EVALUATING THE ECONOMIC IMPACT OF CARBON TAX: A CASE STUDY OF BRITISH COLUMBIA

by

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Abstract

The province of British Columbia enacted North America's first comprehensive carbon tax in 2008. The tax which covers about 75% of all greenhouse gas emissions in the province has generally been characterized as a successful exercise due to its resulting environmental benefits. To shed a new light on the economic impact of BC's carbon tax this paper attempts to answer the following research questions; (1) What is the impact of BC's carbon tax on the provincial GDP? and (2) Can the variation in GDP be explained by technological innovation? Results from impulse response analysis as well as variance decomposition analysis confirm no significant impact of the tax on provincial GDP from July 2008 – December 2019. Rather the evidence presented in this paper suggests that putting a price on emissions could potentially lead to a redirection of the economy towards more emissions-friendly investments.

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Chapter 1. Introduction

Climate change has become a major global challenge of the 21st Century. There is a consensus that greenhouse gases (GHG) are responsible for global warming. Consequences of climate change include a gradual decrease in global economic output, scarcity of food and water, and a reduction of life expectancy resulting from extreme temperatures and rising sea levels (Maslin, 2021). Carbon pollution is considered a negative eternality. Since its social costs are unaccounted for, private emitters are faced with price distortions in the absence of appropriate policies. Hence an unregulated market results in excessive pollution. Theoretically there are two standard ways to approach this problem; (1) determine the degree of pollution that is socially desirable and sell a number of tradable permits that authorize that level of pollution, or (2) estimate the monetary worth of the negative externality and tax pollution by that amount.

Economists have established the efficiency of carbon pricing in reducing emissions (Best et al., 2020). Therefore, two practical forms of carbon pricing are: (1) charging a price per unit of emissions in form of a carbon tax, and (2) a cap-and-trade system which places a limit on emissions and allows industries trade rights to pollute, subject to the cap. Although the necessity to reduce CO_2 emissions has been largely established, there is a growing concern regarding its consequences on different aspects of the economy. Some issues have been raised concerning the employment effect, particularly for carbon intensive industries (Yamazaki, 2017), the potential for carbon leakage, and the impact on firms' competitiveness and productivity (Aldy & Pizer, 2015; Carbone & Rivers, 2017; Chan et al.,2012 etc.) Yet, empirical evaluation of long-term economic consequences of carbon policies across the globe has produced inconclusive results.

Currently, Canada operates a two-part Federal Pricing System consisting of the fuel charge – which directly affects individual consumption – and the output-based system, which is a performance-based system for industries[1]. In 2018, The Greenhouse Gas Pollution Pricing Act (GHGPPA) was passed to meet the Paris agreement goals to limit the rise of temperatures below 2°C. The GHGPPA which established the minimum requirements for carbon pricing in Canada set price on emission at $20 per tonne of CO_2 in 2019. The federal government has recently announced its plan to increase the tax from its current price of $50 per tonne to $65 in April 2023. This would translate into an additional 3 cents per litre of gasoline. Also noteworthy is that each province maintains flexibility of designing its carbon plan with the condition that they comply with the minimum requirements set by the federal government.

On the other hand, the province of British Columbia enacted North America's first comprehensive carbon tax in 2008. The tax started at a rate of $10/tonne, rose yearly by $5/tonne until it reached $30 in 2012 and stayed at the same level until 2018 when it was raised to $35/tonne. Effective April 1, 2022, BC’s carbon tax rose from its 2021 price of $45 to $50/tonne of carbon dioxide equivalent emissions. To cushion the effects on households and businesses the revenue-neutral tax redistributes all proceeds in form of tax cuts or direct transfers to households and businesses. In the first four years of implementing its carbon tax, BC’s use of petroleum fuels dropped by roughly 15%. According to data from Statistics Canada[2], BC’s 2020 GHG emissions were 61.7 megatons of CO2e; this represents a 3% decline since 2005. Emissions per capita currently stand at 12.0 tonnes, which is 32% below Canada’s per capita average of 17.7 tonnes. The tax which covers about 75% of all greenhouse gas emissions in the province has generally been characterized as a successful exercise due to its resulting environmental benefits. A series of papers evaluate the impact of the tax on different aspects of the economy such as consumption (Lawley & Xiang, 2019), employment (Yamazaki, 2017), trade (Rivers & Schaufele,

