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Implications of carbon Taxing policies on the food supply chain in Canada

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ABSTRACT

This paper explores the implications of carbon-taxing policies on food supply chain affordability and competitiveness in Canada. Initiated with Alberta's 2007 carbon levy, Canada's approach to carbon taxation aims to mitigate greenhouse gas emissions while addressing the economic impacts on the food sector. With the federal carbon price set to rise to CAD $170 per ton by 2030, the study investigates the potential for increased food prices and the challenges to food affordability as well as identify the current gaps in understanding the intricacies of Carbon Taxing Policies on the Food Supply Chain in Canada. Graphic analyses and forecasts were created using data from Statistics Canada and the U.S. Census Bureau. The main findings of the analyses reveal shifts in wholesale and industrial prices since the carbon tax's implementation. Findings suggest that carbon pricing may be affecting every level of the food supply chain, highlighting the need for further research to understand its full impact on food affordability and security.

1. Introduction

In December 2020, the Canadian government unveiled its proposal to bolster the climate plan, which included the introduction of a $15 CAD per ton of carbon dioxide equivalent (CO2e) greenhouse gas (GHG) emissions fee from 2023 to 2030 (McKitrick and Aliakbari 2021). The Canadian Institute for Climate Choices conducted an evaluation of carbon pricing systems in Canada, prompting the Government of Canada to revise the federal benchmark. This revision represents a pivotal component of Canada's long-term strategy for carbon pricing beyond 2022. This update solidified the national minimum price on carbon pollution until 2030, while also improving the criteria that all pricing systems must meet (Environment and Climate Change Canada 2023). These measures are designed to ensure that carbon pollution pricing effectively incentivizes cost-effective emission reductions that are necessary to achieve the 2030 greenhouse gas reduction target and facilitate Canada's transition towards a low-carbon future.

Research indicates that carbon taxes can be effective in reducing emissions while having a mixed impact on economic development (Meng et al. 2012; Goulder et al. 2019; Withey et al. 2022). However, the implementation of carbon emissions regulations, such as a carbon tax, inevitably leads to increased production costs for producers and manufacturing firms (Ding et al. 2020), as well as transportation through the supply chain. According to the United Nations, approximately 55 % of the world's population lives in urban areas – a figure that is expected to be around 70 % by 2050 (United Nations 2023). Urbanization creates a positive feedback loop in that as the urban population increases, so does the demand on transportation (Galambos et al. 2024) In recent years, there has been a growing focus on food prices, which are influenced by a complex interplay of global factors. Canada, as a net

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importer of many staple goods, is exposed to the volatility of global markets and external shocks that can disrupt these markets (Taylor et al. 2023). Additionally, conducting a comprehensive analysis of retail pricing reveals the intricacies involved in accurately determining coefficients.

2023 witnessed significant political, environmental, and economic disruptions, affecting Canada (Charlebois et al. 2021; Taylor et al. 2023). The country faced challenges like wildfires and widespread flooding. The Report of the Standing Committee on Agriculture and Agri-Food found that the cost of transporting food has a direct effect on food inflation (House of Commons, Canada, 2023). Ongoing conflicts in Europe and turbulence in the Middle East continued to impact energy costs and commodity prices. Canadians also experienced financial burdens, including rising rental and utility costs, as well as increasing personal debt, which added pressure on both the federal government and grocery wholesalers and retailers to maintain affordable prices. The introduction of a carbon tax has the potential to impact food pricing and affordability in Canada. According to Food Bank Canada's 2023 Hunger Count report, the number of visits to food banks in Canada significantly increased (Matern et al., 2023). In March 2023, there were approximately 2 million visits, marking a 32 % rise compared to March 2022 and a substantial 78.5 % increase compared to March 2019 (Matern et al., 2023). This represents the highest level of food bank utilization ever recorded in Canada. The primary objective of this paper is to investigate the effects of a carbon tax on food affordability and competitiveness within the Canadian food sector.

1.2. Carbon taxes in Canada

In March 2007, the province of Alberta made history as the first jurisdiction in North America to enact a law mandating major industrial emitters to reduce greenhouse gas emissions through a carbon levy, marking the inception of Canada's carbon tax (Saric et al. 2017). The following month, the province of British Columbia (B.C.) joined five U.S. states in the Western Climate Initiative, a market-oriented coalition dedicated to addressing climate change (Klinsky 2015). The provinces of Ontario and Québec also committed to participating in this initiative. In May 2008, John Baird, the Conservative federal environment minister, underscored the significance of carbon trading as a pivotal component of the government's emissions plan, with a specific focus on oil and gas companies and coal-fired power stations (MacDonald 2008). Subsequently, in July of the same year, the province of British Columbia became the trailblazer in implementing a carbon tax, wherein the tax revenue was returned to taxpayers (Murray and Rivers 2015).

The current Canadian federal government's pricing scheme, implemented in 2019, consists of two key components: 1. A levy on fuels to address pollution, and 2. the Output-Based Pricing System (OBPS, 2021), which imposes fees on industrial activities (Withey et al. 2022). The OBPS establishes a benchmark for greenhouse gas emissions per unit of production. The implementation of carbon pricing raises concerns for both industries and governments, as it is believed that imposing a tax or emission fee on carbon may have adverse effects on the competitiveness of enterprises heavily reliant on carbon-intensive practices (Anwar et al. 2021; Okereke and Russel 2010; Venmans et al. 2020; Withey et al. 2022). In Canada, the agriculture and livestock production sector, excluding emissions from fossil fuel usage or fertilizer manufacturing, contributes to 10 % of the country's greenhouse gas emissions (2023). Industrial facilities are often significant sources of greenhouse gas emissions. The primary objective of the OBPS is to introduce a carbon pricing mechanism for companies with annual outputs of 50,000 tons or more to regulate pollution levels (Shideler and Hetzel 2021; Withey et al. 2022). Sectors emitting 10,000 tons or more have the option to participate in the OBPS to address increased competition and the risk of carbon leakage (Shideler and Hetzel 2021).

Canada performs two primary evaluations to establish precise standards: one that evaluates the risk to competitiveness and another that assesses the possibility for carbon leakage. The competitiveness evaluation assesses sectors with low or medium risk by considering 80 % of the average emissions, whereas sectors with high risk are evaluated by considering either 90 % or 95 % of the average emissions (2021). If specific industries surpass these stipulations, they can amass transferable credits that can be sold to other entities emitting pollutants. Two categories may be distinguished by analyzing GHG emissions in the food system[1]: direct emissions and indirect emissions. Evidence suggests that food systems comprise a significant portion of global greenhouse gas emissions (Laborde et al. 2021; Tubiello et al. 2021; Zhao et al. 2023). Emissions have experienced a 16 % rise,[2] going from 14.5 gigatonnes of GtCO2 eq per year in 1990 to 16.8 GtCO2 eq per year in 2018. In 2018, these emissions constituted 31 % (with a variation between 23 % and 42 %) of the overall global GHG emissions (Environment and Climate Change Canada 2023).

