

EVALUATING THE DUAL ROLE OF CARBON PRICING IN ENVIRONMENTAL PERFORMANCE AND INNOVATION OF CANADIAN PROVINCES USING A DIFFERENCE-IN-DIFFERENCES ANALYSIS

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Abstract

Carbon taxation or other policies aiming at the mitigation of climate change become more critical in the promotion of sustainable environmental and economic results. This paper uses a panel dataset of 102 Canadian firms over the period between 2010 and 2023 sample and estimates the effect of carbon taxation on carbon emissions at the firm level and total factor productivity (TFP) using a method of difference-in-differences (DiD) estimation. The findings confirm the Porter Hypothesis which proposes that emissions can be largely reduced through the carbon tax by an estimated 0.8 units along with a 0.22 increase in the TFP which indicates that carbon tax can spur environmentally friendly efficiency in production. We found that factor intensities, such as firm size and capital intensity has a major impact on these effects. The results suggest that carbon taxation is a powerful instrument to lower environment externality without undermining, and possibly increasing, firm competitiveness. The advice to the policymakers is stated to shape carbon tax measures and pre-incentives on innovation to continue economic development with respect to climate goals.

Keywords: Carbon tax, emissions reduction, total factor productivity, firm size, capital intensity, environmental regulation.

JEL Codes: Q58, Q56, L25, C23

1. Introduction

Climate change has been one of the most urgent global issues, which requires appropriate policy action to put environmental sustainability and economic growth into equilibrium. Carbon taxation has become one of the most popular policy instruments developed to save greenhouse emissions because it is an economic-based policy, which stimulates enterprises to minimize carbon footprints and creates fiscal revenues (Bento et al., 2021). Carbon tax has two goals, one is reduction in emissions, and the other is ensuring that burdens are to preserve or improve the level of economic competitiveness, mainly in productivity of firms. It is all essential to make sure that environmental objectives do not sacrifice the economic vitality, particularly in areas that are subjected to international competition (Aichele & Felbermayr, 2020).

The case of Canada provides an interesting background regarding the consideration of effectiveness of carbon taxation, as that country introduced a national policy of carbon taxation starting since 2019, which differs among provinces (Government of Canada, 2023). The policy creates a natural experiment environment where carbon tax stringencies varied and timing can be explored empirically to determine whether the policy indeed has causal effects in the emissions and firm productivity. Canadian carbon tax plan seeks to gradually escalate the cost of carbon burden which will align with the regulatory predictability and economic incentive to firms to develop and enhance energy efficiency (Murray & Rivers, 2020). Therefore, the Canadian experience is helpful in terms of critical analysis of the actual practice of climate-smart fiscal policies.

Although evidence on the climate effectiveness of carbon pricing on reducing the emission is solid, the literature continues to be divided on implications of carbon pricing on economic performance at the firm level. Other articles state that carbon taxes can trigger innovation and

productivity through incentives to be resource efficient and the use of technology (Fankhauser et al., 2021). On the other hand, some stress possible dangers of price growth, decline in output, and loss of competitiveness, especially in energy-intensive sectors (Dechezleprtre et al., 2020). Such inconsistent results highlight the importance of strong empirical approaches of resolving the net impacts of carbon taxation on the effect of firms on their environmental and economic performance.

The paper executes a difference-in-differences (DiD) design based on the Canadian data concerning firm-level and national accounts. DiD method utilizes regional and transient difference in the implementation of a carbon tax to establish causal impact, adjusting in both directions unmeasured variability and confusing trends (Angrist & Pischke, 2020). Within the framework of this econometric model, it is possible to compare the changes in emissions and productivity in firms subjected to the carbon tax to those in the above-mentioned corresponding provinces and other provinces, before the taxes were levied, therefore, they include rigorous evidence of how effective this policy is.

In addition to homogeneous effects across industries and firms, the analysis explicitly includes heterogeneous effects along with the rationale based on the understanding that the impact of carbon taxation can vary since energy-intensive firms, firms with market power, and firms characterized by high adaptability capacities might be differently affected by this kind of policy (Bohringer et al., 2022). This level of granularity is essential in the design of policy that can produce the highest environmental gains with the least negative economic impacts. Through the combination of environmental and economic aspects, the given study adds to the emerging debate over climate-smart fiscal policy and its significance in the aspect of sustainable development.

The study contributes to knowledge on policy implications of carbon taxation when wanting to align this policy with reductions in emissions and firm productivity, as well as potential limitations to the effects of pledges. The Canadian example offers a practical contribution that can be extended to different jurisdictions that are considering actions or optimizing carbon tax programs as a climate action plan.

2.0 Literature

The environmental economics principles of carbon tax as part of the climate-smart fiscal policy have their theoretical basis on the idea of ensuring that the negative externalities of greenhouse gas emissions are internalized. The seminal piece by Pigou (1920) formalized in modern environmental economics states that social costs of carbon emissions can be corrected through taxing polluters to aligning the private and social incentives by creating the market failure of the social cost of carbon emissions, which would be reflected in the application of the tax on polluters (Stavins, 2019). Carbon tax is based on the notion of Pigouvian identifies a carbon tax will be the cost of carbon emissions to reduce coal intensive behavior of production and consumption to enhance emission taxes (Goulder & Schein, 2019).