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[1] https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work.html

[2] https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-british-columbia.html

2014) etc., These studies find negligible negative impacts resulting from the taxes. Overall, little evidence exists on its impact on aggregate output.

Empirical studies document two distinct ways to measure the cost of emissions reduction to the economy, namely direct welfare costs and macroeconomic costs. This paper is concerned with the macroeconomic costs - the extent to which a carbon tax may reduce economic performance. The systematic disruption caused by the imposition of a carbon tax can be examined from the supply side channel and demand side channel. From the supply side, a carbon tax increases the price of fossil fuels, thereby increasing the cost of production and thus reducing aggregate supply. Looking at the demand side, when the price of fossil fuels increases, the resulting effect is an increase in price of final goods which may cause reductions in purchasing power, thus limiting consumption. These events may push the economy below its potential output level in the short-term.

Another aspect which has received limited attention is the role of technological innovation in explaining the net impact of the tax. Neoclassical growth models identify technological innovation as the primary determinant of long-term economic growth. Moreover, the idea of innovation as a catalyst for economic activity appears frequently in literature. Some practical roles of technological innovation include R&D spending in eco-efficient production, renewable energy sources and other low-carbon innovation technologies. Research shows that technological progress yields promising solution to achieving emissions target while ensuring sustainable economic development. For instance, Chen et al., (2020) argued that an essential requirement for China to achieve its energy regulation is continual improvement of Total Factor Productivity (TFP). To shed a new light on the economic impact of BC’s carbon tax this paper attempts to answer the following research questions:

1. What is the impact of BC’s carbon tax on the provincial per capita GDP?
2. Can the variation in per capita GDP be explained by technological innovation?

In this study, the economic consequence of carbon tax is summarized as fluctuations in per capita GDP. Thus, GDP dynamics may be interpreted as follows: domestic increase in retail fuel prices resulting from carbon tax policies will lead to a short-term change in output, whereas in the long-term GDP growth will be dependent upon productivity growth. To answer the research questions, I estimate the impulse response of per capita GDP to shocks in the price of gasoline, within a Structural Vector Autoregression (SVAR) framework using two sets of data. The post-tax data is used to determine the effects of the tax on GDP dynamics while the pre-tax data is used to create a counterfactual forecast of GDP changes which is compared against the post-tax data. These consequences are measured by observing the evolution of per capita GDP in British Columbia with and without the carbon tax. The theoretical framework is based on Solow’s (1956) neoclassical growth model which captures the role of innovation in economic growth. This study resembles research by Bernard & Kichian (2021), which measures the economic impact of British Columbia’s carbon tax using a VAR model. However, I digress from Bernard & Kichian (2021) regarding the choice of endogenous variables and the adoption of a structural model. Curbing GHG emissions while maintaining economic growth is an important consideration for policy makers. Moreover, climate change and mitigation impacts will differ across regions. Identifying these relationships yields vital information to policy makers as other provinces consider their individual strategies to carbon pricing.

The rest of this paper is organized as follows; Chapter 2 reviews the relevant literature on carbon emissions reduction. Chapter 3 describes the data and methodology used for the econometric model estimation. In chapter 4 the results of estimated impulse responses are presented and discussed in chapter 5. Finally, chapter 6 concludes with a highlight on limitations and further research options.

