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Abstract

Exploring the role of carbon pricing policy in reducing carbon emission intensity remains an urgent and ongoing debate among academics and practitioner communities. Unlike the prior research relying on a single-factor indicator for carbon emission intensity with inadequate attention to endogeneity issues, this study investigates the influence of carbon pricing policy on Canadian provinces' carbon emissions over the sample period 2000-2022. The study makes a novel contribution by developing a theoretically grounded empirical model to mitigate the risk of biased estimates from a single-factor indicator while allowing for heterogeneity and addressing the issue of endogeneity in its production SFA (stochastic frontier analysis) settings. The study's SFA results reveal that carbon pricing policy significantly influences the level of the province's carbon emissions by reducing carbon inefficiency. Furthermore, economic growth mitigates carbon emissions intensified by an increase in the amount of capital equipment and energy consumption. On the other hand, multi-factor carbon emission efficiency exhibits significant variations across Canadian provinces. Thus, it is a worthy recommendation for Canadian policymakers to align the use of advanced equipment with carbon emission reduction targets.

1. Introduction

Mitigating climate change remains a great concern for the global ecosystem. This calls for addressing the fundamental causes of climate change such as greenhouse gases (GHGs) emissions (De Miguel et al., 2015, Duan et al., 2019). Canada responded to this climate call

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by introducing a Pan-Canadian Framework on Clean Growth and Climate Change in 2016. This framework is designed to achieve an emission reduction of 30% by 2030 compared to its 2005 levels and attain net zero emissions by 2050 (Statistics Canada, 2017). Furthermore, the federal government pushed up the target to 40% in 2021 and implemented a federal carbon tax in 2022 on provinces without any carbon pricing policies in place (GOC, 2021). The existence of carbon pricing policies in Canadian Provinces exhibits significant variations in terms of their mechanisms. For instance, some Provinces such as Ontario, Manitoba, and Yukon implement a fuel charge system while others such as Prince Edward Island utilise the output-based system. This policy heterogeneity is attributed to the flexible strategies adopted to meet their local specific needs.

The welfare impact of this carbon pricing policy as an upward trajectory of future carbon prices expected, ignites the ongoing debate in academic and stakeholder communities (Parry, 2021). Empirical findings reveal a shrinking effect on economic growth, employment rate, and welfare by 1.8%, 0.8%, and 2.5% respectively due to a future carbon price of CAD$ 170 (McKitrick and Aliakbari, 2021). However, the role of these carbon pricing policies in reducing greenhouse gas emissions has not been adequately explored in the context of Canadian provinces compared to numerous studies (such as Ren et al., 2024; Tian et al., 2021). The existing empirical literature presents inconclusive results on how carbon pricing policy affects carbon emissions. Some studies established a significant and negative effect of carbon policy (Lv and Bai, 2021; Xuan et al., 2022) while others find an insignificant effect with regional heterogeneity (Ding et al., 2021). Thus, this study fills this research vacuum by investigating the impact of carbon pricing policy on carbon emission intensity in Canadian Provinces. To achieve this aim, the study addresses the following questions: Does carbon pricing policy affect carbon emission reductions? If yes, how does this impact manifest? Does the policy impact exhibit heterogeneity across provinces and over time? To provide answers to these questions, this study utilises province-level panel data over the sample periods 2000-2022 in estimating a theoretically grounded model. Along with this, the paper contributes to the existing literature through its novel approach that derives a carbon emission intensity (or efficiency) from micro-production theory to test the effectiveness of carbon pricing on carbon emission efficiency. Furthermore, the novel approach accounts for heterogeneity, mitigates the risk of biased estimates from employing a single-factor carbon intensity measurement (Guo et al., 2023), and addresses the issue of endogeneity. Implementing this empirical strategy, the study provides useful policy insights for quantifying a province-specific assessment of carbon pricing policies based on multi-factor carbon emission efficiency scores. Furthermore, it suggests another important channel to spur carbon emission reduction in complementary to the carbon pricing policies. It also recommends evidence-based interventions that are specific to each Canadian province.