The adoption of carbon tax programs has been popular among policymakers to encourage firms to adopt lower carbon strategies of production, ideally, steering a given sector towards a sustainable path of reduced carbon emissions. From a firm's position, carbon taxes may be seen as impacting its long-term competitive advantages, financial gains, and choices in production, which may or may not impact profitability and competitive advantage domestically and globally (Mugoni et al. 2023; Zhou et al. 2024). Research presents conflicting results about the effects of carbon taxes on competitiveness and economic growth (Liu et al. 2018; Withey et al. 2022; Socci et al. 2023; Köppl and Schratzenstaller 2023; Noubissi et al. 2023; Zhou et al. 2024). Furthermore, the effects on an economy might differ between sectors or industries, contingent upon the level of energy use (Liu et al. 2018).

While there is compelling evidence indicating that carbon taxes are efficacious in mitigating greenhouse gas emissions, implementation unavoidably affects several dimensions of consumer welfare. The carbon tax tends to be regressive in nature, which can be overcome by a redistributive structure (Köppl and Schratzenstaller 2023; Semet 2024). Implementing a revenue-recycling carbon tax system effectively mitigates the negative impact of carbon taxes on GDP and improves income inequality. While debates on the impacts of carbon taxes on social development often include considerations of household spending and energy cost levels, the reaction to a carbon price would be limited in the short term, but it would come with a significant tax burden (Speck 1999; Goulder et al. 2019). Research suggests that targeted lowering GHG emissions in the short-term may be accomplished by introducing a carbon tax rate ranging from 6.25 % to 5.52 % on energy (Wu and Thomassin 2018). A not insignificant amount for many households.

1.3. Food affordability in Canada

Household food insecurity in high-income nations is strongly linked to financial limitations, with the greatest risk occurring in households with low income, limited liquid assets, and no ownership of a property (Tarasuk 2005; Proof 2018; Mendly-Zambo and Raphael 2019; Elgar et al. 2021). In 2017–18, 12.7 % of Canadian families experienced food insecurity, with the incidence increasing to 16.2 % for those with children under the age of 18 (Men et al. 2021). Low-income Canadians have a lack of resources to ensure food security, while food costs have continued to rise since the onset of the COVID-19 epidemic (Charlebois et al. 2023; Taylor et al. 2023, 2024). Canada had a historic surge in

[1] Canada's food system includes "production, processing, manufacturing, transportation, retail, hotels, restaurants, institutions and households" (Holland 2021).

[2] 0.3% of the rise is as a result of rail transportation (Mandegari et al 2023, Rungskunroch et al., 2021) whereas shipping contributes to approximately 3% of carbon emissions (Schwartz et al., 2020), and road transportation contributes approximately 11.9% of carbon emissions, 40% of which stems from road freight (Dehdari, 2023).

inflation in June 2022, with a notable increase of 8.1 % (Taylor et al. 2024). Canadians allocate around 17 % of their disposable income towards food expenditures. However, the cost of vegetables in Canada has risen by 10.3 % as of September 2022 (Taylor et al. 2024). The escalation in food costs can be attributed to recent occurrences, including the conflict in Ukraine, the COVID-19 epidemic, and climate change (Taylor et al. 2023). Undoubtedly, concerns related to supply chain disruptions, along with the consequences of global events, have significantly influenced the cost of groceries. The price of various items has increased significantly since the beginning of the COVID-19 pandemic.

Assessing the total expense of a representative selection of food items that constitute a fundamental healthy diet, has been employed as a reliable substitute for determining the affordability and accessibility of a nutritious diet (Herforth et al. 2022). The results derived from food costing research can offer substantiation for shaping policies that promote food security and overall population wellness. Yet, to what extent the carbon tax impacts the affordability of food in Canada remains unclear. The addition of a significant cost to food producers is likely to raise prices. Firms respond to unfavourable cost incentives by reducing the quantities of their products or altering prices (Colmer et al. 2022). Decisions made at the level of individual firms have a direct influence on many economic outcomes, including productivity and employment.

The global food supply chain has been unsteadied since 2020. Global agricultural regions have seen a decrease in production due adverse weather or geopolitical conflict. The escalation in energy prices has exacerbated the difficulties in obtaining food, particularly for the most impoverished countries worldwide, coupled with shipping bottlenecks due to COVID-19 restrictions, lead to a decrease in commodities stockpiles and an increase in their yearly price fluctuation. This, in turn, heightens the vulnerability of food prices to unexpected events. Given the potential impact of future climatic conditions on agricultural output, it is imperative to implement policies and take initiatives to enhance the stability of food supply at the national levels.

The carbon tax is scheduled to increase to $80 per tonne in April 2024, eventually reaching $170 per tonne by 2030 (Naef 2024). Opponents insist that this increase will contribute to food price inflation and negatively impact food affordability in Canada. While there has been scholarly work on the implantation of carbon taxation as an exogenous variable on food prices, none focus specifically on the Canadian context. This study investigates the potential for increased food prices and the challenges to food affordability as well as identify the current gaps in understanding the intricacies of Carbon Taxing Policies on the Food Supply Chain in Canada.

2. Methodology

2.1. Data collection

Data for this study was collected from open sources through online platforms of governmental repositories of datasets. The food product prices and price indexes for wholesale, retail, and industry are collected from Statistics Canada and the U.S. Census Bureau. The Producer Price Index by Industry dataset for food manufacturing is collected from Statistics Canada in various categories such as fruit and vegetable preserving and specialty manufacturing, grain and oilseed milling, dairy product manufacturing, meat product manufacturing, sea product preparation and packing, sugar and confectionery product manufacturing, bakeries and tortilla manufacturing, animal food and other food manufacturing The Producer Price Index by Industry dataset for US, for the same categories of food manufacturing are collected from the Federal Reserve Economic Data.

2.2. Variables of analysis

This study uses three units of analysis: Industry Product Price Index – Food manufacturing (IPPI), Wholesale Services Price Index – Food, beverage, and tobacco merchant wholesalers (WSPI) and Retail Services Price Index – Food and beverage stores (RSPI).

The IPPI is a price that is collected at the "factory gate" (i.e., when the commodity is sold) and is a measure of what price the producer receives rather than the consumer. The "factory gate" price excludes sales taxes and tariffs, as well as transportation (beyond factory gate) of the goods (Statistics Canada n.d.). The index, therefore, measures the change in the producers' commodity prices over time (Statistics Canada, 2023a). This metric is also a key indicator for Canadian economic health as it provides information on performance of the manufacturing sector and is used as an input to calculate the gross domestic product (Statistics Canada, 2023a).