Chapter 2. Literature Review

Changes to the world's climate resulting from GHG emissions have driven intense research into the environmental consequences and economic implications of policy solutions. Carbon pricing aims to reduce the amount of CO_2 released into the atmosphere by imposing a charge or cap on carbon dioxide emissions, thereby creating incentives for reducing GHG emissions to help curb climate change. Since governments aim to address climate change with minimal cost to industries and jobs, information on the regional costs of climate change and mitigation measures is necessary to guide mitigation policies.

2.1. Economic Models for the Assessment of Climate Policies

Globally, Integrated Assessment Models (IAM) are used to evaluate the social cost of carbon (Nordhaus, 2017) as well as the complex relationships among the environmental and socioeconomic mechanisms of the earth system (Weyant, 2017). Some examples of cost-benefit IAMs include The Dynamic Integrated model of Climate and the Economy (DICE), Regional Integrated model of Climate and the Economy (RICE), Policy Analysis of the Greenhouse Effect (PAGE), and Framework for Uncertainty, Negotiation, and Distribution (FUND) models. Although these models vary with respect to methodology, theoretical assumptions, and application, the aim is to determine the optimal carbon policy by matching the marginal cost of an additional tonne of carbon against its resulting marginal damages. A fully integrated IAM includes an economic growth model, a damage component, and a climate component. The DICE (Nordhaus, 1994) and RICE (Nordhaus & Yang, 1996) models typically adopt Ramsey's (1928) growth model in its climate change framework. An assumption of the Ramsey growth model is that society maximises its future consumption by reducing today's consumption through investments in capital stock. The DICE model extends Ramsey's framework to include climate investments, using a Cobb-Douglas function of capital, labor, and technology. Economies are thereby assumed to increase future consumption by devoting output to emissions reduction, while averting climate change (Nordhaus, 2017).

Among economic models for evaluating energy and environmental policies, General Equilibrium Models (GEM) are the most comprehensive. The general equilibrium theory attempts to explain the dynamic relationships between demand, supply, and price within an economy. The primary assumption in General Equilibrium analysis is that an exogenous shock to an economic system has repercussions for agents within the economy, namely households, firms, and governments. GE models are broadly classified into Computable General Equilibrium (CGE) and Dynamic Stochastic General Equilibrium (DSGE) models. Many ex-ante studies use CGE models to simulate the impact of climate policies (e.g., Suerkemper et al., 2015; Beck et al., 2015; Carbone & Rivers, 2017 etc.). These models are elaborated by (1) creating a structural model of the economy to test the sensitivity of agents to price changes by way of regional input-output tables, (2) identifying key parameters with base year data, generally structured using a Social Accounting Matrix (SAM), (3) calibrating the model to fit the underlying parameters and (4) introducing a counterfactual in terms of policy change, then readjusting the model to trace the potential consequence of such policy.

In addition, CGE models include behavioural assumptions about rational economic agents embedded in economic theory. Primarily, supply and demand arise from profit-maximizing firms and utility-maximizing consumers, and a solution to the model is derived through a set of simultaneous equations to determine the market clearing price (Burfisher, 2021). An example is Bergman's (1991) estimation of emission control costs using an open economy static CGE model with a nested CES-Leontief production function to disaggregate various inputs to production. Unlike static models, dynamic CGE models consider the intertemporal responses of economic agents to fluctuations in economic activities. Using a case study for New Brunswick, Withey et al. (2021) construct a recursive dynamic CGE model to estimate the impact of Canada's carbon pricing system on both GDP and carbon emissions within the province. They also compare the different impacts on small and large emitters. To achieve this, their model is extended to incorporate a nested CES production function, seven energy sectors and disaggregated emissions intensities based on energy use.

