, pulp and paper, aluminum and chemicals to be the five most energy intensive industries in terms of cost of energy as a percentage of total production cost. (Natural Resources Canada, 2013). The DD analysis shows emissions from cement production are down by 10 percent, and the coefficient is statistically significant at a 90 percent confidence interval. Cement production makes use of cheap energy from burning used tires, plastics and other waste products and therefore a reduction in emissions from cement production as a result of a carbon tax is logical. The case for the chemical industry is even more perplexing. In the GDP analysis section, we found that the chemical industry output in BC had declined by 16 percent, although not statistically significant. This would mean that the industry lost output and at the same time released 20 percent more emissions, which is clearly unlikely. The source of this contradiction is clear when we look at the trend comparison for the chemical industry on page vi in the appendix, which shows a clear violation of the parallel trend assumption. Hence the coefficients for certain industries suggest that perhaps the choice of counterfactual for comparison is not equally appropriate for all sectors. The analysis shows a negative and significant impact on emissions from the metal production sectors of -5 percent, with the impact on aluminium being -21 percent and statistically significant. This would be expected since aluminum production is highly carbon intensive.

Table 15 Diff-in-Diff Analysis for Emissions from Industrial Processes

Industrial Processes Emission sub-categories	Diff-in-Diff (Kt CO_2)	% change relative to baseline
a. Mineral Products	-56.95486 (60.47)	-3%
Cement Production	-100.9605* (52.56)	-10%
Lime Production	10.77875 (11.36)	3%
Mineral Products Use	19.48507**(8.81)	8%
b. Chemical Industry	793.3134** (392.34)	20%
Petrochemical Production	1.808*** (0.51)	27%
c. Metal Production[6]	-133.2673 (133.02)	-5%
Aluminum Production	-343.1198** (138.94)	-21%
d. Production and Consumption of Halocarbons	105.97** (35.68)	11%
e. Other & Undifferentiated Production	-276.7308* (129.82)	-6%

*Note 1: *** p<0.01; ** p<0.05; * p<0.1*
Note 2: Robust standard errors are reported in parenthesis

6.2.3 Agriculture

Majority of emissions from the agriculture sector are from enteric fermentation, i.e. from methane (CH_4) produced during the digestive processes in livestock such as cattle, elk, bison etc. Although the quantity of methane thus released is relatively low, methane has a 21 times higher potential for trapping heat in the atmosphere (global warming potential at 100 years =21) (UNFCCC, 2013) than CO_2, hence in CO_2 equivalent terms, is the most significant source of emissions from agriculture.

Table 16 Diff-in-Diff Analysis for Emissions in the Agriculture Sector

Agricultural Emission sub-categories	Diff-in-Diff (Kt CO_2)	% change relative to baseline
a. Enteric Fermentation	-56.90 (38.16)	-5%
b. Manure Management	3.76 (12.30)	1%
c. Agriculture Soils	-247.82*** (57.40)	-133%

*Note 1: *** p<0.01; ** p<0.05; * p<0.1*
Note 2: Robust standard errors are reported in parenthesis

[6] There are no emissions reported from Iron and Steel Production in BC.

Since enteric fermentation is a non-energy related source of emissions, it is not directly taxed. Manure management and Agriculture soils are similarly not covered under the carbon tax. A statistically significant reduction in emissions for agricultural soils at 151 percent seems really high and could indicates a drastic overall increase in production costs, or some other major shock to the industry not controlled for in the regression equation.

6.3 Scope for Model Improvement

In terms of the GDP analysis, the results obtained do not quite match the initial expectation, i.e. to observe a decline is energy intensive sectors where imposition of a carbon tax would increase cost of production and reduce profits and competitiveness, where as non-energy intensive sectors should not experience any big changes. Also, results for a number of energy intensive sectors such as manufacturing construction and energy sectors show a change in the positive direction instead of a decline, potentially questions the validity of the control group as a good counter factual. In the case of manufacturing and mining, the GDP trend comparison is a clear indication of an inappropriate choice of counterfactual, since the trends for BC and the rest of Canada are not only non-parallel, but moving in opposite directions. For other sectors, the slopes of the trend lines are generally moving together, but are not perfectly parallel in most cases, leading to a bias in the treatment effect of varying degrees, depending on the sector. The same is true for all the emissions categories graphically analyzed on pages iv-vi in the appendix.

Other factors that could also lead to an over or under estimation of the DD coefficient could be the presence of sector specific omitted variable bias, as their exclusion from the model would lead to faulty hypothesis testing. Although using a two-way fixed effect, including both time and province specific dummies in the regression filters out a lot of unobserved variables that are constant over time within the provinces or affect all provinces the same way within a time period. There is still potential for time varying missing variables or time specific variables that do not affect all provinces the same way. For instance, the province of British Columbia hosted the 2010 winter Olympics, an event that is specific to BC but is also time varying. The construction of venues and facilities for the Olympics began two to three years prior to 2010 and could easily lead to an over estimation of the GDP in the Construction or Accommodations sectors for example. Similarly, the pine beetle infestation in BC, which is projected to kill 56 percent of the pine volume by year 2017 (Ministry of Forestry, Land and Natural Resource Operations, BC, 2013), could negatively bias the Carbon tax impact in the Forestry sector. Also some time specific effects such as the economic crisis for 2008 affect all provinces, but to varying degrees, introducing a potential for bias despite using two-way fixed effects.

The results obtained for emissions are for the most part as expected. All major sectors indicate a decline in emissions except for Industrial processes, for which the coefficient is statistically insignificant, as well as the parallel trend assumption is severely violated. Overall, the analysis seems to indicate that the choice of counterfactual is more appropriate for the GHG emissions analysis, than for GDP. Again the same general emissions related covariates were used for the regression equations of all 59 categories and sub-categories of GHG emissions and might not be equally valid for each sector. There are econometric techniques available to counter endogeneity due to omitted variables, for example by employing instrumental variables (IV) that act as proxies for the unobserved variables and capture the effect of the missing variables on the output to varying extents, depending on the strength of the IV. This method is more appropriate when conducting a single sector analysis, since the selection of IVs is very tricky and specific to each sector. However, the challenge in our case is that the same set of explanatory variables has been used for all sectors, whereas the unobserved variables effecting GDP or emissions vary from sector to sector, and hence finding a common set of IVs for all sectors involved in a near impossible task. Therefore, for the analysis of this paper, best efforts have been made to counter for the biases given the scope of the empirical exercise; however, the analysis of results is done in full recognition of the fact that there is a potential bias due to the choice of counterfactual and omitted variables. The model can be greatly improved upon if the regression equation is modified using sector specific covariates and employing IVs where appropriate, in addition to using a counterfactual that obeys the parallel trend condition as closely as possible.

An empirical improvement in the current analysis can be made by factoring out not just time and province specific variations, but also their respective interactions with each other. For instance, by including province -by-time fixed effects, variations in the economic activity caused by province specific one-time events such as the 2010 Vancouver Olympics can be screened out. Similarly province specific sectoral variation can be filtered by including province-sector fixed effects in the empirical methodology. This technique enables use of more information available within the existing data, than using only non-interacting time and group fixed effects.

Another improvement in terms of depth of analysis could be made if the performance of the BC carbon tax were measured only in the context of a single other province, or a set of relatively similar provinces, for instance the prairie provinces (Alberta, Manitoba, and Saskatchewan) and limited only to a few of the most prominent industries in the region. This would offer a deeper and more precise analysis, where either one or a set of prairie provinces could be used as a counterfactual.

7. An alternate construction of a counter factual using Arima Forecasts

Autoregressive integrated moving average (ARIMA) modelling is a uni-variate modelling technique, in which a time series is expressed in terms of past values of itself (the autoregressive component) plus current and lagged values of the random error term (the moving average component) (Meyler, Kenny, & Quinn, 1998).

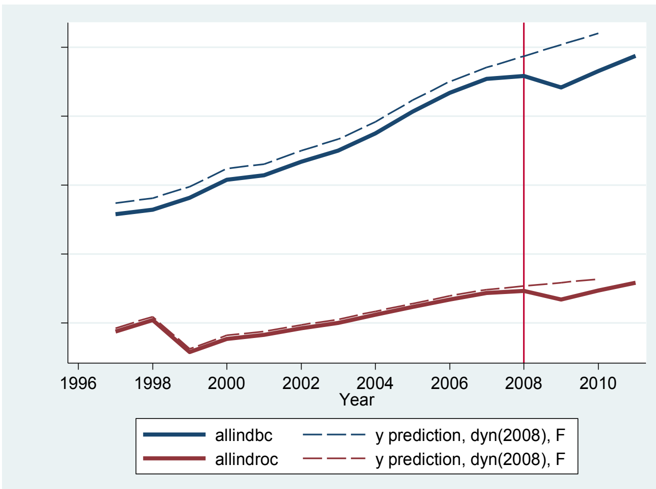
As a check of robustness for the regression results obtained in the previous section, we want to construct a basic Arima model , based on the appropriate choice of differencing and autoregressive and moving average terms determined for each sectors using autocorrelation function (ACF) and partial autocorrelation functions (PACF) in Stata (Huber, 2013). The forecasts thus obtained are crude since they only depend on past values, and therefore cannot control for fixed time and group effects, or exogenous explanatory variables affecting the dependant variable. Since we are interested in isolating the effect of the sectoral impact of the carbon tax in British Columbia, which took effect at the same time as the financial crash of 2008, the Arima model has no way of controlling for such random events. In order to filter out some of variation from such event, the forecasts are computed for BC as well as for the Rest of Canada average beyond 2008, and then a comparison is made between the two groups to determine whether a certain sector experienced an increase or a decrease in its level of output and emissions, relative to the rest of Canada.

The dotted lines in Figure 6 indicate the Arima forecasts for the sector based on historical values. For GDP, the forecasts are extrapolated from 11 previous data points. For total GHG emissions, the calculations are made from 20 historical data points. Since the number of data point is quite limited, the forecasts cannot be expected to be very accurate. The treatment effect is measured as:

Treatment Effect = [Mean (BC Actual post 2008)- Mean(BC forecasts Post 2008)] – [Mean(RoC Actual Post 2008)]- Mean (RoC forecasts Post 2008).