The remainder of the study is structured as follows. Section 2 provides background information on carbon pricing in Canada and develops hypotheses. Section 3 presents a production framework implemented to develop the empirical model and describes data and estimation methods. Section 4 reports and discusses empirical results, while Section 5 concludes with policy implications and the study's limitations.

2. Institutional context and hypothesis development

2.1. Institutional context of Canada Carbon Pricing Policy

The increasingly severe impacts of climate change are not exceptional to Canada, thus resulting in frequent wildfires and extreme weather situations (NRCan, 2019). This triggers the need for urgent measures to mitigate climate change, in which the Canadian government implemented a new carbon pricing measure in 2016 that mandates all its provinces to have a carbon pricing mechanism through the designed Pan-Canadian Framework (GOC, 2018). Then, a carbon emission reduction target of 40% by 2030 against the 2005 level, was stated in the 2019 Greenhouse Gas Pollution Pricing Act. The Canadian pricing system implements two mechanisms known as fuel charge and output-based pricing systems. While the fuel charge system is levied on gasoline and natural gas, the output-based pricing system is an industry performance measure that is applied to industrial operators with GHGs emissions equal to or more than 50 thousand tons of carbon per year in provinces without carbon pricing system (GOC, 2021; IEA, 2022). In addition, the national framework allows each province to choose either one or both of the mechanisms considering their specific needs. With the most updated World Bank Carbon Pricing Dashboard, British Columbia is the only Canadian province that implements both a carbon tax and emission trading system (ETS) in addition to its voluntary credit offsetting. While the ETS is the only carbon pricing policy implemented in Alberta, Ontario, and Quebec, Novia Scotia introduced its voluntary credit offsetting in 2023 to complement its carbon tax (World Bank, 2023). Thus, this strengthens the need to explore the impact of heterogeneous choice of carbon pricing policies among Canadian provinces on their carbon emission efficiency.

2.2. Hypothesis development in the context of related literature

Several empirical studies examine the drivers of carbon emissions while testing the Environmental Kuznet Curve (EKC) hypothesis (Jahanger et al., 2023a; Jahanger et al., 2023b; Jahanger et al., 2023c; Jiang et al., 2022; Yu et al., 2024; Zeraibi et al., 2023). For instance, Jahanger et al. (2023c) utilise the method of moments of quantile regression (MMQR) to study the dynamic influences of atomic energy and ICT on carbon emissions in a cross-country panel setting over the period 1990-2017. Their findings reveal carbon emission reduction due to a rise in both nuclear energy and ICT. Other studies find potential emission reduction drivers to include renewable energy and globalisation in Mexico (Jahanger et al., 2022), economic growth, and economic complexity in BRICS countries (Zeraibi et al., 2023). However, the carbon footprint increases due to urbanisation, greenfield investment, and financial inclusion (Zeraibi et al., 2023), and the presence of an economy rebound effect manifested through an increase in fossil fuel consumption (Jahanger et al., 2023a). The relevance of energy structure and input structure in mitigating energy-related CO2 emissions in China is also empirically established in the literature (Yu et al., 2024; Jiang et al., 2022).