The WSPI quantifies monthly fluctuations in the price movement of wholesale services. The wholesale prices are aggregated and linked together to create a price index and are generated monthly and quarterly (Statistics Canada, 2023b).[3] Index estimates are created by "calculating a weighted average of price relatives by industry" which are then chained together using a Laspeyres chain, to form an index series over time (Statistics Canada, 2023b). The formula for the Laspeyres Price Index (LPI) is as follows:

$$LPI = \frac{\Sigma p_1 q_0}{\Sigma p_0 q_0} * 100 \tag{1}$$

where $p_0 q_0$ represents the price and quantity in the base (current) year and $p_1 q_0$ is the price at observation for the quantity in the base year (Corporate Finance Institute, n.d.). As the Laspeyres Index uses a fixed basket of goods, it is helpful in measuring the cost of living (Mankiw and Scarth, 2010). The purpose of chaining is to update the base period (Statistics Canada does this monthly and quarterly) by recalculating the prices and quantities for the standard basket of goods. This essentially creates a series of monthly or quarterly indices that are then chained together.

The RSPI is a measure of the average change in prices for retail services over time, capturing the fluctuations (Statistics Canada, n.d.). It is employed to address inquiries pertaining to inflation, actual production, and efficiency of the retail industry. The RSPI may also be utilized for assessing performance relative to industry trends, as well as for making international comparisons of productivity, inflation, and trade.

2.3. Data analysis and Forecasting

The data retrieved from the above-mentioned sources are analyzed to explore the trends, patterns, and value data insights of the impact of carbon implementation in the food industry. To facilitate this rigorous data examination and visualization, Excel was used to create exploratory graphs, and the Seasonal Auto-Regressive Integrated Moving Average - with eXogenous factors (SARIMAX) was chosen to create the forecast in Python (version 3.9.12) as the food industry is influenced by seasonal

[3] There is no standard approach for calculating or determining the wholesale price. One of they key factors depends on which party is responsible for the shipping, based on the contract. Under FOB ("Freight on board") pricing, the buyer is responsible for shipping, whereas the shipping is included in the "delivered price", thereby becoming part of cost of goods sold (FST Logistics, n.d.). Another important factor is that the wholesale price is determined before any negotiation occurs. It is important to note that Canada's food retailers function as an oligopoly, meaning the retailer and supplier are in a very uneven power relationship where the advantage rests squarely with the retailer. This results in the retailer's power to command a lower wholesale price (a result of "bargaining"), while still being able to command a high retail price to end-consumers (Wang, 2010). This also underscores that Canada's major food retailers are in a Nash Equilibrium (based on the assumption that food retailers independently influence their own wholesale prices) where retailers are incented to continue their entrenched, predictable patterns (Alchian, 1950) as an oligopoly, with little motivation to change beyond providing "soft" competition (Moghadam, 2020).

cyclicality and is subject to exogenously imposed factors such as exchange rate. The SARIMAX model has often been used for research in the food and agri-foods domains (e.g., Arunraj and Ahrens, 2015; Arunraj et al., 2016; 2022; Mishra, 2021) and addresses the limitation of the SARIMA model which cannot consider the effects of external variables (Falatouri et al., 2022). Formally, SARIMAX is defined as (Vagropoulos et al., 2016):

$$\varphi_p(B)\Phi_p(B^s)\nabla^d\nabla_s^D y_t = B_k x_{k,t}{}' + \theta_q(B)\Theta_Q(B^s)\varepsilon_t \quad (2)$$

where φp(B) is the regular autoregressive polynomial of order p, $\Phi_p(B^s)$ is the seasonal autoregressive polynomial of order P, the differential operators $\nabla^d\nabla_s^D$ to remove any non-seasonal and non-stationarity, y_t is the forecast variable, B_k is the coefficient value of the kth exogenous input variable, $x'_{k,t}$ is the vector including the kth explanatory input variables at time t, B shifts the observation of y_t by one point in time, $\theta_q(B)$ is the moving average polynomial of order q, $\Theta_Q(B^s)$ is the seasonal moving average polynomial of order Q, s defines the seasonal period, and ε_t is a white noise process (Vagropoulos et al. 2016).

A more accessible breakdown of the SARIMAX model is that it contains a non-seasonal component and a seasonal component:

$$SARIMAX(p,d,q)^*(P,D,Q,M) \quad (3)$$

(p,d,q) is the non-seasonal component "where p is the number of autoregressive terms [the number of time lags], d is the number of non-seasonal differences needed for stationarity, and q is the number of lagged forecast errors in the prediction equation" (Nau, n.d.). (P,D,Q,M) is the seasonal component. The uppercase P,D,Q are the same as the lowercase, but for the seasonal part of the model, and M represents "the number of periods in each season" (Rodrigo and Ortiz, 2021). Therefore, the model to forecast each unit of analysis was selected independently using Akaike Information Criterion (AIC) as the optimization function which is commonly used in the literature (e.g., Kuha 2004; Fattah et al. 2018). The AIC is formally defined as:

$$AIC = 2k - 2ln(\widehat{L}) \quad (4)$$

where $\widehat{L}$ is the estimated maximized log-likelihood and k is the number of parameters in the model (Hopkins, 2019). The lower the AIC score, the better the model fits the data (McHugh et al. 2019; Xie et al. 2013). Based on the optimization function, the best model for all units of analysis was (0,1,1,)(0,1,1,12), as these resulted in the lowest AICs. Data was only available from Statistics Canada for all three units of analysis to September 2023. Therefore, the forecast period is October 2023 – December 31, 2030.

The prediction of the industry price index through the SARIMAX model entails the analysis of historical data retrieved from Statistics Canada, and Federal Reserve Economic Data. The initial step involves a thorough examination of historical data related to industry, wholesale, and retail price indexes in Canada and USA. The analysis delves into the industry price index of various categories of food, providing insights into the trends and impact of carbon tax implementation. The resulting historical trends are then highlighted and presented through data visualizations.

3. Results

For each of the graphs presented below, 2019 has been specifically demarcated (dotted line) for comparison, as this is the year that the Canadian government implemented a Canada-wide carbon price, starting at $20 CAD per tonne of equivalent carbon dioxide emissions (tCO2e) (Provincial Government of British Columbia). April 2022 is also demarcated as the is the largest step-up that the carbon pricing has taken – rising to $50 CAD per tonne of equivalent carbon dioxide emissions (up from $20 CAD). The Canadian Government's plan raises the carbon price thereafter by $15 CAD per year, which means that the carbon price by 2030 will be $170 CAD per tonne of equivalent carbon dioxide emissions (Government of Canada, 2023).