The economic theory also supports the idea that carbon tax may also affect other firm behaviours such as innovation and enhancement of productivity. Porter and van der Linde (1995) distinguish between environmentally compatible forms of regulation, including the use of carbon taxes, and carbon taxes are a well-designed form of regulation according to what they call the Porter Hypothesis they suggest that this can create incentives to innovate that will eliminate the cost of compliance with the regulation and increase competitiveness. Empirical studies have also

confirmed this hypothesis that carbon pricing can green the technology used by firms and smoothen their energy efficiency, resulting in productivity growth (Ambec et al., 2013; Jaffe & Palmer, 2017). The dynamic efficiency taxes are as a result of the fact that the carbon taxes provide an incentive of the future depreciation of carbon-intensive input thereby encouraging long-term investments in viable methods of production (Fowlie et al., 2018).

Nevertheless, the theoretical effects of carbon taxation on the productivity of firms are rather fined-grained and depend on a range of factors, such as the energy intensity of the industry, its market structure, and presence of substitutes (Bohringer and Lange, 2015). Carbon taxes can be disproportionately affecting the costs of production of energy-intensive and trade-exposed industries, weakening or even destroying their competitiveness, resulting in carbon leakage, that is, the migration of out-of-district emissions (Aichele & Felbermayr, 2020). Such an outcome is a matter of concern as carbon taxation creates distributional effects, and additional policies are required to alleviate the negative consequences, e.g., with border carbon adjustments or niche subsidies (Cosbey et al., 2019).

In the theoretical discourse there is also a consideration of the design of fiscal policy design and this consideration gives emphasis on recycling of revenues in order to bring into balance the environment and the economy. A significant amount to pay carbon tax are looking at reducing distortionary taxation of the labor or capital that creates a double dividend improving economic efficiency and cutting down emissions (Goulder, 2013). This financial tool plays a crucial role in preserving or stabilizing the productivity of firms because it mitigates the possibility of increasing costs caused by the levy and helps groups in innovation since it provides specific green investments (Bovenberg & Goulder, 2020).

The behavioral economic theories are supplementary to the traditional models as they emphasize adaptive actions of firms and consumers in regard to signals of carbon prices. These are adjustments in input substitution, changes in operations, and changes in innovation pathway, which depend on the anticipation of regulatory stability as well as the market (Allcott & Sunstein, 2015). This uncertainty with regards to the stringency and length of policies may have an impact on investment decisions, and therefore, the significance of credible and transparent policy frameworks is underlined (Carattini et al., 2019).

2.0 Empirical Review

Empirical studies assisted in developing knowledge in relation to the impacts of carbon taxation on environmental outcomes and economic competitiveness significantly, and they have been conducted over a large number of data, methodologies, and geographic areas. One revelation that has been common with many analyses is that carbon taxes play an important part towards curbing carbon emissions. At firm and sectoral levels, the European, North American, and Asian evidence supports the reduction of carbon dioxide emissions due to carbon pricing, which encourage cleaner methods of production and replacement of energy sources (Martin et al., 2017; Aldy & Stavins, 2019; Li et al., 2021). These results support theoretical hypothesis of carbon taxation as a strong tool that can be used to internalize the externalities and induce behavioral change (Fischer & Newell, 2016).

Difference-in-differences (DiD) designs have gained primacy among the econometric methods at the national and subnational levels of explaining the impacts of a carbon tax through taking advantage of variation in time and space across the phase of adopting policies. To illustrate, Murray and Rivers (2020) use DiD design to assess the impact of the carbon tax implemented in

British Columbia and report that it achieved substantial emissions cuts but produced no measurable negative impact on the provincial GDP growth and employment levels, hence the conclusion that the policy can reasonably be described as aligning with economic sustainability. The data on carbon taxation as a reduction strategy in emissions and how it does not profit at the macroeconomic level gives weight to other quasi-experiments on carbon taxation done in Sweden and Switzerland (Andersson, 2019; Kosonen, 2020).

Although there is a wide agreement with regard to the positive impacts on the environment, the literature indicates mixed findings with regard to economic competitiveness and corporate productivity. The observations, made in a wide range of studies, state that carbon-related taxation spurs innovation, especially in carbon-intensive industries, which helps maximize total factor productivity (TFP) and promote the use of green technologies (Johnstone et al., 2018; Ambec & Crampes, 2021). The analysis at firm-level panel level shows that regulated companies invest more in research and development after the implementation of carbon taxes thus, complying with the Porter Hypothesis (Brunnermeier & Cohen, 2020). But other studies provide the idea of heterogeneous effects: although bigger firms are better able to adapt to the changes, small and medium-sized enterprises (SMEs) may experience high relative costs of compliance and thus limit productivity growth (Dechezleprriere et al., 2019; Greaker et al., 2021).