A further extension of this literature has been developed to explore the role of carbon pricing policies in reducing the level of GHGs emissions (Khan et al., 2023; Khurshid et al., 2023a; Khurshid et al., 2023b; Yang et al., 2023). For instance, Khurshid et al. (2023a) examined the relationship between carbon taxes and transport sector GHGs emissions in the OECD region from 1990 to 2020. Their results show a significant impact of carbon taxes on emission reduction, thus concluding that carbon pricing is an appropriate measure to mitigate emissions. In the same vein, green taxes are considered as short-term measures to achieve emission reductions in transport and economic sectors for the EU economies (Khurshid et al., 2023c). Using the firm-level data, Yang et al. (2023a) empirically conclude that low-carbon city pilot (LCCP) policy reduces emissions with variation in its impacts due to firm type, ownership, and location. However, the weaker effect in state-owned enterprises calls for a better understanding of regional drivers given the role of firm size and labour input in reducing the source of GHGs emissions (fossil fuel consumption). This paper responds to the research call by developing a novel model to investigate the effect of the carbon pricing policy on carbon emissions in the context of Canada, as suggested in the literature (Feng et al., 2024). This novel strategy provides useful policy insights on a province-level assessment of carbon emission performance, as well as different appropriate options to achieve carbon emission reduction targets considering the economic activities in each Canadian province. In addition, it extends the existing literature (which is characterised by insufficient investigations, and inconclusive and inconsistent results, due to model parameters and endogeneity issues, etc.) by exploring how production input structure influences carbon emissions in Canada, as suggested in the literature (Feng et al., 2024) that echoes the need to account for fundamental structure. Along with this, it identifies the new mechanism of how carbon policy affects multi-factor carbon emissions. Thus, these contributions are achieved by testing the following hypotheses:

> **Hypothesis 1.** Implementing the carbon pricing policy is likely to influence provinces' carbon emissions.

> **Hypothesis 2.** The policy impact on carbon emission efficiency varies across Canadian provinces and over time.

Two main measurements can be utilised to proxy efficiency (an inverse of intensity). These measurements are single-factor and multi-factor approaches. The single-factor intensity method is based on the ratio of carbon emissions to output (GDP), extensively implemented in the literature (Ren et al., 2024). However, this method fails to account for the influence of other factors such as input substitution, fuel mix, and change in industry structure, on carbon intensity (Ang, 2006; IEA, 2009), thus indicating a weak relationship between intensity and efficiency (Adom, Amakye and Quaidoo, 2018; Filippini and Zhang, 2016). These weaknesses have been addressed with the use of a multi-factor efficiency index. The multi-factor efficiency index is derived from either parametric econometrics or non-parametric methods (He et al., 2021). The parametric econometrics method (stochastic frontier analysis-SFA) specifies a prior functional form in line with fundamental economic theories such as production theory to derive the efficiency index, compared to the non-parametric data envelopment analysis (DEA) which is theoretically weak (Filippini and Hunt, 2015; He et al., 2021) and no statistical underpinnings (Liu et al., 2023). In addition, the SFA decomposes its error term into inefficiency and random error, which is used to derive efficiency by applying a standard stochastic frontier technique (Liu et al., 2023; Kumbhakar and Lovell, 2000). On the other hand, the DEA estimates efficiency by the distance between each decision-making unit (DMU) and the efficiency frontier, using its different versions (see Na et al., 2019; and Sabouhi and Mardani, 2017; for further details). Despite the inappropriate nature of the single-factor indicators, most empirical studies (Ren et al., 2024; Qiao et al., 2024) rely on them to make policy recommendations. Thus, the study explores this biased impact with the following hypothesis:

> **Hypothesis 3**: A single-factor carbon emission measurement is likely to produce biased estimates.

3. Data and methods

This section describes variables and their data source employed in line with econometric model specification. In addition, the approaches to perform the model estimation are presented.

3.1. Variable description and data source

3.1.1 Carbon intensity

This paper gathers yearly province-level panel data between 2000 and 2022 to achieve its research aim. Then, it first uses a single-factor measurement of carbon emission intensity defined as carbon emissions per unit of GDP (Ren et al., 2024) for its explained variable in order to make better comparisons with the previous studies:

$$CEI_{it} = \frac{Carbon_{it}}{GDP_{it}} \tag{1}$$

Where CEI_{it} represents the carbon emission intensity of province i over years t. $Carbon_{it}$ and GDP_{it} are provinces' carbon emissions and real GDP respectively. Owing to the identified weakness of the single-factor approach, the study then employs a multi-factor method to derive carbon emission efficiency from the production SFA techniques (see the details in subsequent subsections).