As seen in Fig. 1, since 2010, the WSPI has been gradually increasing, with a more extended variation during the period of October 2016 to May 2020. After that, the WSPI start its increase, jumping above both the IPPI and RSPI in 2022. Keeping in mind that the wholesale price is what businesses charge each other, the variability and then the jump indicate stress in the wholesale supply chain which could be due to issues such as supply chain problems, demand fluctuations, and margin squeeze after the implementation of the carbon pricing. Road freight transportation – the largest contributor to carbon emissions (discussed in Section 1.2) – primarily uses diesel fuel in Canada (Natural Resources Canada, 2019), and since diesel produces more carbon (Watson et al, 1994), the carbon tax on diesel is higher than on gasoline (Canada Revenue Agency, 2024). This increases the both the wholesale price as well as the retail price of goods (Zhou et al., 2018), which provides further evidence of the margin squeeze.[4] Until road freight transportation becomes more sustainable in its practices (Nkesah, 2023), and the carbon tax continues to rise in Canada, it is likely that the margin squeeze on wholesale will continue.

The WSPI does fall below the RSPI in the last few months of the data collection period (August and September 2023), but there is a noticeable jump in April 2022 (dotted line) when the carbon pricing moves to $50 CAD per tonne of equivalent carbon dioxide emissions, continuing to rise to 140, and then fall back a bit. While the cause of this is not definitively carbon pricing as there are likely other confounding factors such as climate change and supply chain issue, it does suggest that carbon pricing could also be a contributing factor.

Industry Price Index vs Wholesale Services Price Index vs Retail Services Price Index – Canada.

The IPPI, however, does not take the same trajectory. While it has an overall increasing trend, that increase is less sharp than both the RSPI and the WSPI. As well, the fact that the WSPI is above the IPPI (by quite a bit), could signal that the increased costs of wholesale (including the effects of the carbon pricing) could be passed on to the end-consumer, meaning that consumer price inflation may continue. While the WSPI does not increase in lockstep with the implementation of the Canada-wide carbon pricing in 2019, it is important to note that there is likely a lag in the effects, given that it will take time for the carbon pricing (and/or other factors) to work its way through the supply chain. This lag suggests a compounding effect of carbon pricing (and/or other factors), pushing the wholesale price to rise at a faster rate than that of producers.

Given the interest in the Wholesale price raised in Fig. 1, the Canadian WSPI was compared against the US IPI for Wholesale (US-WPI), shown in Fig. 2. In 2010, the US-WPI was considerably higher than the Canadian, yet in 2023, the Canadian rose above the US for a short period of time, in January 2023, before falling marginally below the US. Given that, over time, the US-WPI has risen from just over 100 to 140, Canada's has increased even more significantly over the period from just under 80 to just under 140. This further supports that there is pressure in the Wholesale supply chain. In April 2022 (increase in carbon pricing to $50 CAD per tonne of equivalent carbon dioxide emissions), that is where the jump occurs to bring Canada in line with the US. Again, this is should not be considered "conclusive" evidence of the effect of carbon pricing, but the timing and magnitude of the step up from $20 CAD to $50 CAD does suggest that carbon pricing could be contributing to the increase.

Wholesale Services Price Index – Canada vs. the US.

[4] During the pandemic, food e-commerce companies such as Instacart (2012), SkipTheDishes (2012) or UberEats (2104) became more prominent up in an effort to provide jobs as well deliver goods in a safe, social-distancing manner. Music et al. (2022) found that 62.8% of respondents ordered food online during their data collection period. These companies have continued to flourish post-pandemic, but there is a gap in the data as to how these delivery companies and food ordering practices are affecting carbon emissions.

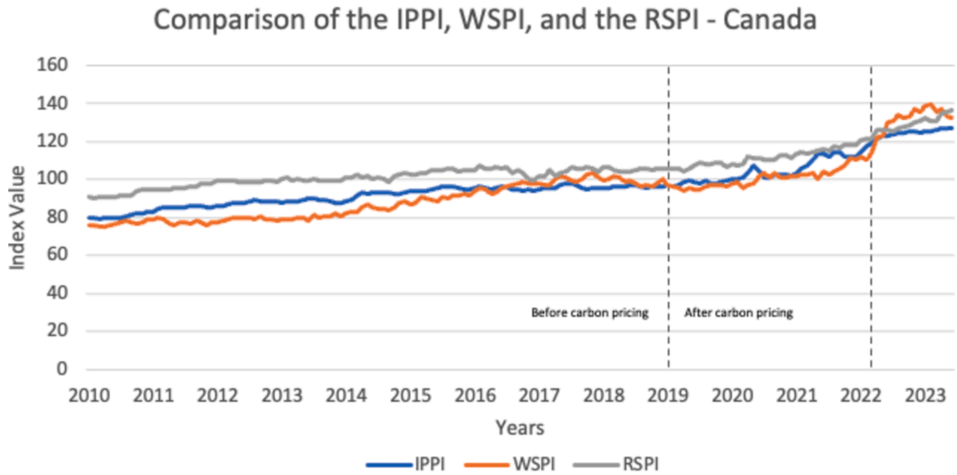

Fig. 1.

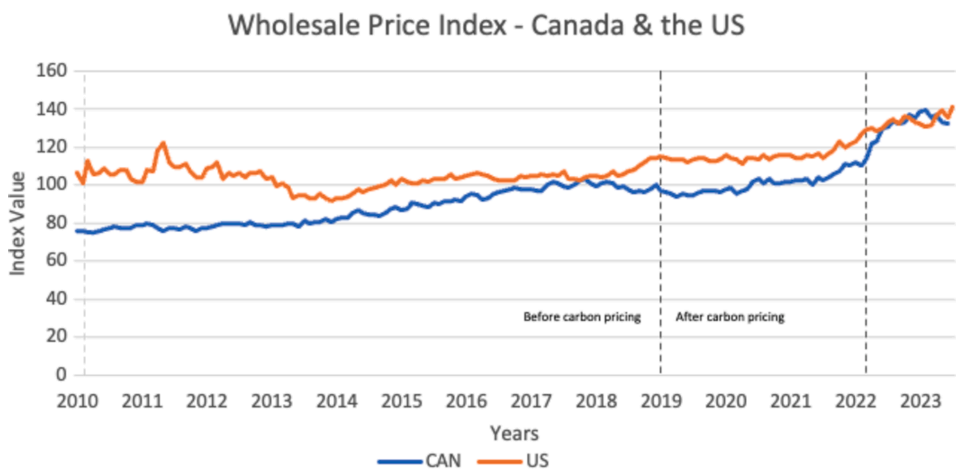

Fig. 2.

Fig. 3 provides the forecast for the Canadian IPPI, WSPI, and RSPI. As can be seen, each is forecasted to increase. The sharpest increase is in the RSPI, which, over the forecast period, is anticipated to rise to just over 180 (from just below 140). The overall behaviour of the three indices is similar to that of the already observed data presented in Fig. 1 in that the three indices are very tightly coupled. In Fig. 1, the WSPI and IPPI become much more tangled, with the WSPI and IPPI trading positions over the observation period. This is also seen in the forecast, though, the WSPI is mainly slightly above the IPPI, only converging at some points.