In the case of GDP, we notice that the gap between the forecasts and output for BC is much larger than the same gap for rest of Canada, indicating that post 2008, aggregate GDP in BC fell more sharply in BC then it did in the rest of Canada. This observation aligns with our regression analysis in the previous section where we found a negative difference in difference coefficient for aggregate GDP to the amount of $1.25 billion. A comparison of the actual numbers obtained is not appropriate since we acknowledge that the forecasts are only a crude measure, hence we will just focus on the sign of the effect for this analysis. At a sectoral level, Manufacturing, industrial production and energy sector show a decline in GDP that is greater in BC relative to the rest of Canada, while agriculture shows a positive effect on GDP, which are all contradictory to our regression analysis findings.

Figure 6 Comparison using Arima Forecasts for GDP and Emissions



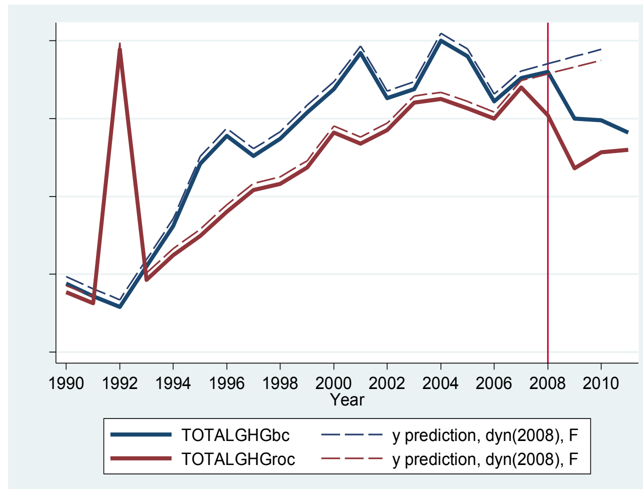


Table 17 Estimates for Carbon Tax impact on GDP using ARIMA Forecasts

GDP Major NAISC Sectors	Treatment Effect in BC relative to RoC
All industries	-3598.57
Goods producing industries	-1264.84
Services producing industries	-2259.93
Industrial production	-1003.32
Energy sector	-107.75
Agriculture, forestry, fishing and hunting	408.1351
Crop and animal production	714.6284
Forestry and logging	-571.554
Fishing, hunting and trapping	-440.238
Mining and oil and gas extraction	93.93851
Utilities	-112.27
Electric power generation, transmission and distribution	-1320.37
Construction	810.3086
Manufacturing	-3579.57
Retail trade	-513.147
Transportation and warehousing	-436.144
Finance and insurance, real estate and renting and leasing and	5.642

management of companies and enterprises	
Administrative and support, waste management and remediation services	61.5359
Educational services	-304.523
Health care and social assistance	208.6941
Arts, entertainment and recreation	-94.2374
Accommodation and food services	-99.3626
Public administration	-3.15483

Note: Treatment Effect = [Mean (BC Actual post 2008)- Mean(BC forecasts Post 2008)] – [Mean(RoC Actual Post 2008)- Mean (RoC forecasts Post 2008)]

For total GHG emissions, Figure 6 demonstrates a steeper decline in emissions for the rest of Canada, relative to BC. The gap between forecasted and actual values also seems to be larger in the rest of Canada, than in BC. This seems to contradict our initial finding that BC had a negative and significant response to the carbon tax of the tax, measuring some 2.45 million tonnes of CO_2 Eq. However, we note that where the trend in BC continues to go downwards after 2008, the rest of Canada seems to be adding more emissions as it recovers from the loss of output from the financial crisis in 2008. Total emissions, emissions from Energy, Stationary Combustion Sources, and agriculture report increases, while industrial processes show in decrease in emissions in contrast to out regression results.

Table 18 Estimates for Carbon Tax impact on emissions using ARIMA Forecasts

Emissions Categories	Treatment Effect in BC relative to RoC
Total GHG Emissions	1695.638
Energy	2130.905
a. Stationary Combustion Sources	2334.566
b. Transport1	-1061.71
c. Fugitive Sources	820.0613
Industrial Processes	-457.349
a. Mineral Products	-158.106
b. Chemical Industry	-28.6378
c. Metal Production	91.0969
Solvent & Other Product Use	76.97233
Agriculture	48.42774
Waste	-6.11228

Results obtained from the above analysis do not reinforce our regression results in the previous section, We recognize this to be a crude method since it lacks many of the controls employed in the regression analysis, however in the scope of this paper, does not prove robustness of results.

8. Conclusion

On July 1, 2008, British Columbia introduced North America's very first, broad-based, revenue-neutral carbon tax as part of its Climate Action plan, which aims for a 33 percent reduction in the province's emissions relative to 2007 levels by 2020. Starting at 10 per tonne of CO_2, the tax plan constituted scheduled increments of $5 per-tonne per year until the final increase took effect on July 1, 2012, fixing the tax rate at $30 per-tonne. The tax covers 70 percent of all reported emissions from fossil fuel combustion by industrial as well as business and household consumers in the province are rates are set in accordance with the carbon content of the fuel.

This paper conducts an econometric analysis to seek what effect the introduction of the carbon tax had on the provincial GDP at a sectoral level, followed by an analysis of the effect of the carbon tax on greenhouse gas emissions in the province. A difference in differences analysis model is used to quantitatively measure the impact of the carbon tax pre and post implementation using the rest of Canada as a counterfactual.

The GDP regression results indicate a statistically significant impact on 58 of the 119 sectors analyzed. Aggregate GDP is seen to have declined by CAD $1.25 billion or 14 percent relative to the pre-tax baseline difference[7]. Although the coefficient is not statistically significant, a negative sign of the carbon tax effect is as expected since lack of cost-effective alternatives in the short run make it feasible for businesses to reduce output or relocate production facilities to lower tax jurisdictions, resulting in a lower GDP at the provincial level.

At the sectoral level, the largest declines are observed in agriculture, forestry, fishing and hunting, utilities, wholesale trade, transportation and warehousing and public administration. The factors behind the decline experienced by these sectors could stem from reduced competitiveness and profitability as costs of production rises due to higher energy prices. The analysis reveals unexpected gains experienced in the construction(although coefficient is insignificant), mining, oil & gas extraction and manufacturing

[7] The calculation is made by taking the ratio of the DD coefficient to the pre carbon tax difference in GDP between BC and the Rest of Canada average.(i.e. treatment effect/ pre-treatment difference between treatment and control group)

sectors, however, the latter two are found in severe violation of the parallel trend assumption. All three of these sectors are highly energy intensive and increased output in response to a carbon tax suggests of presence of bias in the model, which mainly stems from the wrong choice of control group, in this case, the rest of Canada mean, as a good counter factual.

The GHG emissions analysis is conducted using the same difference in differences framework, with results indicating a statistically significant impact on 31 out of 59 emissions categories and sub categories analyzed. Total GHG emissions are seen to have declined by 7 percent relative to the pre-tax baseline difference between BC and Rest of Canada. Decline in emissions is observed in agriculture, metal production, transport and stationary combustion sources, with energy and agriculture sectors experiencing the largest reduction in emission, statistically different from zero with a 99 percent confidence interval.

Looking at results from both GDP and emissions, we see that an overall reduction in emissions of 2.45 Mt CO_2 cost the province a reduction in GDP of $1.25 billion on average. This means the cost of GHG emissions reduction in terms of GDP forgone per tonne stands at about $508/tonne of CO_2, which is almost 17 times more than the current tax rate. However, acknowledging the potential for biases in the analysis, too much cannot be read into this conclusion.

The model used in the analysis could be improved by employing a different choice of counterfactual, either simulated or actual data from jurisdictions that are fundamentally closer in comparison to BC in terms of economy and demographics and upholds the parallel trend assumption. At a sectoral level, inclusion of sector specific covariates and IVs can immensely improve the preciseness of the estimates. Also, the tax is relatively new and as data for subsequent years becomes available, more precise econometric analysis would become possible.

Works Cited

Alatas, V., & Cameron, L. (2003). The Impact of Minimum Wages on Employment in a Low Income Country:An Evaluation using the Difference-in-Differences Approach. *World Bank Policy Research, Working Paper 2985*.

Albouy, D. (n.d.). *Program Evaluation and the Difference in Difference Estimator.* Retrieved 15 October, 2013, from http://emlab.berkeley.edu/users/webfac/saez/e131_s04/diff.pdf

Aldy, J. E., & Stavins, R. (2011). *The Promise and Problems of Carbon Pricing: Theory and Experiance.* Retrieved October 15, 2013, from Working Paper 17569: http://www.nber.org/papers/w17569

Andersen, M. S. (2004). Vikings and virtues: a decade of CO2 taxation. *Climate Policy, 4*(1), 13-24.

Andersen, M. S. (2008). Environmental and Economic Impact of Taxing and Trading Carbon: Some European Experiances. *Vermont Journal Of Environmental Law, 10*.

Angrist, J. D., & Pischke, J.-S. (2008). *Mostly Harmless Econometrics: An Empiricist's Companion.*

Barry, C. (2011). *Fixed Effects.*

Baumol, W. J., & Oates, W. E. (1971). The Use of Standards and Prices for Protection of the Environment. *The Swedish Journal of Economics, Vol. 73, No. 1, Environmental Economics*, 42-54.

Bobinaite, V., Juozapaviciene, A., & Konstantinaviciute, I. (2011). Regression Analysis of Gross Domestic Product and its Factors in Lithuania. *Economics and Management, 16*, 116-126.

Brown, A. S. (n.d.). *Carbon Footprint of Pavements*. Retrieved October 15, 2013, from Asphalt Institute: http://www.asphaltinstitute.org/dotAsset/45e8856f-7b45-49d3-ba8a-51c391ce5b9d.pdf

Bruvol, A., & Larsen, B. M. (2004). Greenhouse gas emissions in Norway: do carbon taxes work? *Energy Policy, 32* , 493–505.