3.1.2. Control variables

Using the microeconomic theory of production framework, this study includes variables such as economic activities (measured by real GDP), labour (captured by a number of employed people), capital (measured by the gross fixed capital formation in constant terms), and energy (measured by energy consumption in Peta joule), to complement its variable of interest which is carbon pricing policy (proxied by a dummy variable) and intensity (proxied by a number of carbon pricing policies in each province).

3.2. Sample

Owing to the data availability restrictions, the study chooses a sample of 10 Canadian provinces' panel data spanning between 2000 and 2022. Table 1 shows the variable description and data sources in a production setting framework while allowing for the role of carbon pricing policy.

Table 1

Variable Description and Data Source

Variables	Short	Unit	Nature	Data Sources
Carbon emissions	*Carbon*	Thousand ton	Output (bad)	Statistics Canada
Gross Domestic Product	*RGDP*	$M Canada	Output (good)	Statistics Canada
Carbon emission intensity	*CEI*	Ratio	Bad/good output	Author
Labour input	*Labour*	Thousands	Input	Statistics Canada
Capital input	*Capital*	$M Canada	Input	Statistics Canada
Energy input	*Energy*	Peta joule	Input	Canada Energy Regulator
Carbon pricing	*PolicyDum*	Dummy		Authors
Policy intensity	*Policy*	Number		World Bank Carbon Pricing Database &Author

The above-mentioned variables are transformed into logarithmic forms except for carbon emission intensity *CEI* and policy variables *(PolicyDum* and *Policy)*, as shown in Table 2. The carbon emission intensity in Canadian provinces ranges between 0.2008 and 1.3513. The economic size range is between 8.3283 and 13.5310, compared to the production inputs of 4.1400-8.9163 (*Labour*), 6.1903-11.5910 (*Capital*), and 3.2015-8.3313 (*Energy*) respectively. On the sample average, *RGDP* records the highest mean of 11.2378, followed by *Capital* with 9.3929 while *PolicyDum* has the lowest mean. Among the production input variables, *Energy* and *Capital* exhibit the highest fluctuations with standard deviations of 1.4598 and 1.4587 respectively.

Table 2

Province-wise summary statistics

Variable	Obs	Mean	Std. dev.	Min	Max
CEI	220	0.5226	0.3043	0.2008	1.3513
RGDP	220	11.2378	1.3935	8.3283	13.5310
Labour	210	6.6643	1.3360	4.1400	8.9163
Capital	220	9.3929	1.4587	6.1903	11.5910
Energy	170	6.2202	1.4598	3.2015	8.3313
PolicyDum	220	0.2182	0.4140	0	1
Policy	220	0.3591	0.7544	0	3

3.3. Methodology

3.3.1. Baseline production model using fixed effect (FE) Technique

This paper develops a production framework based on assumptions that each province carries out its economic activities using three factors of production (capital, labour, and energy) as specified:

$$Y_i = f(Capital_i, Labour_i, Energy_i) \tag{1}$$

Where Y denotes economic activities engaged in each Canadian province i. These economic activities generate good and bad activities (Edziah et al., 2021; Zhao and Lin, 2019):

$$Y_i \in \{Y_{i,good}, Y_{i,bad}\}$$

Where $Y_{i,good}$ denotes good economic activities (proxied by *RGDP*) and $Y_{i,bad}$ represents bad economic activities (proxied by the amount of carbon emissions). The equation (1) can be re-written as:

$$Y_{good,i} + Y_{bad,i} = f(Capital_i, Labour_i, Energy_i) \tag{2}$$

Then, the explicit form takes the following:

$$RGDP_i + Carbon_i = f(Capital_i, Labour_i, Energy_i) \tag{3}$$

Making carbon emissions a subject term, the equation (3) is specified as:

$$Carbon_i = f(Capital_i, Labour_i, Energy_i) + RGDP_i \tag{4}$$

Using the Cobb-Douglas production function, the equation (4) can be elaboratively expressed in a panel setting as follows:

$$Carbon_{i,t} = \alpha_i + \beta lnRGDP_{it} + \gamma lnCapital_{it} + \omega lnLabour_{it} + \delta lnEnergy_{it} + \varepsilon_{i,t} \tag{5}$$