Wholesale Services Price Index – Canada vs. the US.

With any forecast, there is a caveat that must be kept in mind: the further out in time the forecast goes, the less reliable it becomes over

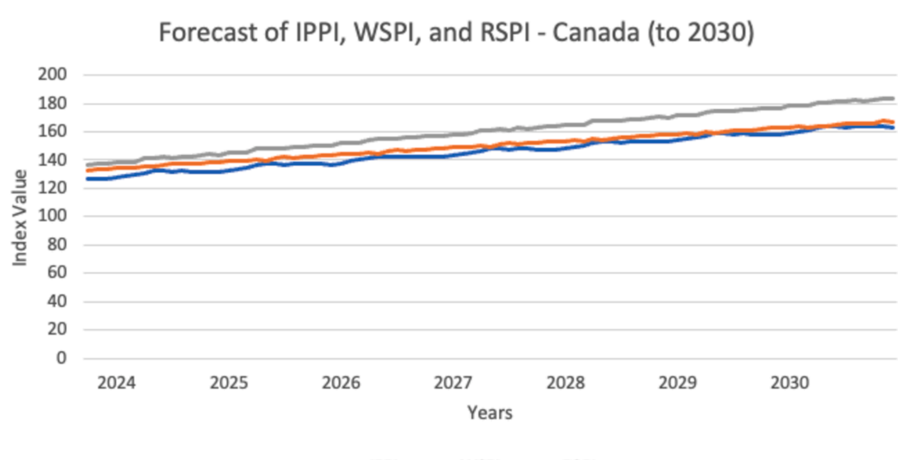

Fig. 3.

time. This means that the forecast is more indicative of what is likely to happen in the short term rather than in the long term. There will be many events (or non-events) that will shape the 2030 forecast, most of which are not known at this time. Examples of these events could be nation state action, climate change, natural disasters, or disruptions in the supply chain. Therefore, this forecast should be interpreted as an informed estimate of the future index values based on the data available today, with the understanding that as events unfold (or do not unfold, as the case may be), the forecast will change.

4. Discussion

This paper sought to understand the impact of carbon taxes on food prices in Canada. Without access to wider, historical dataset at the firm-level, it is challenging to determine any causal factors contributing to the rise in food price inflation in Canada. Moreover, the findings of this study are constrained using general categories without considering the specific practices that influence the competitiveness of unique firms. Therefore, it is crucial to recognize other elements that may contribute to the inflation of food prices in Canada, thereby affecting affordability. It is also important to note that food price inflation is a worldwide phenomenon that has several, diverse causes (Galanakis 2023; Zhou et al. 2023). Therefore, attributing food price hikes to a single exogeneous source without accounting for other factors may only provide a limited understanding of the issue.

In Canada, the agri-business sector is an energy and resource-heavy user, without exemptions for certain producers, the burden from the carbon tax could be significantly borne by food producers. According to the research conducted by the Fraser Institute in 2021, the implementation of taxes will result in significant adverse effects, such as a 1.8 % decrease in Gross Domestic Product and a net loss of approximately 184,000 jobs (McKitrick and Aliakbari 2021). These impacts persist even after considering the jobs created through new government spending and household rebates for carbon charges. The research conducted in the Saskatchewan province revealed that the implementation of a new carbon price will have a significant influence on the province's economy, perhaps leading to the migration of firms to the United States (Liu et al. 2018). Slade (2017) conducted a study that documented the impact of both the intense and extensive margin. The imposition of a tax at the producer level due to the intense market impact not only results in an increase in the price of carbon-heavy products, but also creates a motivation for individual producers to decrease their emissions (Slade 2017). Through the mechanism of broad market impact, a consumer tax is implemented to increase the retail price of high emission items, including beef (Slade 2017). This tax incentivizes customers to transition their consumption towards lower emission alternatives.

The changes in the IPPI, WSPI, and RSPI indicate that the implementation of the carbon price may have affected every level of the food supply chain. Currently, Canada's carbon tax is established at $65 per metric ton of greenhouse gas emissions, however, it is projected to rise to $170 by 2030, thus intensifying its impacts (Thurton 2023). The data presented in results section, specifically Fig. 3, suggest significant shifts in wholesale and industrial prices since the introduction of the carbon tax at the federal level. The findings have uncovered a notable disparity between industrial and wholesale costs. Industrial prices are far more vulnerable to changes in costs, which likely include the impact of carbon pricing. The cost increases throughout the supply chain are highly measurable and traceable. The Industrial Product Pricing Index for food has increased at a faster rate than the Consumer Price Index for food costs. Despite being exempt from taxation, farmers and agri-food industry groups are concerned that it will have a detrimental effect on farmers' income, likely due to the anticipated rise in fuel prices and associated costs, which will reduce their profits (Meng et al. 2012; Murray and Rivers 2015).

The impact of environmental regulation on competitiveness mostly stems from variations in regulatory measures among industries or nations, rather than the regulations themselves (Venmans et al. 2020). An asymmetric environmental strategy between countries leads to variations in costs as a primary consequence. Subsequently, at the firm-level, companies react to new regulations by adjusting the quantities produced, the pricing of their products (for example, by transferring costs to consumers), and making investments to enhance productivity (resulting in indirect consequences). Firm-level decisions have a direct impact on many economic results such as profits, employment, market structures, as well as technical outcomes like product innovation, process innovation, and the development of input-saving technologies. These impacts also extend to international economic outcomes such as trade flows and investment location, resulting in subsequent consequences. Canada is a net importer of food. In the figures series 3, there is a visible shift in production costs after the carbon tax is implemented in Canada, though less volitivity in the diary (Fig. 3c) and meat (Fig. 3d) categories, both of which operate fully or partially under a supply management regime. The increase in costs and volatility in some categories after the implementation of the federal carbon tax leading to a loss in profitability can have an impact on investment decisions in the industry, making the Canadian food industry in several categories – fruit, vegetables, sugars and grains – losing competitive ground.

The primary objective of Canada's federal carbon tax is to mitigate GHG emissions by imposing taxes on the fossil fuels responsible for their production. Early studies on the implementation of carbon price changes in the 1990 s in seven European nations has yielded overall positive outcomes. A comprehensive study found that carbon taxes led to projected reductions in GHG emissions ranging from 2 % to 7 % over a period of ten years or more (Ekins 1994). Additionally, B.C., the first Canadian province to introduce a carbon tax, showed early positive reductions in GHGs. However, research has also indicated that implementing a carbon tax will effectively decrease GHG emissions, but it may also have the unintended consequence of shrinking the economy (Murray and Rivers 2015). Continuing to raise the carbon tax rate will likely lead to significant decreases in the GDP. This suggests that in a resource-intensive economy like Saskatchewan, where there are few options for transitioning to alternative fuels and are a primary exporter of agricultural products such as grains within Canada and globally, implementing a carbon price will likely lead to a reduction in economic activity rather than adaptation to it.