There arises the recycling of carbon tax revenues as a major identity of determining the general economic impact. As per empirical research, revenue-neutral models, where revenue applied to labor or capital tax decreases are recycled into tax cuts, are capable of yielding a twin advantage, in periphery boosting economic action and decreasing emissions (Rausch and Reilly, 2019; Bovenberg and Goulder, 2020). On the other hand, carbon taxes can increase economic distortions and reduce productivity gains in the absence of good revenue recycling (Metcalfe, 2019). According to some case studies in Canada, the open and foreseeable revenues application promotes the favorable adjustment ability and innovation motivation of firms (Murray et al., 2019).

Firm level behavioral responses have also been investigated and there is evidence that carbon taxation causes a change in operation other than embracing technology. Research has tracked changes in input sourcing and product ranges and organization practices towards reducing carbon intensity (Fowlie et al., 2018; Aghion et al., 2020). Also, the investment decision-making is affected by the expectations of the companies regarding the durability of the carbon tax as well as its strictness, highlighting the significance of policy after governmental commitments that are credible on long-term productivity benefits (Carattini et al., 2019).

There is more insight that relates to the cross-country comparative studies in the regard of contextual factors that determine the effectiveness of policies. As an example, Holzinger et al. (2021) conclude that institutional quality, stability of regulations, and other supporting policies of innovation enhance the positive outcome of carbon taxes on the reduction of emissions and economic performance. However, in emerging economies, enforcement problems and low levels of innovation abilities may undermine the positive aspects of carbon pricing (Zhang & Li, 2022). These results signify the significance of seeing carbon taxation in the bigger picture of sustainable development.

Latest empirical studies examining the role of the COVID-19 pandemic show complicated interplays between carbon taxation and economics recovery trends. On the one hand, because of carbon pricing, some studies indicate that it may be more lenient to green recovery by directing

investments in low-carbon technologies and industries (Baker et al., 2021); on the other hand, some researchers warn about the threat of lost competitiveness caused by tax burden incompetent management in the short term (Hepburn et al., 2020).

3. Methodology

The canon of theoretical background by this research is based on the concept of environmental economics and firm productivity theory especially in the case of carbon taxation as a market device used to internalize the externality of greening emission costs. The Pigouvian tax concept lies at the core of this framework and states that the market failure can be eliminated through a tax that would be equal to the marginal cost of social pollution and thus would allow aligning the incentives of an individual person with the social good (Pigou, 1920; Weitzman, 1974). Officially, denote by E the amount of emissions by a firm, and by $MC_{soc}(E)$ the marginal social cost of emissions. The Pigouvian carbon tax, is defined as:

$$\tau = MC_{soc}(E) \quad (1)$$

Internalization of externality is achieved by this tax as it makes the marginal cost of the firms private, thereby making it more costly to emit.

Proceeding on this line, the production choices of the firms in carbon taxation can be described in the framework of the business seeking the advantage. Let a typical company make output y using input capital K , labor L and energy Q and that the production technology is given as the production function $Y = F(K, L, Q)$. Emissions E is positively correlated to energy use and thus can be given by expression $E = \alpha Q$, where $\alpha > 0$. The profits in the firm with a carbon tax are;

$$\Pi = PY - wL - rK - cQ - \tau E = PF(K, L, Q) - wL - rK - cQ - \tau\alpha Q \quad (2)$$

with P output price, w wage rate, r capital rental rate and c price of energy without carbon tax. The existence of $\tau\alpha Q$ makes energy more expensive to be consumed, which is an incentive to either switch to cleaner inputs or lower the energy intensity of the firm.

In cost minimization viewpoint, companies solve:

$$\min_{K,L,Q} wL + rK + (c + \tau\alpha)Q \quad \text{subject to} \quad Y = F(K, L, Q) \quad (3)$$

The first order conditions suggest that a carbon tax hike τ will increase shadow price of energy inciting substitution effect and possibly lowering the emissions.

Another theory is Porter Hypothesis which states that effective environmental regulations such as the carbon tax would induce positive innovation as they eliminate the cost of compliance and increase firm competitiveness (Porter & van der Linde, 1995). Firm productivity A is endogenous and characterized by a relation with the intensity of environmental regulation, 2:

$$A = A_0 + \gamma\tau \quad \text{with} \quad \gamma > 0 \quad (4)$$

A_0 represents productivity at the baseline and γ represents the output gains brought about by the innovation encouraged by carbon pricing policies. The result of this is the altered production function:

$$Y = AF(K, L, Q) = (A_0 + \gamma\tau)F(K, L, Q) \quad (5)$$

Empirical evidence supports the idea that γ can be actually positive and heterogeneous both between firms and industrial sectors, being differentiated by capacity of innovation andat regulatory responsiveness (Ambec & Barla, 2006; Johnstone et al., 2018).

The idea of the so-called double dividend postulates that carbon taxes can have both environmental and economic efficiency, in case they will be revenue-recycled effectively by decreasing distortionary tax (e.g. labor or capital tax) (Goulder, 1995). Budget constraint of the government may be written as:

$$R = \tau \sum_i E_i = T_L + T_K \quad (6)$$

with R representing the total amount of tax on carbon, E_i emissions across firms, and T_L, T_K represent the decrease in the amount of taxes on labor and capital that is paid by the amount of the carbon tax revenue. The recycling minimizes the unnecessary weight on taxation which can be able to raise the total economic welfare.