Carbontax Center. (2013). *Where Carbon is Taxed*. Retrieved November 15, 2013, from carbontax.org: http://www.carbontax.org/progress/where-carbon-is-taxed/

Card, D., & Krueger, A. B. (1994). Minimum Wages and Employment: A Case Study of the Fast Food Industry in New Jersey and Pennsylvania. *American Economic Review, 84*, 772-793.

CCEMC. (2013). *About*. Retrieved October 15, 2013, from ccemc.ca: http://ccemc.ca/about/

Dale, S. B., & Krueger, A. B. (2002). Estimating the Payoff to Attending a more Selective College: An Application Of Selection on Observables and Unobservables. *The Quarterly Journal of Economics*, 1491-1527.

David Suzuki Foundation. (n.d.). *Canada's Emissions*. Retrieved October 2013, from http://www.davidsuzuki.org: http://www.davidsuzuki.org/issues/climate-change/science/canada-climate-change/canadas-emissions/

Doda, B. (2013). *Emissions- GDP Relationship in Times of Growth and Decline.* Retrieved October 15, 2013, from http://www.lse.ac.uk/GranthamInstitute/publications/WorkingPapers/Papers/110-19/WP116-emissions-gdp-growth-and-decline.pdf

Ekins, P., & Baker, T. (2002). Carbon Taxes and Carbon Emissions Trading. *Journal of Economic Survey, Vol 15, No.3*.

Elgie, S., & Mcclay, J. (2013). *BC's Carbon Tax Shoft After Five Years: Results- An Environmental (and Economic) Success Story.* Sustainable Prosperity, University of Ottawa.

Enevoldsen, M. (1998). Joint Environmental Policy-Making and Other New Abatement Strategies for Industrial CO2 Pollution: Austria, Denmark and the Netherlands. *Environmental Sociology Publication*.

Enevoldsen, M. (2000). Industrial energy efficiency, Ch. 4. In J. P. Arthur , V. L. Mol, & D. Liefferink (Eds.), *The Voluntary Approach to Environmental Policy: Joint Environmental Policy-making in Europe.* Oxford, UK: Oxford University Press.

Finlayson, J. (2013, August 01). *B.C.'s carbon tax hurting businesses*. Retrieved November 5, 2013, from Vancouver Sun: http://www.vancouversun.com/business/2035/carbon+hurting+businesses/8739247/story.html#ixzz2kxdaOJNw

Goto, N. (1995). Macroeconomic and sectoral impacts of carbon taxation. *Energy Economics, Vol. 17*(4), 277-292.

Goulder, L. H., & Parry, I. W. (2008). Instrument Choice in Environmental Policy. *Review of Environmental Economics and Policy, Vol 2, Issue 2* , 152–174.

Government of British Columbia. (2008). *Climate Action Plan.* Retrieved October 15, 2013, from http://www.gov.bc.ca/: http://www.gov.bc.ca/premier/attachments/climate_action_plan.pdf

Government of British Columbia. (2013). *Budget and fiscal Plan 2013/14 - 2015/16.* Retrieved October 15, 2013, from http://www.bcbudget.gov.bc.ca/: http://www.bcbudget.gov.bc.ca/2013_June_Update/bfp/2013_June_Budget_Fiscal_Plan.pdf#TaxMeasures

Greene, W. H. (2012). Treatment effects and Difference in Difference Regression. In W. H. Greene, *Analysis, Econometric* (7th ed., pp. 155-158).

Harrison, K. (2012). A Tale of Two Taxes: The Fate of Environmental Tax. *Review of Public Research*, 383-407.

Huber, C. (2013). Introduction to ARMA/ARIMA Models in Stata.

IPCC. (2013). *Intergovernmental Panel on Climate Change (IPCC) (2The Physical Science Basis, Summary for Policy Makers.* Retrieved October 2013, from http://www.climatechange2013.org.

IPCC. (2013). *Intergovernmental Panel on Climate Change (IPCC) (2The Physical Science Basis, Summary for Policy Makers.* Retrieved October 2013, from http://www.climatechange2013.org.

Joberta, T., Karanfil, F., & Tykhonenko, A. (2010). Convergence of per capita carbon dioxide emissions in the EU: Legend or reality? *Energy Economics, 32*(6), 1364–1373.

Josheski, D. (2008). Infrastructure Investment and GDP Growth: A Meta-Regression Analysis.

Knoema. (2013). *Total primary energy consumption - Ranking - World Data Atlas*. Retrieved November 2013, from Knoema: http://knoema.com/atlas/ranks/Total-primary-energy-consumption

Labandeira, X., Labeaga, J., & Rodríguez, M. (2004). Green Tax Reform in Spain. *European Environment, 14*, 290–299.

Lane, J.-E. (2013). Energy: The Link between GDP and Emissions. *Research in World Economy, 4*(1), 49-54.

Li, H., Yi , J., & Zhang, J. (2011). Estimating the Effect of the One-Child Policy on the Sex Ratio Imbalance in China: Identification based on the Difference-in-Differences. *Demography, 48*, 1535–1557.

Lin, B., & Li, X. (2011). The Effect of carbon Tax on Per Capita CO2 Emissions. *Energy Policy, 39*, 5137–5146.

Meng, S., Siriwardana, M., & McNeill, J. (2013). The Environmental and Economic Impact of the Carbon Tax in Australia. *Environmental and Resource Economics, 54*(3), 313–332.

Meyer, B. (1995). Natural and Quasi-natural Experiments on Economics. *Joural of Business and Economic Statistics, 13*(2), 151-161.

Meyler, A., Kenny, G., & Quinn, T. (1998). *Forecasting Irish Inflation Using Arima Models.* Retrieved November 10, 2013, from http://www.centralbank.ie/publications/documents/3RT98.pdf

Ministry of Agriculture, BC. (2013). *Greenhouse Carbon Tax Relief Grant Program*. Retrieved November 10, 2013, from http://www.agf.gov.bc.ca/ministry/AgScPolicy/GHCarbonTaxRelief.htm

Ministry of Energy and Mines, BC. (2012). Retrieved October 15, 2013, from http://www.empr.gov.bc.ca/Mining/MineralStatistics/IndustryOverviews/Pages/default.aspx

Ministry of Finance, British Columbia. (2012). *Carbon Tax Review, and Carbon Tax Overview*. Retrieved November 15, 2013, from http://www.fin.gov.bc.ca/: http://www.fin.gov.bc.ca/tbs/tp/climate/carbon_tax.htm

Ministry of Finance, British Columbia. (2012). *How the Carbon Tax Works*. Retrieved November 15, 2013, from http://www.fin.gov.bc.ca/: http://www.fin.gov.bc.ca/tbs/tp/climate/A4.htm

Ministry of Forestry, Land and Natural Resource Operations, BC. (2013). *Provincial-Level Projection of the Current Mountain Pine Beetle Outbreak.*

Natural Resources Canada. (2013). *Improving Energy Performance in Canada – Report to Parliament Under the Energy Efficiency Act For the Fiscal Year 2010-2011*. Retrieved November 5, 2013, from Office of Energy Efficiency: http://oee.nrcan.gc.ca/Publications/statistics/parliament10-11/chapter1.cfm?attr=0

Nyboer, J., & Kniewasser, M. (2012). *Energy and GHG Emissions in British Columbia 1990-2010.* Pacific Institute for Climate Solutions.

OECD. (2013). *Climate and carbon: Aligning prices and policies. OECD Environmental Policy Paper No. 1.*

Olmstead, S. M., & Stavins, R. N. (2011). hree Key Elements of a Post-2012 International Climate Policy Architecture. *Review of Environmental Economics and Policy, volume 6, issue 1*, 65-85.

Portney, P. R., & Robert, S. N. (2000). *Public Policies for Environmental Protection.* Resources from the Future.

Rivers, N., & Schaufele, B. (2012). Carbon Tax Salience and Gasoline Demand.

Robinson, J. B. (1990). Decarbonating Energy Systems: The Potential for Reducing CO2 Emissions Through Reduced Energy Intensity in Canada. *Energy Studies Review, 2*(1).

Shopley, J., & Brasseur, D. (1996). Summary Report on Two Micro-Economic Case Studies in the Field of Business and the Environment. *Conference on Environmental Economic Policies: Competitiveness and Employment.* Brussels, Belgium.

Stavins, R. N. (1998). *Market-Based Environmental Policies, Discussion Paper 98-26.* Resources from the Futture.

Sustainable Prosperity. (2012). *British Columbia's Carbon Tax Shift: The First Four Years.* University of Ottawa.

UNFCCC. (2013). *Global Warming Potentials*. Retrieved November 11, 2013, from United Nations Framework Convention on Climate Change: http://unfccc.int/ghg_data/items/3825.php

Weitzman, M. L. (1971). Prices vs. Quantities. *The Review of Economic Studies, Vol. 41, No. 4*, 477-491.

Whited, T. M. (2007). *Endogeneity II: Natural Experiments and Difference-in-Differences.* Retrieved October 15, 2013, from http://www-personal.umich.edu/~jizhu/jizhu/Empirical%20Finance/Letures%20Toni/02-Diffindiff.pdf

Wissema, W., & Dellink, R. (2007). AGE analysis of the impact of a carbon energy tax on the Irish economy. *Ecological Economics, 61*, 671 – 683.

World Bank. (2013). *Mapping Carbon Pricing Initiatives: Developments and Prospects.* Washington DC.

Yildiz, A. C., Barnes, T., & Yildiz, I. (2013). Assessment of Carbon Tax as a Policy Option in Canada. *EIC Climate Change Technology Conference*, (p. Paper Number 1569695585).