Based on the existing data at the firm level, it is impossible to ascertain the scope and extent of effects that the federal carbon tax has on the affordability of food. The marginal cost of carbon emissions is fixed, not variable, and it is incurred at the point of sale. Consequently, expenses associated with greenhouse gas emissions become the responsibility of taxpayers. The federal government determines the price of carbon, and tax revenue is collected like any other tax. Carbon taxes have a wide range of applicability and apply to both individual consumers and industries. This can lead to a broader spectrum of benefits for in terms of GHG reduction. Provinces and territories with autonomous carbon pricing regimes allocate the revenue from carbon taxation according to their discretion. In the provinces subject to the federal carbon tax, the Canadian government through Climate Action Incentive payments, provides payments distributed on a quarterly payment schedule. Low-income household are the primary beneficiaries of the redistributive nature of this carbon tax regime. Although low-income households do spend a disproportionate share of their income towards food and consumption taxes, this is a response from the demand side of food consumption to a problem originating from the supply side of food production.

The political feasibility of imposing a carbon pricing within the food industry is unlikely to be popular among voters (Raymond 2020). Indeed, the discussion around the imposition of taxes on food continues to be ongoing and includes taxes other than the carbon tax alone. Vilified food products, such soft drinks, have been subjected to what are known as 'fat' taxes, although these levies have had minimal success in Canada. "Shrinkflated" products – products that have been significantly decreased in size to the point where they are no longer considered grocery items but rather snacks – have also been subjected to taxation. Consumers, weary of high prices, and subjected to multiple consecutive quarters of food price inflation expect relief. The rationale for implementing a carbon price on essential food items vital for subsistence is weak. From a political standpoint, imposing further financial strain on already limited food budgets may not be viable for supporters of the carbon tax.

There is a scarcity of data that establishes a direct connection between the activities of individual firms and the specific amount of carbon tax paid at the retail level during manufacturing in Canada. As a result, consumers have limited knowledge of the carbon tax and its impacts on the agri-food industry and are skeptical of the underlying reasons driving price hikes. It is unsurprising that consumers have a fundamental misunderstanding of the objectives and outcomes of the carbon tax. The federal government should be concerned about the deceptive way both sides of the carbon price issue spread misinformation (Raymond 2020). Lack of transparency is a widespread problem in agricultural businesses worldwide, and it is not limited to Canadian firms. In addition, the complex nature of food supply chains, which involve worldwide commodities partners and the participation of several third-party businesses, such as shipping, transportation, packaging, and manufacturing, creates a system that seems to lack a clear origin (Music et al. 2022). The global character of our food supply poses challenges in compelling firm transparency at the national level. Without firm level transparency in the agri-food sector, the impacts of the carbon tax on prices will remain subject to debate while at the same time, Canadian sector specific commodities loss ground competitively with their global counterparts.

5. Conclusion

The findings of this study underscore the complexity and challenges in measuring the direct impacts of carbon taxation on the agri-food sector in Canada due to a lack of detailed firm-level data. It highlights the observable effect of carbon taxation on wholesale food prices but calls for further, more granular research to understand the broader implications on food affordability and security. Food price inflation is a worldwide phenomenon that has several, diverse causes. Therefore, attributing food price hikes to a single exogeneous source without accounting for other factors may only provide a limited understanding of the issue. This need for deeper investigation reflects the intricacies of carbon taxation's effects across different levels of the food supply chain, underscoring the necessity for targeted studies to elucidate the specific impacts on food prices and market competitiveness within Canada.

Carbon tax plans are favoured by politicians to incentivize enterprises to implement more environmentally friendly manufacturing methods, with the goal of guiding a specific sector towards a sustainable reduction in carbon emissions. Our findings suggest that carbon taxes can affect a firm's long-term competitive advantages, financial benefits, and production decisions, potentially influencing profitability and competitive advantage. Yet, without historical data at the firm level, we cannot provide evidence of the impact of carbon taxes on firm-level competitiveness and economic growth. Future study in this area should focus on analyzing data at the firm level, if compelled to be accessible, to gain a comprehensive understanding of the effects of the carbon price on individual businesses.

CRediT authorship contribution statement

Sylvain Charlebois: Writing – review & editing, Writing – original draft, Resources, Investigation, Formal analysis, Data curation, Conceptualization. **Gumataw Abebe:** Methodology. **Tony R. Walker:** Methodology. **Vlado Keselj:** Methodology. **Janet Music:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Keshava Pallavi Gone:** Writing – original draft, Validation, Resources, Investigation, Formal analysis, Data curation. **Karim Tuffaha:** Methodology. **Janele Vezeau:** Methodology. **Bibhuti Sarker:** Writing – review & editing, Writing – original draft. **Stacey Taylor:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Following the literature, the Akaike Information Criterion (AIC) was used to select the best SARIMAX model. Recalling that the parameters of the SARIMAX function are (p,q,d) for the non-seasonal component and (P,Q,D) for the seasonable component, these values typically range from 0 to 2, with M set as 12 to denote the number of months in the year. The number of combinations tested using the range of 0–2 was 3^6 resulting in running 729 combinations per dataset (IPPI, WSPI, and RSPI), for a total of 2,187 combinations. This method is similar to a grid search where each combination of the parameters is systematically run to find the model with the lowest AIC score for each dataset.

Although each dataset was tested independently, the best model for all units of analysis (IPPI, WSPI, and RSPI) was (0,1,1)(0,1,1,12). These parameters translate to the following:

(p,d,q)(P,D,Q,M) = (0,1,1)(0,1,1,12).

where.

p = 0, meaning that there are 0 autoregressive *non-seasonal* terms in the model,

d = 1, meaning that there is one *non-seasonal* difference needed for stationarity,

q = 1, meaning that there is one lagged *non-seasonal* forecast error in the prediction equation,

P = 0, meaning that there are 0 autoregressive *seasonal* terms in the model,

D = 1, meaning that there is one *seasonal* difference needed for stationarity,

Q = meaning that there is one lagged *seasonal* forecast error in the prediction equation, AND.

M = 12, meaning that the model has accounted for 12 periods in each season (year), and therefore, monthly data is used for this forecast.

Although the most common values range for p,d,q and P,D,Q range from 0 to 2, initial experiments with the IPPI dataset were run to test out an extended range of 0–4. The means that each parameter could take on 5 possible values: 0,1,2,3,4. This proved, however, to be extremely computationally expensive as the number of combinations that had be tested was 5^6, resulting running 15,625 combinations. The lowest AIC score was found for (0,1,1)(0,1,1,12). Therefore, for the remaining two datasets (WSPI and RSPI), the common values of 0–2 were kept, dropping the combinations from 15,625 to 729 per dataset.