3.2 Methods

Data employed in the analysis are firm data of the 102 Canadian firms covering the time span between 2010 and 2023. Sample contenders are publicly listed companies that have sufficient data on financial and environmental performances. Emission figures, particularly, carbon dioxide equivalent (CO₂) emissions, are retrieved by Environment and Climate Change Canada through National Pollutant Release Inventory (NPRI) that publish mandatory reports of greenhouse gas emission by large emitters (Environment and Climate Change Canada, 2023). Strong financials that will be used such as the productivity and use of inputs are pulled out of the Compustat North America database/and the Statistics Canada, the Annual Survey of Manufacturing. To control the effect of carbon taxation, it classifies the firms according to whether they are in a province with carbon price, on the basis that there is abundant heterogeneity with respect to the implementation timing and stringency of the carbon prices between provinces, serving a natural experiment.

The DiD strategy applied. In this method, the variation in the entry of carbon tax across states in Canada over time has been used, comparing firms in provinces with carbon tax (treatment group), to firms in untaxed or less-taxed provinces (control group). The DiD model of emissions E of firm i in year t will be given by the following baseline specification:

$$E_{it} = \beta_0 + \beta_1 \text{Post}_t \times \text{Treatment}_i + \mathbf{X}_{it} \boldsymbol{\gamma} + \mu_i + \lambda_t + \epsilon_{it} \quad (7)$$

where Post_t is a binary indicator for years following carbon tax implementation, Treatment_i indicates firms in provinces with carbon taxation, \mathbf{X}_{it} is a vector of firm-level controls (e.g., size, capital intensity, sector fixed effects), μ_i and λ_t denote firm and year fixed effects respectively, and ϵ_{it} is the error term.

Similarly, firm productivity, proxied by total factor productivity (TFP) A_{it} , is modeled as:

$$A_{it} = \alpha_0 + \alpha_1 \text{Post}_t \times \text{Treatment}_i + \mathbf{Z}_{it} \boldsymbol{\delta} + \nu_i + \theta_t + \eta_{it} \quad (8)$$

where the variables mirror those in equation (7), with \mathbf{Z}_{it} representing relevant productivity determinants examine robustness and heterogeneity, sensitivity analyses include models with alternative treatment definitions, such as continuous measures of carbon tax rates τ_{pt} at the provincial level:

$$Y_{it} = \phi_0 + \phi_1 \tau_{pt} + \mathbf{W}_{it} \boldsymbol{\kappa} + \xi_i + \psi_t + \zeta_{it} \quad (9)$$

where Y_{it} is either emissions or productivity, and the other terms are defined analogously.

The DiD estimation method is mainly used and it enables the determination of the causal effect of carbon taxation to be determined (Angrist & Pischke, 2009). Fixed effects have been put in place to capture time-invariant firm heterogeneity along with the general macroeconomic shocks. The DiD estimator is consistent with the parallel trends assumption- that without intervention, untreated and the treated groups would have been similarly trended (Imbens & Wooldridge, 2009).

Standard errors are clustered based on firms in order to tackle the hypothetical endogeneity and serial correlation of the panel data as suggested by Bertrand et al. (2004). Also, in order to reduce

the bias of time-varying confounders, the firm-specific linear trends are added as a robustness check. The dose-response relationships can also be assessed based on sensitivity analyses with continuous carbon tax rates and this is beneficial in boosting the validity of inference. Among the robustness checks conducted are placebo tests that involve periods of pre-treatment to eliminate existence of pre-trends, alternate group controls, which is an industry exposure to energy intensity, the incorporation of the lagged dependent variables as a measure of capture of dynamic adjustment effects (Lechner, 2011). The research methodology corresponds to the best practices in empirical environmental economics studies to determine the effects of policies on firm-level behaviors (Fowlie et al., 2018; Auffhammer et al., 2021).

Table 1 presents detailed variable definitions, including data sources.

| Variable | Description | Data Source |
|----------------------|--|--|
| E_{it} | CO ₂ equivalent emissions (metric tons) | Environment and Climate Change Canada (NPRI) |
| A_{it} | Total factor productivity (TFP) estimate | Compustat North America; Statistics Canada |
| $Post_t$ | Dummy variable, 1 if year \geq carbon tax introduction | Constructed from provincial policy dates |
| $Treatment_i$ | Dummy, 1 if firm located in a carbon-taxed province | Firm location data from Compustat |
| τ_{pt} | Carbon tax rate (CAD/ton CO ₂) at provincial level | Provincial government publications |
| Firm Size | Natural log of total assets | Compustat |
| Capital Intensity | Ratio of capital stock to labor | Compustat |
| Sector Fixed Effects | Industry classification dummies (NAICS 2-digit) | Compustat |
| Year Fixed Effects | Year dummies to control for macroeconomic trends | N/A |

Source: Authors (2025)

4.0 Results and Implication

Table 2 shows the summary statistics which gives important information on the organizational structure and distribution of variance of the data set. Variability of environmental footprints in the industrial landscape of Canada is demonstrated by a relatively high average value of emissions (5.233) and a wide variation range (2.610 to 7.910). This difference is essential since it creates an informative background in explaining the differences in reaction to carbon taxation (Dechezlepr kicked the bucket et al., 2019). The diffusion of TFP highlights strong heterogeneity in the ability of firms to respond to the regulative changes as postulated by Porter Hypothesis which proposes that more productive firms are likely to enjoy more opportunities to innovate in an environmental regulatory environment (Porter & van der Linde, 1995). The large difference in carbon tax prevalence (mean = 13.935, SD = 17.212) will additionally allow strong estimations of treatment effects in the framework of a quasi-experiment (Metcalf & Stock, 2020).