Where α_i is unobserved time-invariant province-specific characteristics and $\varepsilon_{i,t}$ represents the error term that is assumed to be normally distributed. $\beta, \gamma, \omega, and\ \delta$ are regression parameter coefficients. Then, the equation (5) is extended to control for the year effect τ_t:

$$Carbon_{i,t} = \alpha_i + \beta lnRGDP_{it} + \gamma lnCapital_{it} + \omega lnLabour_{it} + \delta lnEnergy_{it} + \tau_t + \varepsilon_{i,t} \tag{6}$$

3.3.2. Extended production model using stochastic frontier analysis (SFA)

Equation (5) is extended to derive the carbon emission efficiency index for each province in Canada, by decomposing the error term $\varepsilon_{i,t}$ as follows:

$$\varepsilon_{i,t} = v_{i,t} + u_{i,t}$$

$$v_{i,t} \sim N[0, \sigma_v^2],$$

$$u_{i,t} = |U_i|, U_{i,t} \sim N[0, \sigma_u^2] \tag{7}$$

Where the error term $\varepsilon_{i,t}$ is decomposed into the two independent components $v_{i,t}$ and $u_{i,t}$. $v_{i,t}$ is a non-negative and time-varying random disturbance with normal distribution while $u_{i,t}$ reflects the carbon emission efficiency used as an indicator of the level of inefficiency in emission reductions, with a half-normal distribution (Filippini and Hunt, 2015). This paper incorporates carbon pricing policy into the carbon inefficiency equation while addressing endogeneity issues. Equation (8) indicates the minimum amount of carbon emissions in each province given their good output *RGDP* and factors of production (*Capital*, *Labour*, *Energy*).

Then, the level of carbon emission efficiency $CEE_{i,t}$ for each Canadian province in each year is obtained as:

$$CEE_{i,t} = \frac{CE_{i,t}^{F}}{CE_{i,t}} = exp\ (-\hat{u}_{i,t})$$

Where $CE_{i,t}^{F}$ is carbon emissions of the frontier.

4. Results and discussions

4.1. Main results

Columns (1) and (2) reveal the one-way fixed results that do not include the year effect. As observed in column (1), the adoption of a carbon pricing policy does not significantly influence carbon emission intensity with a theoretically unexpected sign (Dong et al., 2022). The level of good economic activities and energy consumption significantly affect carbon emission intensity in Canada. While good economic activities reduce emission intensity, energy consumption amplifies the level of emission intensity with a semi-elasticity estimate of 0.395, thus implying a 1% rise in energy consumption leads to about a 3.95% increase in emission intensity on the sample average holding other factors constant. However, GDP quenches emission intensity as every 1% in its value reduces the level of emission intensity by 6.62% on average, keeping other things unchanged. Similar results are obtained in column (2) for considering the number of carbon pricing policies. However, the carbon emission intensity increases by 2.3% as the number of carbon policies rises by 1. The inclusion of the year effect in columns (3) and (4), turns policy variables *PolicyDum* and *Policy* to be stronger but in a theoretically unexpected way. The impact of capital input on carbon emission intensity becomes marginally significant, while energy input turns out to be weaker. In addition, GDP becomes marginally significant in mitigating carbon emission intensity in Column (4). As observed in the table, the explanatory power of the emission intensity model indicated with R-squared increases from about 66% in one-way fixed estimation methods to about 80% in the two-way fixed effects. Thus, it implies that about 80% of what explains the level of carbon emission intensity in Canadian provinces is captured by the estimated two-way fixed effect model.