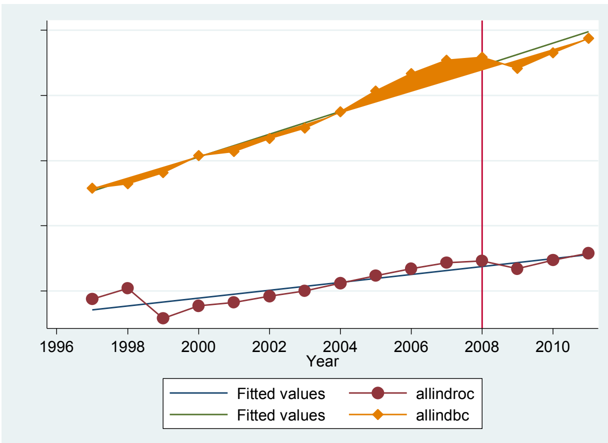
Zhang, Z. (2008). Macro-economic and Sectoral Effects of Carbon Taxes: A General Equilibrium Analysis for China. *Economic Systems Research, 10*(2), 135-159.

Zhanga, Z., & Baranzini, A. (2004). What do we know about carbon taxes? An inquiry into their impacts on competitiveness and distribution of income. *Energy Policy, Vol. 32*, 507–518.

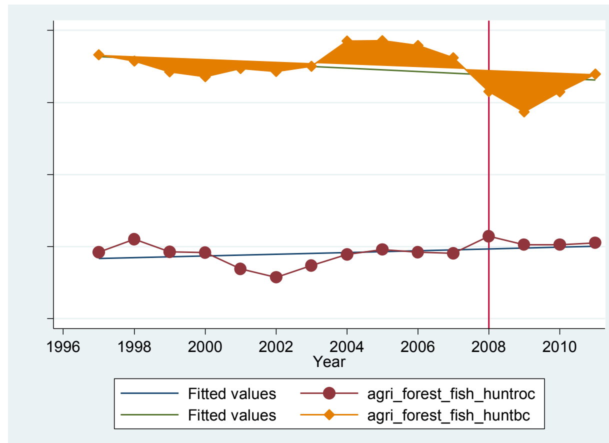
Appendix

Trend Analysis for Sectoral GDP (million $)

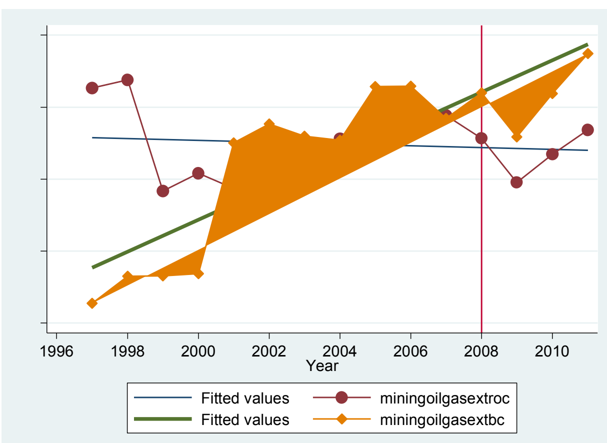
All Industries



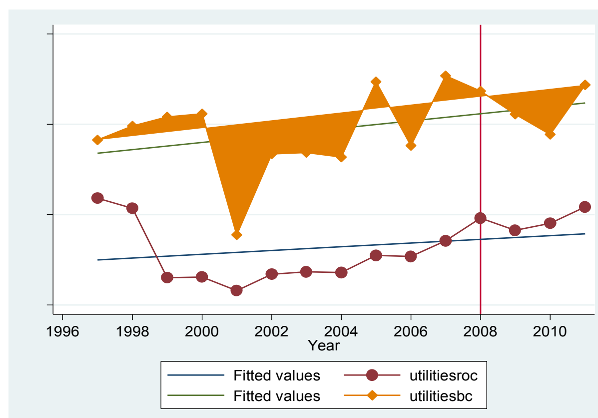
Agriculture



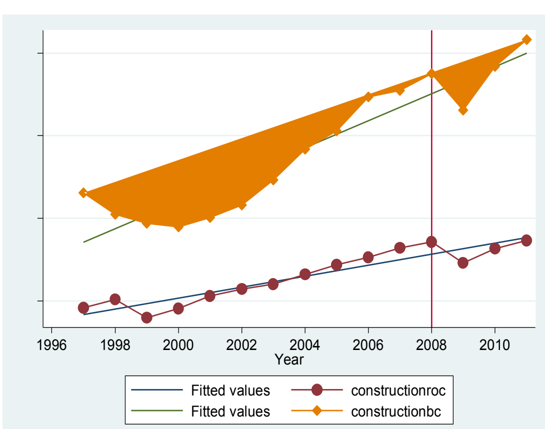
Mining and oil and gas extraction



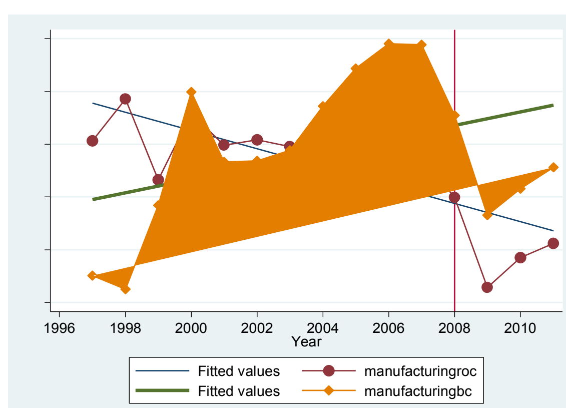
Utilities



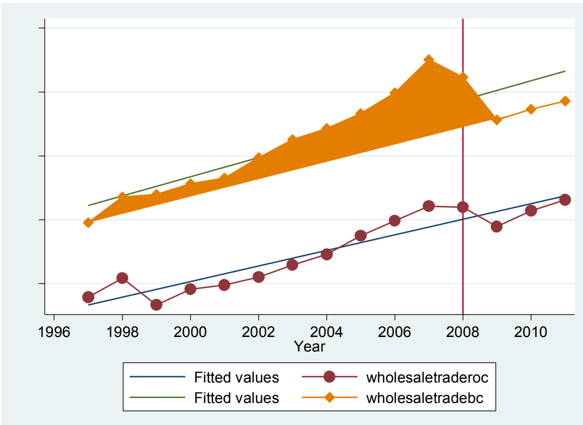
Construction



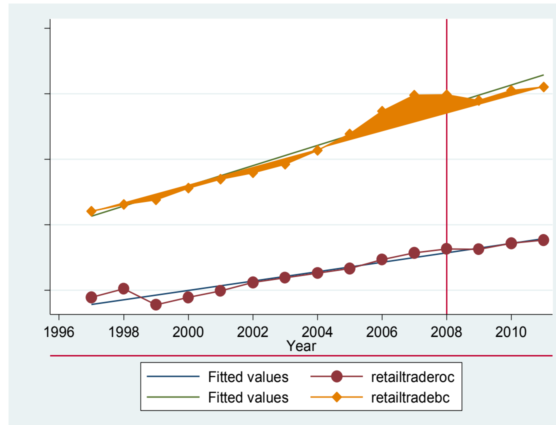
Manufacturing



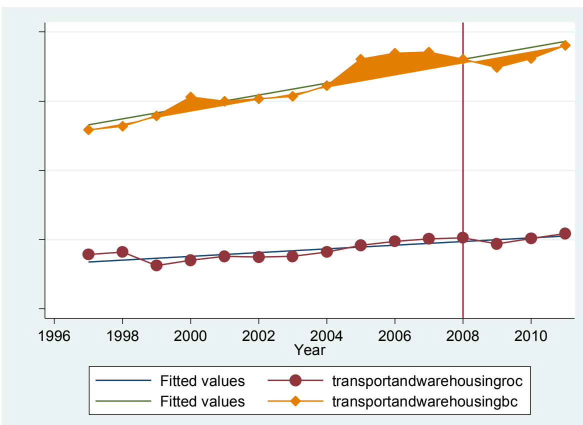
Wholesale



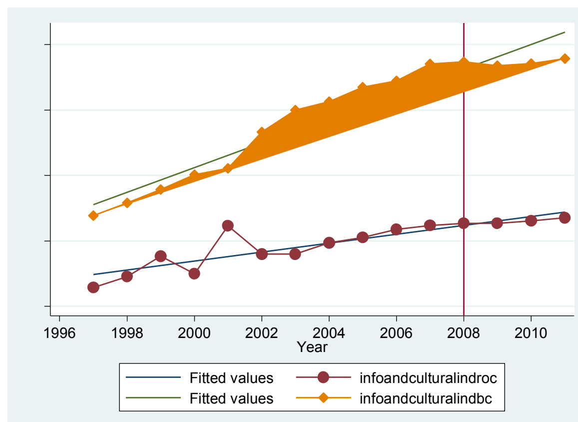
Retail



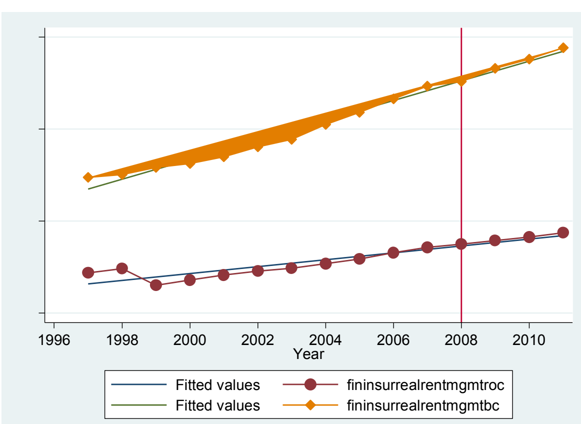
Transportation and Warehousing



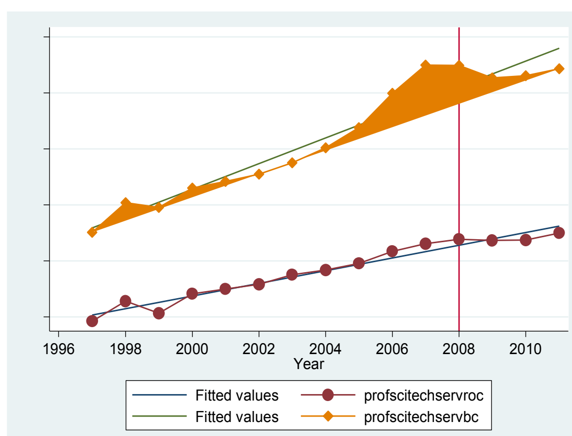
Information and Cultural Services



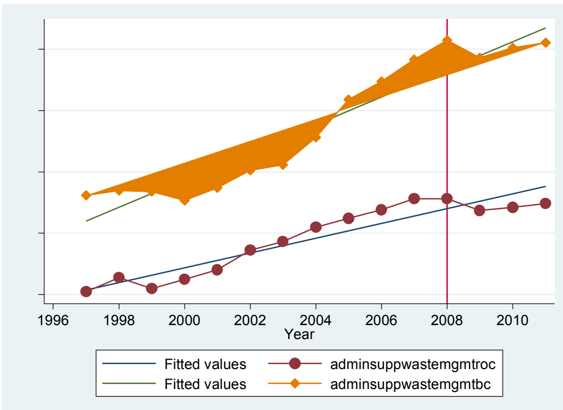
Financial and Insurance, Rental, lease, Company Management