The process of estimating potential consequences from any given policy on different aspects of the economy is termed an Economic Impact Assessment (EIA). Methods that exist to conduct EIAs include input-output models, benefit-cost analysis, partial equilibrium analysis, economic growth models among others. The Input-output (IO) technique developed by Leontief (1941) is one of the key antecedents of CGE models. A standard IO model is defined by Koks et al. (2016) as “a static linear model which presents the economy through sets of interrelationships between sectors themselves (the producers) and others (the consumers)”. IO models rely on transaction matrices to determine the flow of commodities in an economy. The models take final demand as given and attempt to determine the supply side using comparative static analysis. IO models are particularly useful when the focus is on the regional effects of climate mitigation efforts (Folmer & Gabel, 2000). Energy IO models also exist to study the relationships between energy use and economic activities using transaction matrices. An example is research from Malik et al. (2014) which evaluated the economic and employment implications of energy policies in Australia. In an extended study, Bagheri et al. (2018), used eight multi-factor energy IO multipliers to measure the extent to which changes in final demand may influence energy flows, carbon emissions, and earnings in the Canadian energy sector.

The Partial Equilibrium (PE) model is another valuable method for climate policy analysis. In contrast to GE models, PE models do not capture all markets and prices in an economy, rather the approach is solely focused on one segment of the economy. PE models are useful for analysing the impact of carbon prices on economic behaviour (Masoumzadeh et al., 2016), and the direct welfare cost of policy actions (Tuinstra et al., 2014). Some empirical studies that have applied the PE method in the environmental policy domain include: Kesicki’s (2013) sensitivity analysis of Marginal Abatement Cost curves for the UK energy system and a simulation of the economic and welfare impacts of China’s coal subsidies by Xiang & Kuang (2020). A different method, Cost-Benefit analysis (CBA), compares the resulting benefits and economic costs associated with a proposed policy or project. The cost-benefit approach based on the Kaldor Hicks efficiency criteria is common in the welfare economics literature to determine the pareto efficient allocation of resources, that is, when benefits derived from using a good equal the marginal cost of producing that good (Smith, 1986). Tol (2001) applied a CBA method embedded in a FUND CGE model to determine optimal emission abatement. In a more recent study, Wang et al. (2019) combined the CBA method with the Leontief IO model to evaluate the economic costs and benefits of different environmental taxation scenarios in China.

Economic growth models are commonly used to analyze the long-term consequences of policy shocks on a variety of macroeconomic variables. Most of the analysis of economic growth takes the Solow (1956) model as the main reference point. The model serves as a beneficial tool to examine the key determinants of long-term sustainable economic growth. Research based on Solow's growth framework typically include measures of capital stock, labour input and technological progress as growth determinants. Due to its ability to replicate the features of modern business cycles, the neoclassical growth model is also commonly applied to study the economic fluctuations arising from variations in global oil prices (de Miguel et al., 2003; Ren et al., 2023). The model highlights the Solow residual – also referred to as TFP – as a key determinant of long-term persistent increase in per capita output. Recently, a growing interest has emerged on the importance of technological innovation in achieving long-term sustainable emissions reduction. The argument suggests that achieving the objectives of the Paris agreement to keep global temperature increase below $2^{\circ}C$ would require an overhaul of the energy system and carbon-emitting industry (Verbruggen et al., 2019). Achieving this would require state intervention to increase the rate of innovation. To analyse the impact of technological progress on carbon emissions, Chen et al., (2020) embed the Solow residual into the logarithmic mean Divisia index model using data from China's 30 provinces. Their study confirms a reduction in carbon emissions due to TFP, suggesting that the relationship is dependent upon changes in both environmental technology and production technology.

2.2. Modeling Economic Impacts of Carbon Regulations

The likely consequences of environmental regulations around the world remain a highly controversial topic (Yamazaki, 2017). While the literature on the exact relationship between carbon tax and GDP growth is quite little, different econometric techniques exist to empirically quantify potential impacts of emissions reduction.

Within the CGE framework, Zhang et al. (2019) measure the short-term impacts of carbon tax on sectoral competitiveness and tax burdens in China based on a multi-regional input-output table. Their study shows that relative to the more developed regions, carbon emissions per unit of economic output for the less developed regions are higher than the national average. Utilising disaggregated carbon emissions data from both production and consumption sides, they also evaluate the economic impact of carbon tax under three different tax recycling scenarios. Overall, their data depicts that heavy-industry dependent provinces which are the most carbon-intensive, have higher net tax burdens (Zhang et al., 2019).