Table 3
Fixed-effect regression results

	One-way fixed effects		**Two-way fixed effects**	
	1	2	3	4
PolicyDum	0.027		0.046**	
	(0.015)		(0.016)	
Policy		0.023*		0.025**
		(0.010)		(0.009)
GDP	-0.662***	-0.700***	-0.271	-0.317*
	(0.165)	(0.158)	(0.165)	(0.149)
Labour	-0.183	-0.188	0.138	0.101
	(0.181)	(0.199)	(0.253)	(0.294)
Capital	0.057	0.060	0.068*	0.067*
	(0.037)	(0.036)	(0.033)	(0.032)
Energy	0.395***	0.380***	0.214*	0.205*
	(0.115)	(0.112)	(0.104)	(0.106)
Constant	6.180***	6.701***	0.739	1.569
	(1.380)	(1.327)	(2.271)	(2.439)
Province effect	Yes	Yes	Yes	Yes
Year effect	No	No	Yes	Yes
Year FE				
Observations	160	160	160	160
R-squared	0.643	0.657	0.796	0.789
F stat (Year)			9.58***	7.74***

Note: Standard errors are indicated in parentheses. ***, **, and * denote significant at 1%, 5% and 10% respectively.

To correct the identified single-factor measurement bias of carbon emission intensity, the study estimates the equation (1) using the SFA techniques. Table 4 reports the SFA results for three modified models. The true fixed effect (TFE) (suggested in Green's (2005)) results based on the exogeneity assumption, reveal similar patterns of coefficient signs but substantial changes in the magnitude of the regression coefficients. The magnitude of the GDP effect increases to -0.877 while the energy effect decreases to 0.490, thus assigning more relevance to GDP in mitigating carbon emissions. Relaxing the exogeneity assumption, the table presents two versions (exogenous and endogenous columns) results for better comparisons. Since there is a possibility of reverse causality between carbon emission and GDP, the paper treats GDP as an endogenous variable instrumented by one-year lagged GDP (Barge-Gil and López, 2014). In addition, carbon pricing policy is incorporated into a carbon inefficiency model in the SFA setting. The SFA results in columns (2) and (3) show that carbon emission is mainly driven by GDP, capital, and energy, even at the significance level of 1%. While GDP remains a promoter of carbon emission reductions, more capital and energy inputs amplify the level of carbon emissions in Canada. Furthermore, implementing a carbon pricing policy reduces carbon emission inefficiency at a 10% significance level. The relevance of dealing with endogeneity is established with the statistical significance of the endogeneity test.

Table 4
Carbon emission efficiency SFA regression results

	TFE	**Exogenous**	**Endogenous**
GDP	-0.877***	-0.651***	-0.712***
	(0.226)	(0.111)	(0.180)
Labour	-0.535	0.113	0.166
	(0.410)	(0.109)	(0.168)
Capital	0.052	0.097***	0.105***
	(0.049)	(0.026)	(0.026)
Energy	0.490***	1.074***	1.068***
	(0.129)	(0.065)	(0.066)
Usigma			
Constant	-8.209	-0.341	-0.292
	(4.994)	(0.479)	(0.493)
PolicyDum		-0.084*	-0.095*
		(0.047)	(0.052)
Vsigma	-4.851***	-5.893***	-5.922***
	(0.213)	(0.116)	(0.116)
Observations	160	160	160
Endogeneity test		3.62*	
Mean tech efficiency		0.581	0.577
Median Tech efficiency		0.5339	0.525

Note: Standard errors are indicated in parentheses. ***, **, and * denote significant at 1%, 5% and 10% respectively.

In summary, the SFA results in Table 4 indicate that carbon emission is mainly driven by output, energy, and capital inputs while establishing the negative role of carbon pricing on carbon emission inefficiency which is theoretically expected and marginally significant. The negative coefficient of the carbon pricing policy (0.086) implies that the implementation of the carbon policy reduces the carbon emission inefficiency in the production process.