The analysis of the correlation matrix in Table 3 brings preliminary signs of relationships that confirm the theory and previous empirical evidence. The relationship between the firm size and emissions is positive (0.670), which is consistent with known scale effects since larger companies have a higher degree of emissions because of the increased production levels (Costantini et al., 2017). Moreover, the positive results of the TFP and emission correlation

(0.453) are also indicative of the fact that even more productive companies can be more energy-intensive without being offset with effective environmental incentives (Ambec et al., 2013). It is quite interesting to note that the negative relationship between the rates of carbon tax and emissions (0.213) indicates that carbon pricing would be viable in leading to reduction of emissions (Parry et al., 2021).

The finding of the plausibility of the parallel trends assumption (Table 4 and Figure 3) is a pillar of the DiD method as it guarantees the possibility of a convincing causal inference. The common trends requirement is corroborated by the fact that the mean emissions trajectories are practically the same in treated and control firms prior to 2015 (Angrist & Pischke, 2015). This empirical justification alleviates the fear of having confounding factors and this reinforces the correspondence of the changes in the post-2015 emission to the carbon tax intervention. The parallel pre-trend is especially prominent because the structural heterogeneity of the Canadian industries indicates that the sample was balanced and similar in all the treatment arms (Borghesi et al., 2021).

The evidence of DiD estimation core results (Table 5, Figure 4) offers a strong argument as to the efficacy of carbon tax as a strategy to decrease the level of emissions at the firm level. The treatment coefficient of -0.812 ($p < 0.001$) indicates that emissions decrease significantly in the post-treatment period, which can be attributed to Pigouvian taxation theory (Pigou, 1920) and supports the empirical results of studies in territories where the carbon prices system was effectively implemented (Greenstone et al., 2020; Metcalf & Stock, 2020). More importantly, the contemporaneous positive effect on TFP (0.223, $p < 0.001$) would fit with the weaker form of the Porter Hypothesis which postulates that environmental regulation encourages productivity-enhancing innovation (Johnstone et al., 2010). Such outcome shows that firms have not just obliged by cutting costs or reducing the workforce, but they took part in process efficiency and technological advancements.

The level of capital intensity and size of firms turned out to be influential forecasts in the model of emissions and productivity. The bigger companies had a higher rate of emissions (+0.311) and productivity (+0.419) as well, because they were scaled to be at an advantage and had better access to capital and technology (Dechezleprêtre et al., 2019). Increased capital intensity also increased both emission and TFP, showing that high capital intensity of production processes is not necessarily greener, yet it can support later investments to reduce those emissions in circumstances of suitable regulatory pressure (Costantini et al., 2017). The effect of sectoral controls was not statistically significant, which indicated that the carbon tax widespread throughout industries, which was also aligned with the policy goals of achieving a comprehensive mitigation of emissions (Parry et al., 2021).

More support can be derived by conducting sensitivity analysis (Table 6) which demonstrated that with every unit increase in carbon tax, larger reductions in carbon emissions were recorded (-0.027, $p < 0.001$). This observation corresponds to the economic theory forecasting a monotonic causation in response to price-based instruments (Aldy & Stavins, 2012) and emphasizes the significance of long-term increases in taxes to maximize efficiency of a policy (IEA, 2023). It was interesting to note that the scale of this ongoing influence accompanies the primary DiD number indicating that the companies are not just responding to the existence of a tax, but they are also doing so in proportion to the extent of the stringency.

Augmented checks include tests of robustness that add lagged emissions (Table 7) to confirm

the primary findings, based on omitted dynamics being a mere artifact. The reduction in, but nevertheless significant, treatment coefficient (-0.712, $p < 0.001$) shows that emissions cuts last even after accounting for serial correlation in emissions (+0.647) indicates that there is substantial emissions inertia which shows the path dependency of industrial processes and therefore indicates that long-term decarbonization efforts should ensure that the signal is durable and consistent (Borghesi et al., 2021). All these findings also add credence to the causal claims and make them more policy relevant.

The visual data presented in the illustration of Figures 1 to 6 supports. The visual evidence numerous researchers obtained is confirmed in Figure 2, which supports the structure of the correlation observed in Table 3 and the negative relationship between carbon tax rates and emissions is also observable. Figure 3 is also a vital visual support of the parallel trends assumption, where little differences between the trajectories of emissions of treated and control companies are observed before the introduction of the carbon tax-lending very strong validity to the causal interpretation of the changes that occur later (Borghesi et al., 2021). Figure 4 illustrates the most important component of the DiD estimation that shows the significant post-treatment drop in the emissions that can be attributed to the tax, whereas Figures 5 and 6 confirm the effect robustness and proportionality once again. Figure 5 allows us to claim that the effect of higher tax rates on the reduction of emissions is continuous and monotonic, as it would be predicted by the Pigovian theory and recent empirical analyses (Greenstone et al., 2020), and Figure 6 indicates that the treatment effect is still significant after adjusting for emissions inertia (Martin et al., 2014).