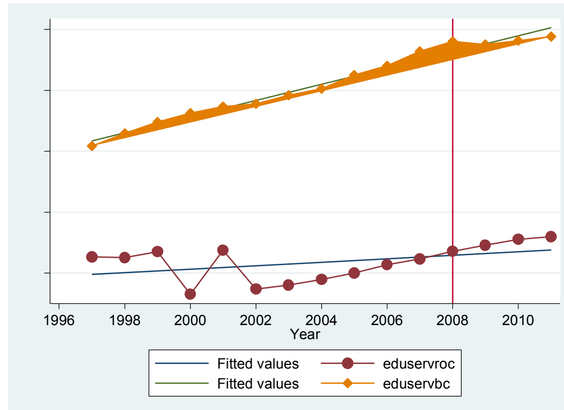
Professional, Science and Technical Services



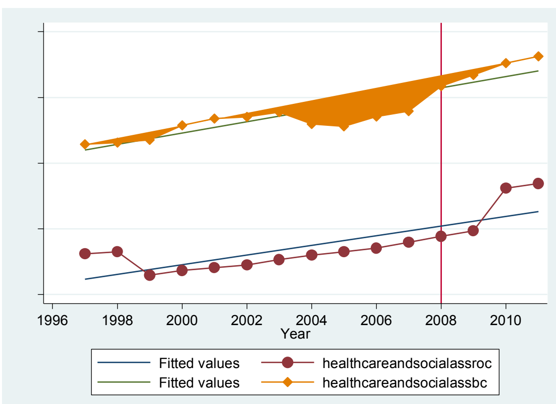
Admin support and Waste Mgt



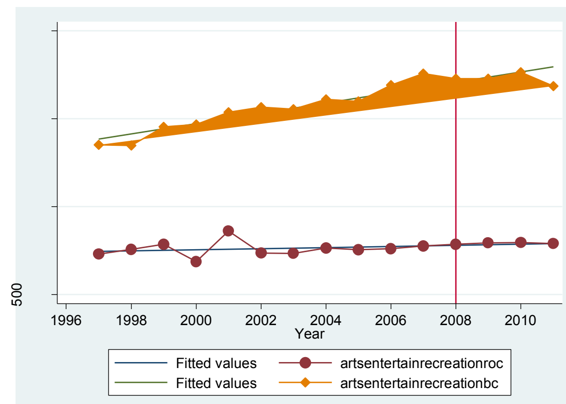
Educational Services



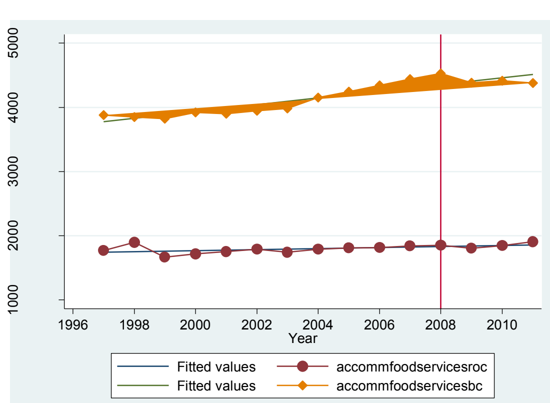
Healthcare and Social Assistance



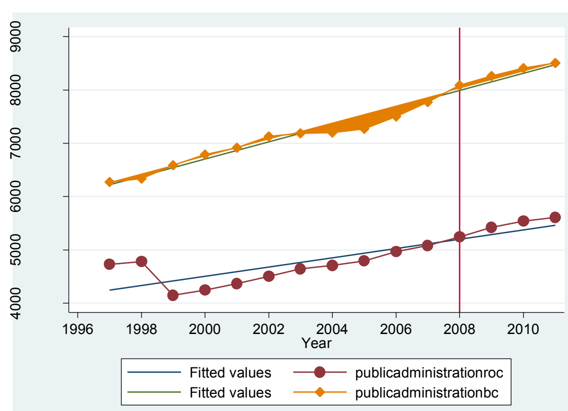
Arts and Entertainment



Accommodation and Food

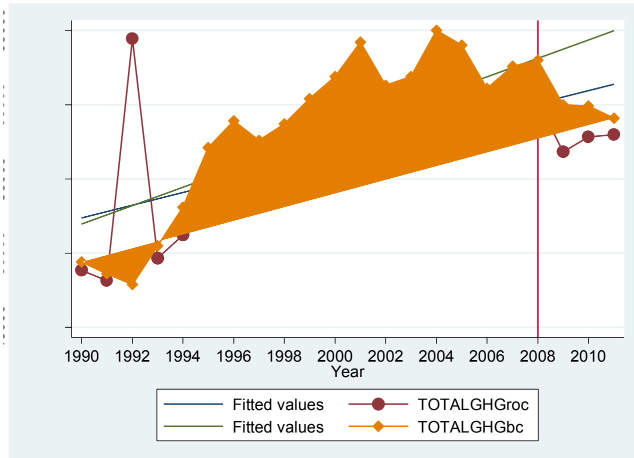


Public Administration

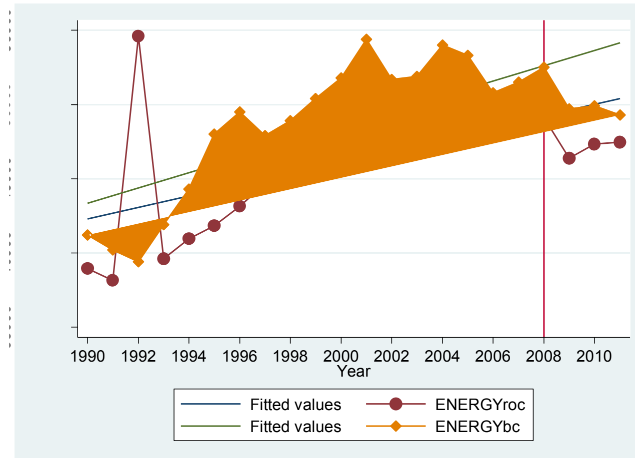


Trend Comparison for GHG Emission Categories

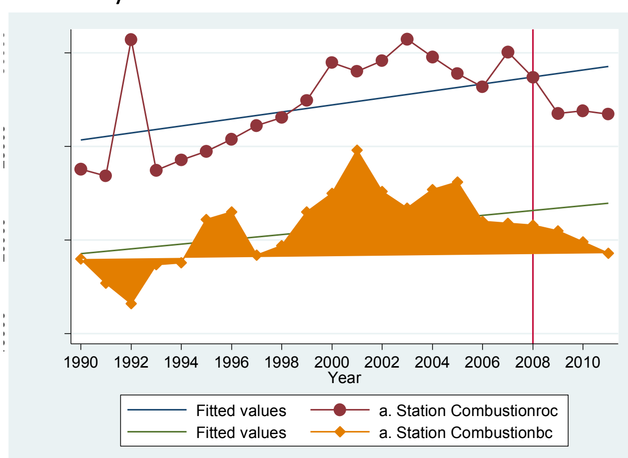
Total GHG Emissions



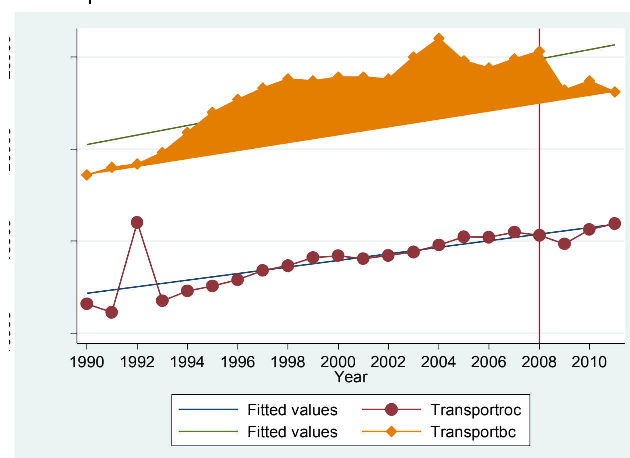
Energy



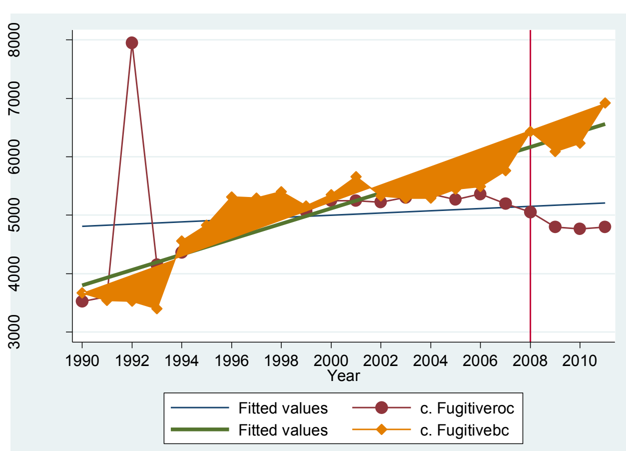
Stationary Combustion sources



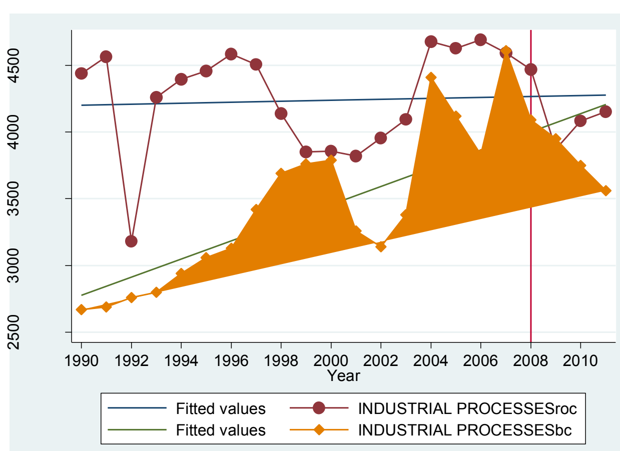
Transport



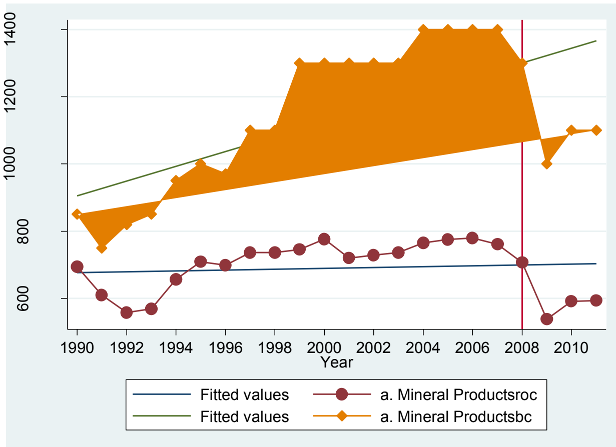
Fugitive Sources



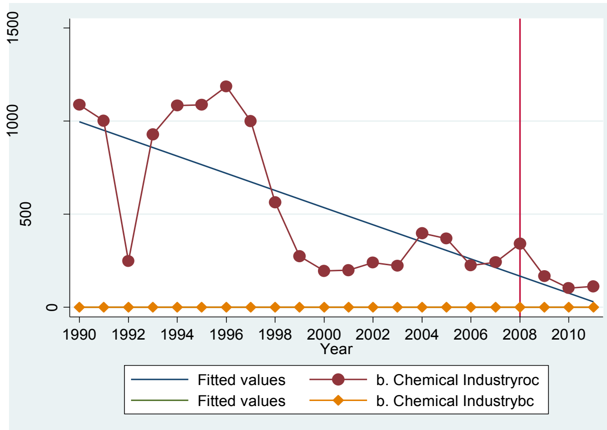
Industrial Processes



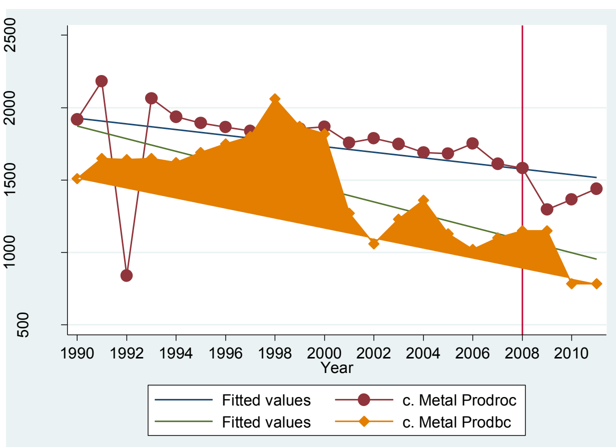
Mineral Products Use



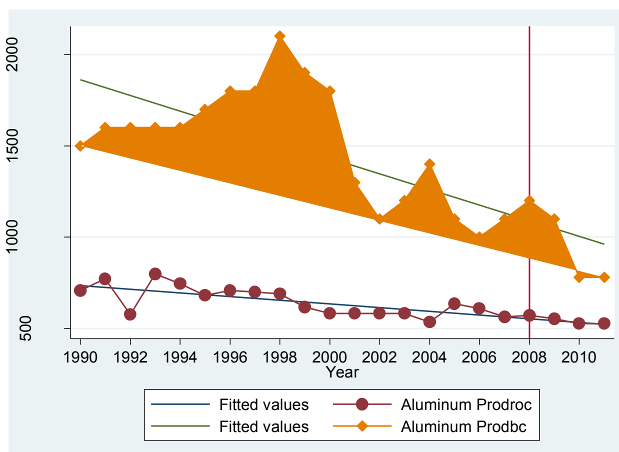
Chemical Industry



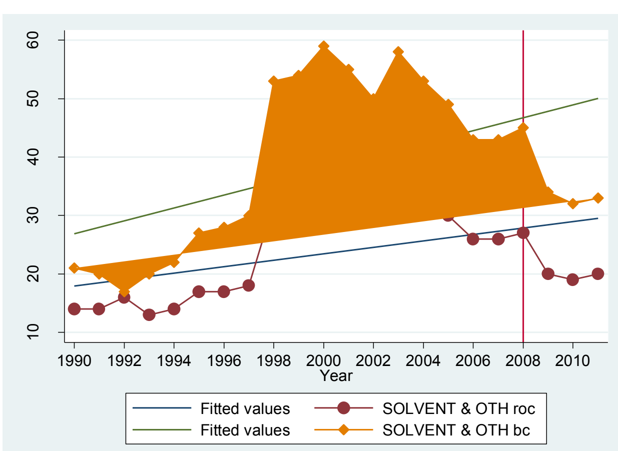
Metal Production



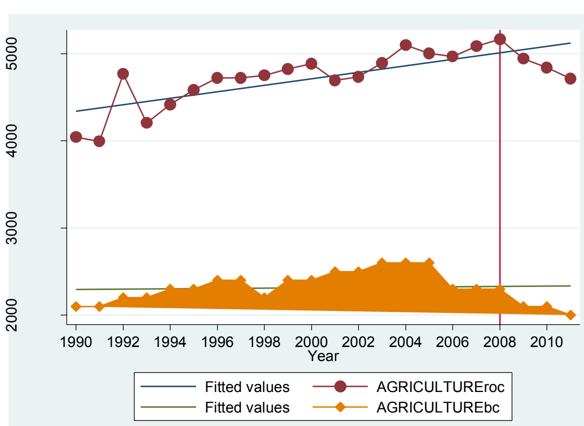
Aluminium



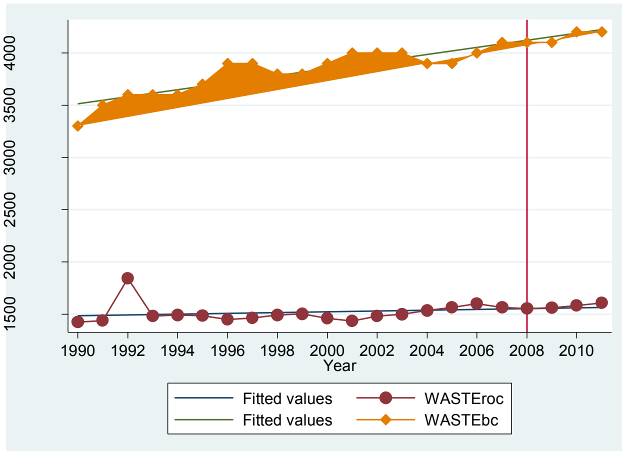
Other Solvents



Agriculture



Waste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Regression Coefficients for Sectoral difference and Difference Estimators

Table A1. Sectoral GDP Difference-in-differences Regression coefficients

GDP Sectors	DD Coefficient (million $)	Standard Error (Robust)	N	R^2	DD relative to baseline
All industries	-1256.03	1115.997	100	0.999892	-14%
Goods producing industries	3706.323**	1560.15	100	0.996025	6%
Services producing industries	-4075.111**	1371.414	100	0.999656	-6%
Industrial production	4111.156**	1516.194	100	0.993173	7%