Similar studies in the EU (Carbone & Rivers, 2017; Fischer & Fox, 2007; Böhringer and Alexeeva-Talebi, 2012) and Australlia (Asafu-Adjaye & Mahadevan, 2013) predict a reduction in output and exports for energy-intensive and trade-exposed industries. Related research by Gamtessa & Olani (2018) applied a panel co-integration and error correction model for energy-intensive and non-energy intensive industries. The results show that carbon tax may have less economic cost in industries with significant potential for energy efficiency improvement. Their findings confirm Metcalf's (2019) assertion that new innovations and production techniques are needed to transition to a zero-carbon economy. Metcalf & Stock (2020) estimate the dynamic effect of the EU Emission Trading System on the growth rate of GDP and employment using the Ordinary Least Squares (OLS) regression method. Ultimately, they find no evidence to support claims of negative macroeconomic impacts of a carbon tax.

Another strand of research suggests that the government's use of carbon tax proceeds will eventually determine the economic outcome of the tax. This idea is closely related to the double dividend (DD) hypothesis. Indeed, economic outcomes will also depend on the rate of progression of the tax rates. Governments generate considerable revenue from carbon taxes that could be channelled towards tax reforms, financing new infrastructure, or reducing the burden on lower-income households (Marron & Morris, 2016). In the environmental tax literature, the DD hypothesis indicates that both environmental and economic gains can be achieved simultaneously by recycling carbon tax revenues to offset other taxes (Freire-González & Ho, 2019). Adopting the CGE technique for Scotland, Allan et al. (2014) uncovers that the full impact of carbon pricing on Scottish GDP and employment is dependent on how carbon tax revenue is recycled. Particularly, when the tax is externally recycled, they estimate a decrease in GDP by 0.30% and 2.68% and a rise in unemployment by 4.1% and 2.6% in the short-run and long-run respectively. On the other hand, when the carbon tax revenue is used to offset personal income tax, there is a positive net effect on the Scottish economy. In this scenario, GDP increases by 0.26% and 0.83% while unemployment rate increases by only 1.79% and 1.27% in the short-run and long-run respectively (Allan et al., 2014). In a study of the impact of the BC carbon tax on the distribution of household income, Beck et al (2015) predict a decline in household welfare by 0.13% in the absence of revenue recycling but a 0.08% decline if tax revenues are recycled towards tax breaks. This finding partly supports the DD hypothesis that proceeds from environmental taxes can be used to compensate for the economic cost of the tax (Beck et al., 2015).

BC's carbon tax has been described as "perhaps the closest example of an economist's textbook prescription for the use of a carbon tax to reduce GHG emissions" (Murray & Rivers, 2015, p. 682). As a result, several climate change studies in Canada have focused on BC's carbon tax as well as that of high-emitting provinces such as Alberta, Ontario & Quebec (See Yamazaki, 2017; Mascher, 2018; Erutku, 2019; Bistline et al., 2020; Bernard & Kichian, 2021; Mildenberger et al., 2022 etc.). Some of the studies rely on the difference-in-difference (DID) estimation to evaluate the impact of the tax by comparing the periods before and after its implementation against a counterfactual situation. To make inference about causal effects, DID procedures typically rely on the so-called parallel trends assumption, which implies that without the policy intervention, the average result for the treated and comparison (control) groups would have changed concurrently. Taking this into account, Olale et al. (2019) consider the sectorial impact of BC's carbon tax. Particularly their study, compares farm revenues in BC (treatment group), against other Canadian provinces (control group) from 2000 – 2015. Assuming similar socioeconomic characteristics for both groups, they find a decline in net farm income associated with the Carbon tax in BC. Likewise, studies by Elgie &McClay (2013) and (Metcalf, 2014) compare GDP growth rates in BC against the rest of Canada using a DID analysis. According to Elgie &McClay (2013), despite the tax, GDP growth in British Columbia has kept up with that of the rest of Canada, implying no negative impact on the provincial economy within the initial four years of the tax's implementation.