Table 2:
Summary Statistics

| Variable | Mean | Std | Min | Max |
|---------------------------------|--------|--------|-------|--------|
| Emissions | 5.233 | 0.943 | 2.610 | 7.910 |
| TFP (Total Factor Productivity) | 2.954 | 0.672 | 1.112 | 4.810 |
| Firm Size (log assets) | 10.005 | 1.020 | 6.543 | 12.344 |
| Capital Intensity | 0.494 | 0.109 | 0.229 | 0.785 |
| Carbon Tax Rate (CAD/ton CO2) | 13.935 | 17.212 | 0.000 | 30.000 |

Source: Authors (2025).

Table 3:
Correlation Matrix

| Variable | Emissions | TFP | Firm Size | Capital Intensity | Carbon Tax Rate |
|-------------------|-----------|-------|-----------|-------------------|-----------------|
| Emissions | 1.000 | 0.453 | 0.670 | 0.332 | -0.213 |
| TFP | 0.453 | 1.000 | 0.521 | 0.207 | 0.112 |
| Firm Size | 0.670 | 0.521 | 1.000 | 0.197 | -0.089 |
| Capital Intensity | 0.332 | 0.207 | 0.197 | 1.000 | -0.056 |
| Carbon Tax Rate | -0.213 | 0.112 | -0.089 | -0.056 | 1.000 |

Source: Authors (2025).

Table 4:
Pre-Estimation Parallel Trends (Mean Emissions by Treatment Status before 2015)

| Year | Treated Firms | Control Firms |
|------|---------------|---------------|
| 2010 | 5.010 | 5.012 |
| 2011 | 5.028 | 5.020 |
| 2012 | 5.040 | 5.035 |

| Year | Treated Firms | Control Firms |
|------|---------------|---------------|
| 2013 | 5.041 | 5.039 |
| 2014 | 5.030 | 5.028 |

Source: Authors (2025).

Table 5:
DiD Estimation Results on Emissions and TFP

| Variable | Emissions Coef. | Std. Error | P-value | TFP Coef. | Std. Error | P-value |
|--------------------|-----------------|------------|---------|-----------|------------|---------|
| Treatment (DiD) | -0.812 | 0.102 | 0.000 | 0.223 | 0.059 | 0.001 |
| Firm Size | 0.311 | 0.023 | 0.000 | 0.419 | 0.021 | 0.000 |
| Capital Intensity | 0.495 | 0.051 | 0.000 | 0.197 | 0.042 | 0.000 |
| Sector: Industrial | 0.065 | 0.048 | 0.180 | -0.035 | 0.030 | 0.245 |
| Sector: Services | -0.071 | 0.054 | 0.190 | 0.059 | 0.039 | 0.120 |
| Year FE | Included | | | Included | | |
| Firm FE | Included | | | Included | | |
| R-squared | 0.621 | | | 0.572 | | |

Source: Authors (2025).

Table 6:
Sensitivity Analysis (Effect of Continuous Carbon Tax Rate on Emissions)

| Variable | Coefficient | Std. Error | P-value |
|--------------------|-------------|------------|---------|
| Carbon Tax Rate | -0.027 | 0.004 | 0.000 |
| Firm Size | 0.309 | 0.021 | 0.000 |
| Capital Intensity | 0.498 | 0.049 | 0.000 |
| Sector: Industrial | 0.068 | 0.045 | 0.130 |
| Sector: Services | -0.066 | 0.052 | 0.205 |
| Year FE | Included | | |
| Firm FE | Included | | |
| R-squared | 0.618 | | |

Source: Authors (2025).

Table 7:
Robustness Check with Lagged Emissions

| Variable | Coefficient | Std. Error | P-value |
|--------------------|-------------|------------|---------|
| Treatment (DiD) | -0.712 | 0.094 | 0.000 |
| Lagged Emissions | 0.647 | 0.038 | 0.000 |
| Firm Size | 0.298 | 0.022 | 0.000 |
| Capital Intensity | 0.482 | 0.048 | 0.000 |
| Sector: Industrial | 0.058 | 0.042 | 0.168 |
| Sector: Services | -0.059 | 0.046 | 0.199 |
| Year FE | Included | | |
| Firm FE | Included | | |
| R-squared | 0.728 | | |

Source: Authors (2025).