Energy sector	475.1553*	212.6735	90	0.99895	9%
Agriculture, forestry, fishing and hunting	-924.716***	127.4426	100	0.982153	-15%
Crop and animal production	-421.5762***	117.592	100	0.971998	-19%
Forestry and logging	-396.5371***	120.2494	100	0.99112	-11%
Fishing, hunting and trapping	-32.68813***	8.195393	100	0.986387	-34%
Support activities for agriculture and forestry	-128.0481***	14.89557	100	0.995055	-24%
Mining and oil and gas extraction	883.4995***	156.3767	100	0.999056	12%
Oil and gas extraction	249.3458**	98.42439	76	0.999536	6%
Coal mining	-17.6135	53.13371	64	0.989144	-3%
Metal ore mining	206.6092***	45.63272	69	0.934333	11%
Non-metallic mineral mining and quarrying	70.1811	60.97457	62	0.952066	21%
Support activities for mining and oil and gas extraction	297.2821**	111.9187	63	0.989049	4%
Utilities	-441.0079***	106.6058	100	0.997508	-16%
Electric power generation, transmission and distribution	-504.6049***	117.5575	74	0.996267	-14%
Natural gas distribution	0	0	42	0.988395	0
Water, sewage and other systems	0	0	19	0.99877	0
Construction	323.3081*	176.2676	100	0.998123	25%
Residential building construction	87.04738	125.2711	100	0.996118	4%
Non-residential building construction	348.7471***	96.95987	100	0.992383	14%
Transportation engineering construction	-140.6254	84.71191	88	0.955532	-15%
Oil and gas engineering construction	364.4545	302.4682	79	0.973998	9%
Electric power engineering construction	79.75772	92.83932	85	0.952655	5%
Communication engineering construction	28.58922*	15.61091	65	0.947956	36%
Other engineering construction	-267.9806*	141.2025	61	0.952288	-20%
Repair construction	-169.5481***	24.03865	100	0.999044	-43%
Other activities of the construction industry	-1.44957	7.574501	100	0.994335	-1%
Manufacturing	3298.11*	1508.984	100	0.991608	6%