In the context of the related literature, the paper's results reinforce the literature (Qiao et al., 2024) that finds a negative effect of the province's GDP on carbon emission. The significant role of carbon pricing policy in reducing carbon emission inefficiency is consistent with the literature (Feng et al., 2024; Lu et al., 2024; Ren et al., 2024; Yang et al., 2023) that links lower emissions to the carbon policy. In addition, the carbon pricing policy influences emissions by reducing inefficiency (Chen and Mu, 2023), thus adding to the indirect channels established in the literature (Feng et al., 2022; Gu et al., 2020; Dong et al., 2021; Du and Li, 2020; Sun and Wang, 2021). On the other hand, the paper reinforces the literature (Guo et al., 2023) that traces biased estimates by using a single factor indicator. The single-factor method in the Canadian context leads to under-biased GDP and over-biased energy input estimates. Moreover, the role of capital input in carbon emissions becomes irrelevant if endogeneity is not addressed.

Using the SFA estimation results in Table 4, the study derives the average carbon emission efficiency scores over time and across provinces, as shown in Table 5. The average CEE scores record an upward trend of slight improvement over the sample periods except for 2009 and 2020. The low carbon emission efficiency for the two years might be due to the 2007/2008 Global Financial Crisis and COVID-19 events. The average CEE scores among provinces are similar with an average of 0.984, thus indicating carbon emissions can be reduced by about 3% given the current economic activities and existing inputs.

Table 5

Carbon Emission Efficiency (CEE) Index

	Average CEE value
2005	0.9811
2006	0.9823
2007	0.9838
2008	0.9839
2009	0.9814
2010	0.9822
2011	0.9833
2012	0.9836
2013	0.9838
2014	0.9840
2015	0.9843
2016	0.9845
2017	0.9852
2018	0.9857
2019	0.9863
2020	0.9827

Provinces	Average CEE values
Alberta	0.9832
British Columbia	0.9833
Manitoba	0.9836
New Brunswick	0.9831
Newfoundland	0.9838
Nova Scotia	0.9839
Ontario	0.9839
Prince Edward	0.9840
Quebec	0.9839
Saskatchewan	0.9835

To explore the province heterogeneity, Figure 1 shows each province's CEE scores over the sample periods. As can be observed in the figure, some Canadian provinces such as British Columbia, Manitoba, Alberta, and Quebec improved their efficiency scores. However, other provinces such as New Brunswick and Nova Scotia witnessed a downward trend in efficiency scores. The highest efficiency score attributed to New Brunswick in 2005, shifts to British Columbia in 2020. In addition, New Brunswick becomes the lowest carbon emission performance province at the end of 2020.