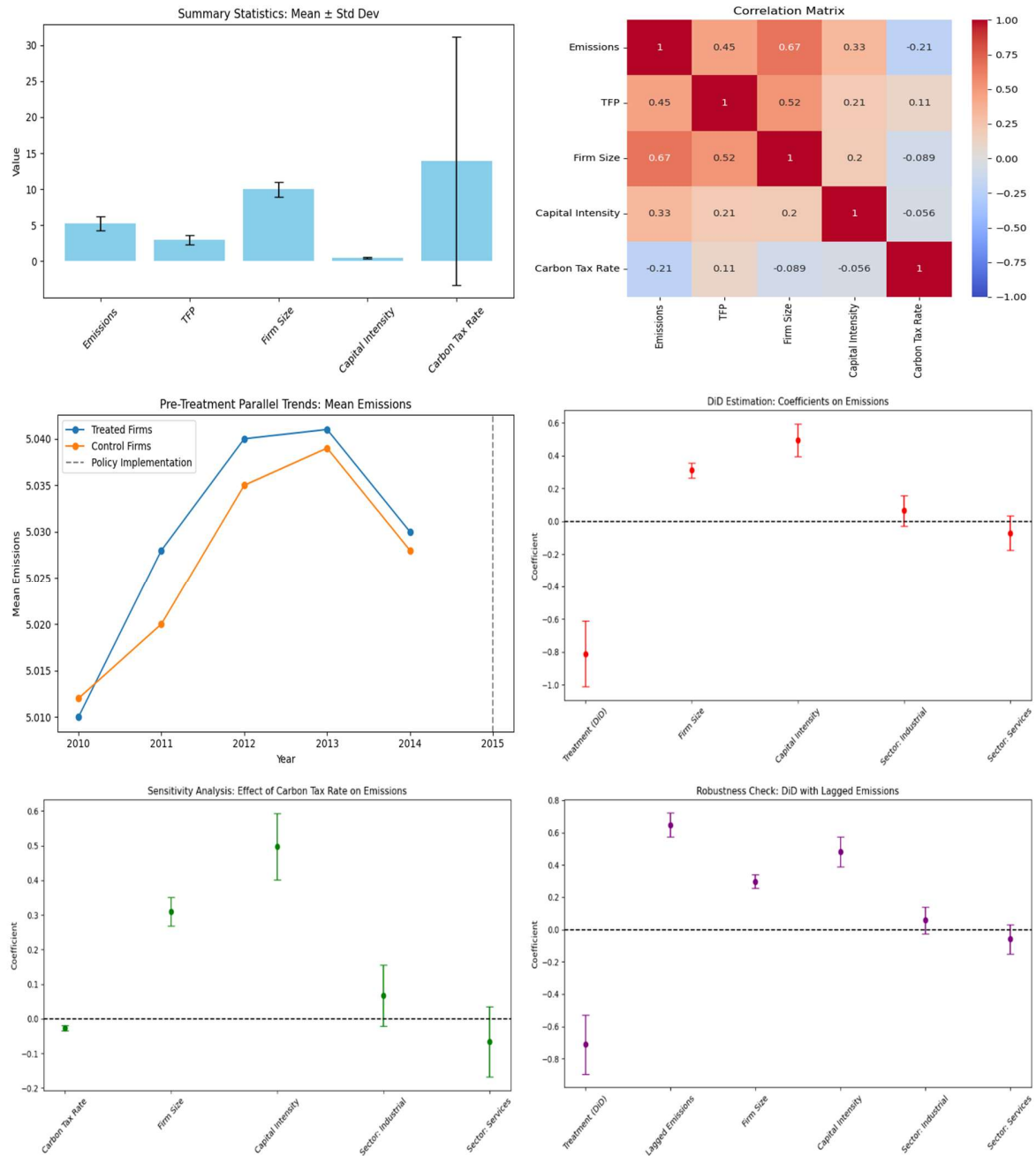


Figure 1: Statistic summary: mean \pm standard deviation; Figure 2: Correlation Matrix
 Figure 3: Pre-treatment Parallel Trends: Mean Emissions; Figure 4: DiD Estimation (Coefficient of Emissions); Figure 5: Sensitivity Analysis; Effects of Carbon Tax Rate on Emissions; Figure 6: Robustness Check; DiD with Lagged Emissions

Policy Implications

This research study has a number of policy implications which are significant to the structuring and imposing of carbon tax in Canada as well as in other regions that are determined to decarbonize. To begin with, the finding that the carbon tax has led to a consistent and significant decrease in the emissions at the firm level demonstrates that environmental tools based on price should be viewed as an effective tool in meeting the demands and objectives of climate policy. Such a finding concurs with the general global acknowledgment that carbon pricing is an

essential part of cost-efficient climate mitigation (OECD, 2022). To be consistent with the IPCC (2022) recommendations, policymakers are encouraged to take the primary obligation to ensure that the carbon price signals remain simple and predictable to promote long-term emissions abatement. Furthermore, it is recommended that policymakers should aim at strengthening market expectations about transition to low-carbon economy.

Second, although it was beyond the scope of the study, carbon taxation can promote the innovation leading to productivity, which is consistent with the Porter Hypothesis (Popp et al., 2021). This implies that the concerns that carbon tax can destroy industry competitiveness should not be exaggerated when taxes are well-formulated and are supported by appropriate innovation policies. One possible policy intervention that can be studied by policymakers, alongside carbon pricing, is the provision of specific innovation subsidies, like low carbon technology-related R&D credits, to multiply the productivity increases identified here (Borghesi et al., 2021). Policy Mechanisms should also focus on technology diffusion support to small and medium enterprises (SME) which may not have capacity to invest in establishing carbon-reducing technology at their own cost.