Durable goods manufacturing	1630.805	999.4312	90	0.987183	5%
Non-Durable goods manufacturing	1833.952**	564.7913	90	0.995722	7%
Animal food manufacturing	13.88239	12.9617	74	0.958707	10%
Sugar and confectionery product manufacturing	47.82632***	8.076038	54	0.996657	26%
Fruit and vegetable preserving and specialty food manufacturing	13.73059	42.79569	44	0.989351	2%
Dairy product manufacturing	-55.9885*	29.8647	49	0.991678	-19%
Meat product manufacturing	-169.5831**	65.87066	76	0.975276	-11%
Seafood product preparation and packaging	0	0	70	0.954992	0%
Miscellaneous food manufacturing	79.41012**	33.75717	78	0.998059	20%
Soft drink and ice manufacturing	-91.64159*	42.15247	46	0.953722	-3%
Breweries	50.67962	46.1036	37	0.974993	3%
Wineries	11.49611*	5.75981	40	0.997662	16%
Distilleries	0	0	43	0.976739	0%
Tobacco manufacturing	0.481731	0.33448	68	0.47379	28523%
Textile and textile product mills	212.6597**	79.26862	81	0.910204	10%
Clothing manufacturing	0	0	49	0.918397	0%
Leather and allied product manufacturing	15.34891	18.95798	51	0.887087	3%
Wood product manufacturing	-463.7966	277.1244	92	0.982141	-10%
Pulp, paper and paperboard mills	3.361343	82.84126	51	0.986347	0%
Converted paper product manufacturing	-87.3098	50.31441	42	0.996126	-27%
Printing and related support activities	60.14668	55.74095	88	0.987239	3%
Petroleum and coal products manufacturing	0	0	38	0.985725	0%
Basic chemical manufacturing	-48.1912	55.16835	58	0.978307	-16%
Resin, synthetic rubber, and artificial and synthetic fibres and filaments manufacturing	143.8562*	67.1095	58	0.971933	7%
Pesticide, fertilizer and other agricultural chemical manufacturing	0	0	40	0.867671	0%
Pharmaceutical and medicine manufacturing	26.18991	55.98918	65	0.962576	3%
Miscellaneous chemical product manufacturing	0	0	82	0.976479	0%
Plastic product manufacturing	0	0	46	0.975613	0%
Rubber product manufacturing	0	0	44	0.971376	0%
Cement and concrete product manufacturing	-17.109	39.18637	71	0.990557	-3%
Miscellaneous non-metallic mineral product manufacturing	-14.1982	28.57876	78	0.981742	-5%
Primary and fabricated metal product	578.7062	435.2201	71	0.993284	54%

manufacturing					
Machinery manufacturing	150.2785	122.1973	84	0.987275	2%
Computer and peripheral equipment manufacturing	12.83447	20.24516	55	0.973034	20%
Electronic product manufacturing	118.0036	76.15976	54	0.98893	7%
Household appliance manufacturing	0	0	48	0.960984	0%
Electrical equipment and component manufacturing	80.70728	54.55089	50	0.976726	4%
Motor vehicle manufacturing	0	0	37	0.994514	0%
Motor vehicle body and trailer manufacturing	0	0	65	0.969391	0%
Motor vehicle parts manufacturing	0	0	40	0.989728	0%
Aerospace product and parts manufacturing	-239.666	251.7337	59	0.982769	-10%
Railroad rolling stock manufacturing	0	0	50	0.878306	0%
Ship and boat building	-85.06409**	27.2989	43	0.943976	-18%
Other transportation equipment manufacturing	0	0	41	0.921406	0%
Furniture and related product manufacturing	331.6031**	127.0257	73	0.984947	8%
Miscellaneous manufacturing	8.729642	28.27203	60	0.991136	1%
Wholesale trade	-1350.114***	231.9605	100	0.998826	-15%
Retail trade	-381.5933***	89.13095	100	0.999434	-6%
Transportation and warehousing	-242.1113	143.9247	100	0.999437	-9%
Truck transportation	20.23336	47.56085	100	0.997908	6%
Transit and ground passenger transportation	-71.0912	75.16695	38	0.997346	-5%
Pipeline transportation	46.02174	28.85452	80	0.990715	2%
Air, rail, water, scenic and sightseeing, and other support activities for transportation	-292.417***	57.64384	100	0.998762	-111%
Postal service and couriers and messengers	-0.51747	15.94939	54	0.999818	-1%
Warehousing and storage	-15.6353	17.01419	43	0.993954	-3%
Information and cultural industries	-311.5044*	140.8345	100	0.99893	-7%
Motion picture and sound recording industries	64.77786	105.6985	34	0.994888	11%
Broadcasting and telecommunications	0	0	53	0.998153	0%
Publishing industries, information services and data processing services	0	0	69	0.99868	0%
Finance and insurance, real estate and renting and leasing and management of companies and enterprises	-181.89	592.3715	100	0.999239	-1%
Monetary authorities and depository credit intermediation	-273.8518*	128.4434	100	0.997881	-4%

Insurance carriers	-175.2464*	93.56451	87	0.997846	-12%
Lessors of real estate	538.1047***	133.7173	100	0.999305	114%
Owner-occupied dwellings	1201.147***	329.2185	100	0.998882	16%
Rental and leasing services and lessors of non-financial intangible assets (except copyrighted works)	-52.6838	31.45232	89	0.997504	-33%
Other finance, insurance and real estate, and management of companies and enterprises	-1131.656***	201.8118	96	0.9984	-14%
Professional, scientific and technical services	-169.389**	70.70296	100	0.999817	-4%
Administrative and support, waste management and remediation services	-87.9195	98.0109	100	0.998754	-2%
Administrative and support services	-16.4819	84.33787	100	0.998527	0%
Waste management and remediation services	-81.02037**	25.52262	100	0.996208	-6%
Educational services	-661.2107***	179.6078	100	0.998386	-11%
Universities	-262.7611**	101.2579	72	0.994497	-5%
Educational services (except universities)	-661.2107***	179.6078	100	0.998386	-11%
Health care and social assistance	-261.257	337.9263	100	0.998848	-7%
Hospitals	-315.7477*	160.0139	100	0.998591	-77%
Health care services (excluding hospitals) and social assistance	42.11839	184.5658	100	0.998664	1%
Arts, entertainment and recreation	5.675156	19.04535	100	0.999638	1%
Accommodation and food services	265.8363**	110.4224	100	0.998116	6%
Other services (except public administration)	-163.9528***	23.58048	100	0.999815	-141%
Repair and maintenance	-0.48984	42.1222	100	0.994514	0%
Religious organizations	8.971496*	4.115808	100	0.999054	140%
Grant-making and giving services, civic, and professional and similar organizations	-142.0383**	52.92686	100	0.996973	-6%
Personal and laundry services and private households	-38.00062**	12.20036	100	0.999681	-17%
Public administration	-645.1167**	274.7877	100	0.998223	-8%
Defence services	-185.2725***	46.86647	100	0.995413	-20%
Federal government public administration (except defence)	-290.4848**	112.9099	100	0.997708	-8%
Provincial and territorial public administration	-58.9011	67.55818	100	0.998965	-15%
Local, municipal and regional public administration	-100.866	64.99842	100	0.998099	-4%

Note: DD relative to baseline measures the % change in the gap between treatment and control groups before and after the treatment.

Table A2. Sectoral Emissions Difference-in-differences Coefficients

Sectoral Emissions	Difference-in-difference (DD)Coefficient (Kt CO_2)	Standard Error (Robust)	N	R2	DD relative to baseline
TOTAL GHG	-2451.641**	1104.261	150	0.9987167	-7%
ENERGY	-2761.965***	922.5526	150	0.9989722	-11%
a. Stationary Combustion Sources	-2317.64***	733.986	150	0.9976473	-43%
Electricity and Heat Generation	10.30117	558.5221	150	0.9934083	1%
Fossil Fuel Production and Refining	1035.925**	381.008	150	0.9873359	50%
Mining & Oil and Gas Extraction	-917.1312**	332.9843	150	0.8900177	-7%
Manufacturing Industries	-1713.719***	283.1523	150	0.9940302	-15%
Construction	-27.31971*	14.55057	150	0.9652004	-36%
Commercial & Institutional	-467.1398**	179.6266	150	0.9903036	-30%
Residential	-140.3673	217.8721	150	0.993866	-5%
Agriculture & Forestry	-20.50822	74.86193	150	0.9482901	-17%
b. Transport1	-1942.131***	610.4552	150	0.9986464	-14%
Civil Aviation (Domestic Aviation)	-197.1371***	27.24982	150	0.9963529	-15%
Road Transportation	-605.7042***	181.144	150	0.9993763	-11%
Light Duty Gasoline Vehicles	-106.4134*	59.09645	150	0.9994599	-2%
Light Duty Gasoline Trucks	-575.2751***	129.483	150	0.9983255	-1291%
Heavy Duty Gasoline Vehicles	-110.4043**	41.98713	150	0.992496	-10%
Motorcycles	-1.033311	0.764394	150	0.9751076	-6%
Light Duty Diesel Vehicles	1.626634	2.986044	150	0.98672	5%
Light Duty Diesel Trucks	-36.94714***	7.917239	150	0.9873409	-23%
Heavy Duty Diesel Vehicles	213.5466	155.4013	150	0.9970341	63%
Propane & Natural Gas Vehicles	-12.74778	20.38206	150	0.9524866	-2%
Railways	-240.5959*	126.8317	150	0.8252625	-412%
Navigation (Domestic Marine)	684.2004**	248.1438	150	0.9087162	59%
Other Transportation	-1386.766*	668.4687	150	0.9827083	-26%
Off Road Gasoline	-82.05901	63.7688	150	0.9672103	-7%
Off Road Diesel	-1367.25*	671.733	150	0.9486465	-266%
Pipelines	53.90253	86.85114	150	0.9282668	2%
c. Fugitive Sources	1451.402***	186.0887	150	0.9972575	22%