Data availability

Data will be made available on request.

References

Alchian, A.A., 1950. Uncertainty, evolution, and economic theory. J. Polit. Econ. 58 (3), 211–221.

Anwar, M., Rahman, S., Kabir, M.N., 2021. Does national carbon pricing policy affect voluntary environmental disclosures? A global evidence. Environ. Econ. Policy Stud. 23, 211–244. https://doi.org/10.1007/s10018-020-00287-2.

Canada Revenue Agency, 2024. Fuel charge rates. Government of Canada. https://www.canada.ca/en/revenue-agency/services/forms-publications/publications/fcrates/fuel-charge-rates.html.

Charlebois, S., Juhasz, M., Music, J., 2021. Supply Chain Responsiveness to a (Post)-Pandemic Grocery and Food Service E-Commerce Economy: An Exploratory Canadian Case Study. Businesses 1, 72–90.

Charlebois, S., Le Bouthillier, M., Music, J., Vézeau, J., 2023. Unraveling Elusive Boundaries: A Comprehensive Framework for Assessing Local Food Consumption Patterns in Nova Scotia. Canada, Foods, p. 12.

Colmer J, Martin R, Muûls M, Wagner U (2022) Does Pricing Carbon Mitigate Climate Change? Firm-Level Evidence from the European Union Emissions Trading Scheme. IDEAS Working Paper Series from RePEc.

Dehdari, P., Wlcek, H., Furmans, K., 2023. An updated literature review of CO2e calculation in road freight transportation. Multimodal Transportation 2 (2), 100068.

Ding, J., Chen, W., Wang, W., 2020. Production and carbon emission reduction decisions for remanufacturing firms under carbon tax and take-back legislation. Comput Ind Eng 143, 106419. https://doi.org/10.1016/j.cie.2020.106419.

Ekins, P., 1994. The impact of carbon taxation on the UK economy. Energy Policy 22, 571–579. https://doi.org/10.1016/0301-4215(94)90076-0.

Elgar, F.J., Pickett, W., Pförtner, T.-K., et al., 2021. Relative food insecurity, mental health and wellbeing in 160 countries. Soc Sci Med 268, 113556. https://doi.org/10.1016/j.socscimed.2020.113556.

Environment and Climate Change Canada (2023) Canadian Environmental Sustainability Indicators: Greenhouse gas emissions.

FST Logistics. (n.d.). FOB price vs. delivered price for logistics savings. FST Logistics. Retrieved October 31, 2024, from https://fstlogistics.com/fob-price-vs-delivered-price-for-logistics-savings-fst-logistics/.

Galambos, K.J., Palomino-Hernández, A.B., Hemmelmayr, V.C., Turan, B., 2024. Sustainability initiatives in urban freight transportation in Europe. Transp. Res. Interdiscip. Perspect. 23, 101013.

Galanakis, C.M., 2023. The “Vertigo” of the Food Sector within the Triangle of Climate Change, the Post-Pandemic World, and the Russian-Ukrainian War. Foods 12.

Goulder, L.H., Hafstead, M.A.C., Kim, G., Long, X., 2019. Impacts of a carbon tax across US household income groups: What are the equity-efficiency trade-offs? J Public Econ 175, 44–64. https://doi.org/10.1016/j.jpubeco.2019.04.002.

Herforth, A., Venkat, A., Bai, Y., et al., 2022. Methods and options to monitor the cost and affordability of a healthy diet globally Background paper for. The State of Food Security and Nutrition in the World 2022. IDEAS Working Paper Series from RePEc.

Holland, A., 2021. Canada's food system: An overview 2021. The School of Public Policy, University of Calgary https://www.policyschool.ca/wp-content/uploads/2021/09/JSC8_Canadas-Food-System_Holland.pdf.

House of Commons, 2023. Canada. Report of the Standing Committee on Agriculture and Agri-Food, Growing the agricultural sector while mitigating emissions https://www.noscommunes.ca/Content/Committee/441/AGRI/Reports/RP12503602/agrirp10/agrirp10-e.pdf.

Klinsky, S., 2015. Justice and Boundary Setting in Greenhouse Gas Cap and Trade Policy: A Case Study of the Western Climate Initiative. Ann. Assoc. Am. Geogr. 105, 105–122. https://doi.org/10.1080/00045608.2014.960043.

Köppl, A., Schratzenstaller, M., 2023. Carbon taxation: A review of the empirical literature. J Econ Surv 37, 1353–1388. https://doi.org/10.1111/joes.12531.

Laborde, D., Mamun, A., Martin, W., et al., 2021. Agricultural subsidies and global greenhouse gas emissions. Nat Commun 12, 2601. https://doi.org/10.1038/s41467-021-22703-1.

Liu, L., Huang, C.Z., Huang, G., et al., 2018. How a carbon tax will affect an emission-intensive economy: A case study of the Province of Saskatchewan, Canada. Energy 159, 817–826. https://doi.org/10.1016/j.energy.2018.06.163.

MacDonald, L., 2008. Baird calls climate change the 'defining issue of my generation'. The Hill Times.

Mandegari, M., Ebadian, M., Saddler, J.J., 2023. Decarbonizing North America's rail sector, international initiatives and local opportunities. Transp. Res. Interdiscip. Perspect. 21, 100859.

Matern R;, Seer S, Ozga P;, et al (2023) Huner Count 2023.

McKitrick R, Aliakbari E (2021) Estimated Impacts of a $170 Carbon Tax in Canada Revised Edition.

Men, F., Urquia, M.L., Tarasuk, V., 2021. The role of provincial social policies and economic environments in shaping food insecurity among Canadian families with children. Prev Med (baltim) 148, 106558. https://doi.org/10.1016/j.ypmed.2021.106558.

Mendly-Zambo, Z., Raphael, D., 2019. Competing Discourses of Household Food Insecurity in Canada. Soc. Policy Soc. 18, 535–554. https://doi.org/10.1017/S1474746418000428.

Meng, S., Siriwardana, M., McNeill, J., 2012. The Environmental and Economic Impact of the Carbon Tax in Australia. Environ Resour Econ (dordr) 54, 313–332. https://doi.org/10.1007/s10640-012-9600-4.

Moghadam, H.M., 2020. Price and non-price competition in an oligopoly: an analysis of relative payoff maximizers. J. Evol. Econ. 30 (2), 507–521.

Mugoni, E., Nyagadza, B., Hove, P.K., 2023. Green reverse logistics technology impact on agricultural entrepreneurial marketing firms' operational efficiency and sustainable competitive advantage. Sustainable Technol. Entrepreneurship 2, 100034. https://doi.org/10.1016/j.stae.2022.100034.

Murray, B., Rivers, N., 2015. British Columbia's revenue-neutral carbon tax: A review of the latest "grand experiment" in environmental policy. Energy Policy 86, 674–683. https://doi.org/10.1016/j.enpol.2015.08.011.