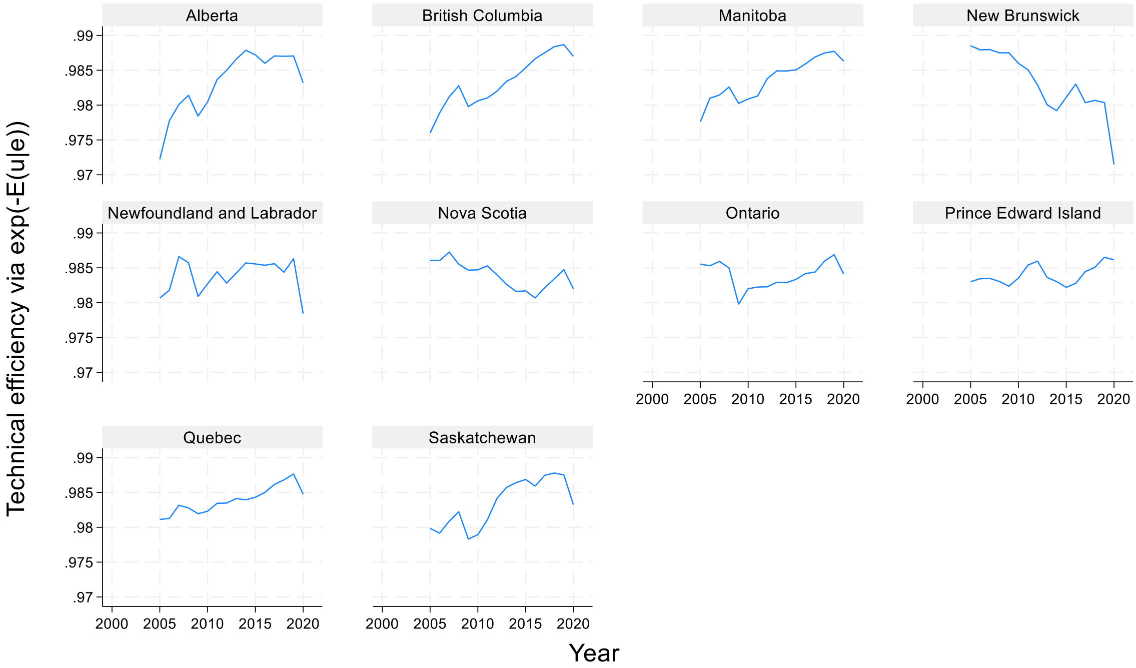

Figure 1: Plot of Province's carbon emission efficiency index from 2005 to 2020

While Nova Scotia's CEE scores exhibit a downward trend, Quebec's scores trend upward in most periods. This striking postulation might be due to different carbon pricing instruments, economic structure, and geographical characteristics (Lin and Huang, 2022; Lu et al. 2024). For example, Nova Scotia's main economic activity relies on the fishery, compared to Quebec whose economic activity is mainly driven by the capital-intensive service sector. In addition, Quebec's economy is more open relative to Nova Scotia.

5. Conclusion and policy recommendations

This paper examines the impact of the carbon pricing policy on provinces' carbon emissions in Canada. Using the province-year panel data, the study develops a theoretically grounded model that aligns with the production framework and appropriate carbon emission efficiency measurement. Then, the developed model is estimated using both fixed effect and stochastic frontier techniques that deal with endogeneity issues. The study finds that carbon pricing policy at the Canadian province level plays a significant role in reducing carbon emission inefficiency. Emission intensity is mainly driven by GDP, capital, and energy consumption. GDP reduces carbon emissions that are intensified by an increased use of capital equipment and more consumption of energy, especially fossil fuels. Over the sample periods, provinces' carbon emission efficiency scores exhibit heterogeneity. New Brunswick turned out to be the lowest performance in 2020 compared to its leading role in 2005. British Columbia maintained an upward improvement to reach the highest score at the end of 2020.

Given these findings, the study suggests the following policy recommendations:

- Boosting economic growth is an avenue to achieve significant carbon emission reductions.
- Energy-induced carbon emissions can be addressed through adequate deployment of renewable energy in carrying out economic activities.
- Adopting sophisticated equipment in producing goods and services must be aligned to reduce carbon emissions.
- Strengthening carbon pricing effectiveness would be a worthy strategy to reduce carbon emission inefficiency.
- Careful assessment of each province's carbon pricing policy on carbon emission efficiency is critically important to achieve Canada's emission reduction targets.

- Providing an efficient and effective way to encourage the sharing of best practices among provinces is important in implementing carbon pricing policy to achieve commonly identified desirable goals.
- Province implementation of carbon pricing policy needs to be aligned with production structure and geographical conditions.

The study's limitations can be turned into future research in the following ways. First, it would be interesting to implement the method in different contexts to provide more general empirical evidence. Second, utilising industry-level data in Canada is a great area of research to account for the role of production input structure in carbon emission intensity. Third, an in-depth investigation of different carbon policy measures (mandatory and voluntary) beyond the use of dummy, in influencing carbon emission intensity is a worthy area of future research.

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