Coal Mining	26.80673	48.32451	150	0.9610944	4%
Oil and Natural Gas	1447.156***	164.4	150	0.9972496	24%
INDUSTRIAL PROCESSES	432.2726	478.1782	150	0.9835299	16%
a. Mineral Products	-56.95486	69.53793	150	0.992162	-3%
Cement Production	-100.9605	59.38429	150	0.9912096	-10%
Lime Production	10.77875	10.0121	150	0.9874361	3%
Mineral Products Use	19.48507**	7.706378	150	0.977877	8%
b. Chemical Industry	Limited Data				
Nitric Acid Production	-2.026354	6.44799	150	0.9918652	-3%
Adipic Acid Production	793.552*	401.128	150	0.6643421	19%
Petrochemical Production3	1.808433***	0.516649	150	0.9802574	27%
c. Metal Production	-133.267	133.0271	150	0.9928386	-5%
Iron and Steel Production	No Data				
Aluminum Production	-343.12**	138.9432	150	0.9910872	-21%
SF6 Used in Magnesium Smelters and Casters	No Data				
d. Production and Consumption of Halocarbons and SF6	105.9757**	35.67926	150	0.9890847	11%
e. Other & Undifferentiated Production	-276.731*	129.8234	150	0.9527335	-6%
SOLVENT & OTHER PRODUCT USE	-8.28013**	3.177203	150	0.9721899	-18%
AGRICULTURE	-285.066***	87.00653	150	0.9973136	-18%
a. Enteric Fermentation	-56.9084	38.16941	150	0.9949314	-5%
b. Manure Management	3.762848	12.30689	150	0.9956182	1%
c. Agriculture Soils	-247.818***	57.40173	150	0.9940996	-133%
Direct Sources	-151.562***	37.82555	150	0.9905668	-151%
Pasture, Range and Paddock Manure	-29.8475***	7.280665	150	0.9933918	-16%
Indirect Sources	-4.09081	62.90151	150	0.9634002	-1%
d. Field Burning of Agricultural Residues	0.999871	2.376307	150	0.7423185	2%
WASTE	175.3327***	42.64734	150	0.9980358	6%

Note: DD relative to baseline measures the % change in the gap between treatment and control groups before and after the treatment.

Stata Code For GDP Analysis

```
clear all

use "E:\MA Paper\Data7Nov\Stage 1 files\DataSetStage1newnames.dta"

**********************************************************

*Generating interaction term variable for BC and tax dummy

**********************************************************

g dtax=0

replace dtax=1 if year>2007 & province=="British Columbia"

**********************************************************

*Generating Province ids for panel data setup

**********************************************************

gen provid=0

replace provid=1 if province=="Newfoundland and Labrador"

replace provid=2 if province=="Prince Edward Island"

replace provid=3 if province=="Nova Scotia"

replace provid=4 if province=="New Brunswick"

replace provid=5 if province=="Quebec"

replace provid=6 if province=="Ontario"

replace provid=7 if province=="Manitoba"

replace provid=8 if province=="Saskatchewan"

replace provid=9 if province=="Alberta"

replace provid=10 if province=="British Columbia"

replace provid=11 if province=="Yukon"

replace provid=12 if province=="Northwest Territories"

replace provid=13 if province=="Nunavut"

**********************************************************

* setting data as panel

**********************************************************
```

```
xtset provid year

*********************************************************************

*Generating a matrix to store the regression coefficients for each sector

*********************************************************************

matrix diff = J(3,119,.)

scalar col=1

**************************************************************************

* Running regressions for each sector in a loop and storing coefficients in a
matrix

**************************************************************************

foreach var in allind goodsprodind serviceprodind industrialprod energy
agri_forest_fish_hunt cropanimalprod forestrylogging fishhunttrap
supportagri_forest miningoilgasext oilgasext coalmining metaloremining
nonmetalminiquarry supportminioilgasext utilities electricpowgentransdist
naturalgasdist watersewothsys construction resbuildingconst
nonresbuildingconst transengconst oilgasengconst electricpowengconst
commengconst otherengconst repairconst otherconstind manufacturing
durablesmanu nondurablesmanu animalfoodmanu sugarconfectprodmanu
fruitvegepresvspecfoodmanu dairyprodmanu meatprodmanu seafoodprodpreppack
miscfoodmanu softdrinkandicemanu breweries wineries distilleries tobaccomanu
textileproductmills clothingmanu leatherprodmanu woodprodmanu pulppapermills
convpaperprodmanu printingandrelatedact petroleumcoalprodmanu basicchemmanu
resinsynrubbfibmanu pestfertagrichemmanu pharmamedmanu miscchemmanu
plasticprodmanu rubberprodmanu cementconcreteprodmanu miscnonmetalminprodmanu
primfabmetalprodmanu machinerymanu computerperipheralequipmanu
electronicprodmanu householdappmanu electricalequipcompmanu motorvehiclemanu
motorvehiclebodytrailermanu motorvehiclepartsmanu aerospaceproductpartsmanu
railroadrollingstockmanu shipandboatbuilding othertransportequipmanu
furniturerelatedprodmanu miscmanu wholesaletrade retailtrade
transportandwarehousing trucktransportation transitandgroundpasstrans
pipelinetransportation airrailwaterscenicsupp postalcouriersmessengers
warehousingandstorage infoandculturalind motionpicturerecind
broadcastandtelecom pubinfoservdataproc fininsurrealrentmgmt
monauthdepcredinter insurancecarriers lessorsofrealestate owneroccupieddwel
rentleaslesnonfin otherfininsurrealmgmt profscitechserv adminsuppwastemgmt
adminsupportservices wastemgmtremed eduservexcuni universities eduservexcuni
healthcareandsocialass hospitals healthcareexchossocass
artsentertainrecreation accommfoodservices otherservicesexcpublicadmin
repairandmaintenance religiousorganizations grantcivicprofsimorg
personallaunprivhouseh publicadministration defenceservices
fedgovpubadminexcdef provterrpublicadmin localmuniregpublicadmi {
```

```
xi:xtreg `var' i.province employment cfc  multifactorproductivity investment
dtax, fe i(year) vce(robust)

estimates store `var'


scalar t = _b[dtax]/_se[dtax]

matrix diff[1,col]= _b[dtax]

matrix diff[2,col]= 2*ttail(e(df_r),abs(t))

matrix diff[3,col]=_se[dtax]

scalar col=col+1

}

matrix diffindiff=diff'

*********************************

*Converting matrix into a varible

*********************************

svmat diffindiff

*************************************
```

Stata Code for Emissions Analysis

```
clear all

use "G:\MA Paper\Data7Nov\Stage 2 files\DataSet1Stage2.dta"

**********************************************************

*Generating interaction term variable for BC and tax dummy

**********************************************************

g dtax=0

replace dtax=1 if year>2007 & province=="British Columbia"

**********************************************************

*Generating Province ids for panel data setup

**********************************************************

gen provid=0

replace provid=1 if province=="Newfoundland and Labrador"

replace provid=2 if province=="Prince Edward Island"

replace provid=3 if province=="Nova Scotia"

replace provid=4 if province=="New Brunswick"

replace provid=5 if province=="Quebec"

replace provid=6 if province=="Ontario"

replace provid=7 if province=="Manitoba"

replace provid=8 if province=="Saskatchewan"

replace provid=9 if province=="Alberta"

replace provid=10 if province=="British Columbia"

replace provid=11 if province=="Yukon"

replace provid=12 if province=="NWT and Nunavut"

**********************************************************

* setting data as panel

**********************************************************

xtset provid year
```

```
***********************************************************************

*Generating a matrix to store the regression coefficients for each sector

***********************************************************************

matrix diff = J(3,59,.)

***************************************************************************

*Running the regression with fixed effect, BC vs Rest of Canada for all 57
sectors and sub sectors and store DD coefficients with p-values and se in a
matrix

***************************************************************************

scalar col=1

foreach var in totalghg  energy  astationcombustion
electricityheatgeneration  fossilfuelprodrefining  miningoilgasext
manufacturingindustries  construction  commercialinstitutional  residential
agricultureforestry  btransport1  civildomesticaviation  roadtransportation
ldutygasolineveh  ldutygasolinetrucks  hdutygasolinevehicles  motorcycles
ldutydieselveh  ldutydieseltrucks  hdutydieselvehicles propanenatgasveh
railways  navigationdommarine  othertransportation  offroadgasoline
offroaddiesel  pipelines  cfugitive  coalmining  oilnaturalgas
industrialprocesses  amineralproducts  cementproduction  limeproduction
mineralproducts  bchemicalindustry  nitricacidprod  adipicacidprod
petrochemicalprod  cmetalprod  ironandsteelprod  aluminumprod  sf6
dprodnconsumphalocarbsf6  eotherundiffprod  solventoth  agriculture
aentericfermentation  bmanuremanagement  cagriculturesoils  directsources
pastrangepadman  indirectsources  dfieldburnagriresi  waste
asolidwastedispland  bwastewaterhand  cwasteinciner {


xi: xtreg `var' i.province dtax  electricitybyfossil  energyintensity
energymix  gdp industrystructure,fe i(year) vce(robust)


estimates store `var'


scalar t = _b[dtax]/_se[dtax]

matrix diff[1,col]= _b[dtax]

matrix diff[2,col]= 2*ttail(e(df_r),abs(t))

matrix diff[3,col]= _se[dtax]

scalar col=col+1
```

```
*replace temp=0

}

matrix diffindiff=diff'

**********************************

*Converting matrix into a varible

**********************************

svmat diffindiff

**************************************
```