Music, J., et al., 2022. Telecommuting and food E-commerce: Socially sustainable practices during the COVID-19 pandemic in Canada. Transp. Res. Interdiscip. Perspect. 13, 100513.

Music, J., Charlebois, S., Marangoni, A.G., et al., 2022. Data deficits and transparency: What led to Canada's 'buttergate'. Trends Food Sci Technol 123, 334–342. https://doi.org/10.1016/j.tifs.2022.02.005.

Naef, A., 2024. The impossible love of fossil fuel companies for carbon taxes. Ecol. Econ. 217, 108045. https://doi.org/10.1016/j.ecolecon.2023.108045.

Natural Resources Canada. (2019). Energy use in the transportation sector. https://oee.nrcan.gc.ca/publications/statistics/trends/2019/transportation.cfm.

Nkesah, S.K., 2023. Making road freight transport more Sustainable: Insights from a systematic literature review. Transp. Res. Interdiscip. Perspect. 22, 100967.

Noubissi ED, Nkengfack H, Messie Pondie T, Ngounou BA (2023) Economic impact of the carbon tax: Evaluation of the reduction in CO2 emissions. Nat Resour Forum n/a: https://doi.org/https://doi.org/10.1111/1477-8947.12348.

Okereke, C., Russel, D., 2010. Regulatory Pressure and Competitive Dynamics: Carbon Management Strategies of UK Energy-Intensive Companies. Calif Manage Rev 52, 100–124.

Proof (2018) Food Insecurity Policy Research.

Raymond, L., 2020. Carbon pricing and economic populism: the case of Ontario. Clim. Pol. 20, 1127–1140. https://doi.org/10.1080/14693062.2020.1782824.

Rungskunroch, P., Shen, Z.J., Kaewunruen, S., 2021. Getting it right on the policy prioritization for rail decarbonization: Evidence from whole-life CO2e emissions of railway systems. Front. Built Environ. 7, 638507.

Saric, D., Carson, L., Guido, B., 2017. Managing your carbon footprint: impacts and opportunities arising from alberta's climate change legislation. Alta Law Rev 55, 317–348.

Schwartz, H., Gustafsson, M., & Spohr, J. (2020). Emission abatement in shipping–is it possible to reduce carbon dioxide emissions profitably?. Journal of Cleaner Production, 254, 120069.

Semet, R., 2024. Coordinating social equity and emissions: Challenges in carbon tax policy. Energy Policy 185, 113954. https://doi.org/10.1016/j.enpol.2023.113954.

Shideler, J.C., Hetzel, J., 2021. Policy Frameworks BT - Introduction to Climate Change Management: Transitioning to a Low-Carbon Economy. In: Hetzel, J. (Ed.), Shideler JC. Springer International Publishing, Cham, pp. 21–49.

Slade, P., 2017. The Effects of Pricing Canadian Livestock Emissions. Canadian Journal of Agricultural Economics/revue Canadienne D'agroeconomie 66, 305–329. https://doi.org/10.1111/cjag.12157.

Socci, C., Ahmed, I., D'Andrea, S., et al., 2023. Role of carbon tax in a sustainable economic growth. Environ Dev Sustain. https://doi.org/10.1007/s10668-023-03516-2.

Speck, S., 1999. Energy and carbon taxes and their distributional implications. Energy Policy 27, 659–667. https://doi.org/10.1016/S0301-4215(99)00059-2.

Statistics Canada. (n.d.). Survey of household spending *(SHS)* (SDDS 2318). Retrieved [October 31, 2024] from https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=2318.

Tarasuk V (2005) Household Food Insecurity in Canada. Toronto.

Taylor, S., Charlebois, S., Music, J., 2023. Affordability of Canada's Food Guide: Current challenges amid COVID-19, War in Ukraine, and other world events. Frontiers in Nutrition.

Taylor, S., Charlebois, S., Crowell, T., Cross, B., 2024. The paradox of corporate sustainability: analyzing the moral landscape of Canadian grocers. Frontiers in Nutrition.

Thurton, D., 2023. Carbon price jumps to $65/tonne, but rebates will also rise for millions of households. In: Canadian Broadcasting Corporation. Canadian Broadcasting Corportation.

Tubiello, F.N., Rosenzweig, C., Conchedda, G., et al., 2021. Greenhouse gas emissions from food systems: building the evidence base. Environ. Res. Lett. 16, 65007. https://doi.org/10.1088/1748-9326/ac018e.

United Nations, 2023. The Sustainable Development Goals Report 2023: Goal 11 - Make cities and human settlements inclusive, safe, resilient, and sustainable. United Nations. https://unstats.un.org/sdgs/report/2023/goal-11/.

Venmans, F., Ellis, J., Nachtigall, D., 2020. Carbon pricing and competitiveness: are they at odds? Clim. Pol. 20, 1070–1091. https://doi.org/10.1080/14693062.2020.1805291.

Wang, H., 2010. Buyer power, transport cost and welfare. J. Ind. Compet. Trade 10, 41–53.

Watson, J.G., Chow, J.C., Lowenthal, D.H., Pritchett, L.C., Frazier, C.A., Neuroth, G.R., Robbins, R., 1994. Differences in the carbon composition of source profiles for diesel-and gasoline-powered vehicles. Atmos. Environ. 28 (15), 2493–2505.

Withey, P., Sharma, C., Lantz, V., et al., 2022. Economy-wide and CO2 impacts of carbon taxes and output-based pricing in New Brunswick, Canada. Appl Econ 54, 2998–3015. https://doi.org/10.1080/00036846.2021.2001422.

Wu, T., Thomassin, P.J., 2018. The Impact of Carbon Tax on Food Prices and Consumption in Canada. In, 2058th edn.

(2023) Greenhouse gas emissions and agriculture.

(2021) Review of the OBPS Regulations: Consultation paper.

Zhao, L., Lv, Y., Wang, C., et al., 2023. Embodied greenhouse gas emissions in the international agricultural trade. Sustain Prod Consum 35, 250–259. https://doi.org/10.1016/j.spc.2022.11.001.

Zhou, Y., Hu, F., Zhou, Z., 2018. Pricing decisions and social welfare in a supply chain with multiple competing retailers and carbon tax policy. J. Clean. Prod. 190, 752–777.

Zhou, X.-Y., Lu, G., Xu, Z., et al., 2023. Influence of Russia-Ukraine War on the Global Energy and Food Security. Resour Conserv Recycl 188, 106657. https://doi.org/10.1016/j.resconrec.2022.106657.

Zhou, X., Zhu, Q., Xu, L., et al., 2024. The effect of carbon tariffs and the associated coping strategies: A global supply chain perspective. Omega (westport) 122, 102960. https://doi.org/10.1016/j.omega.2023.102960.