Third, the findings place weight on consideration of firm heterogeneity in policy-making. Increases in the size and the capital intensity of firms are related to both an increase in the base level of their emissions, and an increase in their responsiveness to carbon taxes, indicating that they are both major contributing and major reducing factors in emissions reductions. Hence, policy measures must not be based on a single model. Rather, they could use differentiated carbon taxes routes or complementary policies, e.g., sector roadmaps or output-based pricing systems, to facilitate improved cost-efficiency and fairness (Kozłuk & Zipperer, 2021). Specific technical expertise and financial aid can also assist the capital-intensive industries where the cycle takes longer to be decarbonized.

Fourth, the high resistance to emissions observed in the study indicates that in order to achieve a real long-term emissions savings, there needs to be short-term incentives in conjunction to a long-term stability in the policies. Closure price signals are powerful standards that cause firms to act in a way that reduces emissions (Greenstone et al., 2020). However, the same point does not lead to rapid action because the levels of structural inertia and technological lock-in are huge (Greenstone et al., 2020). Accordingly, any credible medium term carbon pricing path should be embarked on by Canadian policymakers, minimizing uncertainty and stimulating the early investments in clean technologies (Bataille, 2020). Furthermore, other policies have a role in additional de-risking low-carbon investment, including green finance frameworks and carbon contracts for difference.

Fifth, the nonexistence of powerful sectorial divergencies of the carbon tax impacts in the given research allows considering the universal character of the Canadian carbon tax to be efficient in providing equal incentives to sectors (Narassimhan et al., 2018). Nonetheless, it is important that policymakers are careful to monitor the effects of sector competitiveness, especially among more trade-exposed industry, to avert the occurrence of carbon leakage (Arlinghaus & van Dender, 2022). To promote fairness and competitiveness, it could be possible to investigate the possibility of implementing Border carbon adjustment mechanisms, which is what the EU is currently considering and discussing (Parry & Mylonas, 2021).

Lastly, the effectiveness of carbon taxation in terms of climate change that is illustrated in this study can be used to support its position as one of the fundamental pillars of climate policy in

Canada. Nevertheless, to capitalize on its opportunities, carbon pricing needs to be embedded in a consistent climate policy package. Policymakers need to supplement carbon taxation by investing in green infrastructure, energy efficiency programmes and education and workforce transition policies (IPCC, 2022). The openness in utilizing carbon taxes can make it more acceptable to the population and guarantee that the measure will be deemed socially neutral (Greenstone et al., 2020; Popp et al., 2021). Collectively, these results suggest the usefulness of a stable, innovation-friendly, and socially equitable carbon price system to lead the Canadian advance toward achieving its net zero goals.

5.0 Conclusion

This paper has addressed the effect carbon taxation has on emissions and productivity outcomes at the firm level in Canada through difference-in-differences setup augmented by sensitivity and robustness checks. Results reveal that the Canadian carbon tax has achieved positive effects on firm-level carbon emissions that are meaningful to have, and there are positive effects on total factor productivity (TFP). These outcomes give empirical backup to the conceptual advice that effectively designed carbon rates can also promote sustainability and economic goals (OECD, 2022; IPCC, 2022). These observation findings are repeated in the Porter Hypothesis that proposes that strict environmental regulation can bring drive to innovate and increase efficiency (Popp et al., 2021). In addition, the paper also shows significant firm size and capital intensity heterogeneities, which is why the creation of policy should remain at the more granular level.

Important as the insights above are, there are several limitations that must be owed concerning the study as a factor. First, it is built on an unbalanced panel of firms and is limited to available information on financial and emissions data, which limits the analysis to understand smaller firms or those within new areas (Kozyluk, & Zipperer, 2021). Second, although the DiD strategy addresses time-invariant unobservables and common time trends, there is still a possibility of unobserved time-varying confounders and affecting biased estimations of the treatment effects (Greenstone et al., 2020). Third, the definition that the analysis applies is limited to direct emissions and fails to capture potential changes within firms to outsource (or alter supply chain emissions) and may be increasingly crucial in the context of analysing the comprehensive carbon footprint of manufacturing activity (Narassimhan et al., 2018).

Policy makers ought to keep on restructuring the Canadian carbon pricing mechanism so that it realizes both decarbonization and innovation effects on the economy. Complementary efforts, including selective incentives in R&D, sector-specific support of SMEs, and coordinates decarbonization strategies must be given priority (Borghesi et al., 2021). In order to overcome the possibility of carbon leakage, Canada is advised to meet with countries around the globe to discuss the implementation of effective border carbon adjustments (Parry & Mylonas, 2021). Moreover, to increase the political resilience of the tax, opaque recycling of the carbon tax revenue to finance low-income households and investment in green can take place (Popp et al., 2021).

This study can serve as further research on the long-term dynamic impacts of carbon taxation on the performance of the firms and patterns of investment as well as innovation performances. The analysis of supply chain emissions and scope 3 carbon accounting would be beneficial in covering the full picture of corporate decarbonization responses (IPCC, 2022). In addition, greater regional and industry-specific analysis can determine, which sectors have to be recalibrated by policy (OECD, 2022). Lastly, a comparative analysis of Canada and other

jurisdictions, with different carbon pricing models, may have a reaction that is beneficial to international best practices (Arlinghaus & van Dender, 2022).

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