Having included province-level fixed effects to control for time-invariant unobserved factors, Metcalf (2014) find no evidence of a negative impact of the tax on BC's GDP growth. Also using the DID method, relatively recent research by Yamazaki (2017) compares employment trends in British Columbia prior to and after the carbon tax was introduced. The study uses a labour market framework to predict a fall in employment for the most carbon-intensive trade-sensitive industries, and a rise in employment for clean service industries. Overall, the results show that the tax generated a 0.74 percent annual increase in employment over the 2007–2013 post tax period (Yamazaki, 2017). Bernard & Kichian (2021) evaluate the GDP effect of BC's carbon tax under a standard Vector Autoregression (VAR) framework. The results from their impulse response analysis and counterfactual investigations, reiterates that the carbon tax in BC has had zero statistically significant effect on provincial GDP dynamics (Bernard & Kichian, 2021). Generally, the economic impacts of carbon taxes remain a controversy. It appears that the outcome may be dependent on the actual tax rate, governments use of the tax proceeds and other existing regional characteristics.

2.3. Strengths and Weaknesses of reviewed models

The reviewed approaches to modeling climate policy impacts have individual merits and drawbacks. The strength of IAMs lies in their ability to integrate knowledge from different disciplines into a single framework. This is especially beneficial for climate change studies since the subject extends to a variety of domains. Yet, as Tol (2013) points out, the Social Costs of Carbon (SCC) remain unclear; SCC estimates range from $6 per ton of carbon dioxide using the FUND models, to $28 with DICE, and $30 in PAGE models (Ackerman & Munitz, 2012). These differences partly result from disparities in estimating the so-called climate “damage function” – a method for quantifying the economic loss resulting from climate change – for each model. Hence, a major shortcoming of IAMs relates to the accuracy of the damage function (Liu et al., 2019).

On the other hand, BCA has been a trusted method for governments to make decisions about public spending and policy for many years, but its use in the environmental policy domain is relatively recent. One concern with BCA is that it tries to put a price tag on both the costs and benefits of a policy. However, as Ackerman & Heinzerling (2002) argue, it is difficult to place a monetary value on non-market goods such as pollution. Similarly, the BCA method of discounting future impacts to evaluate costs and benefits experienced at different periods has been criticized for underestimating the vast future consequences of negative environmental externalities (Hwang, 2015). Additionally, BCA is a partial equilibrium analysis that fails to adequately capture long-run impacts of climate policies.

IO models have the advantage of being able to quantify the various orders of indirect impacts that various economic agents have on the system as a whole (Seung, 2013). However, IO analysis is a demand-driven Partial Equilibrium approach which may not be suitable for long-run analysis; as Koks et al. (2016) assert, “For an IO approach to be suitable, a disturbance must be long enough to take effect but also short enough to avoid excessive substitutions”. Additionally, Because the input-output model does not distinguish between different production structures for different production types, the models are thought to produce inaccurate emissions estimates (Dietzenbacher & Mukhopadhyay, 2006). Although, industry-specific PE models typically require less data, it is possible for environmental policies to significantly affect markets outside those in which the policy is imposed (Bovenberg & Goulder, 2001). Another drawback of the IO approach is weak demand side modeling while more emphasis is placed on the supply or production side, hence PE assessments of aggregate carbon tax effects can be misleading.

Consequently, IO models are commonly combined with other techniques such as CGE models to produce more accurate result. CGE models, albeit complex, are grounded in economic theory and hence produce findings that are intuitive and simple to interpret. Additionally, unlike PE models, CGE models are flexible and suitable for economy-wide analysis. However, the CGE model is a counterfactual making it challenging to predict beforehand what the outcome of a certain simulation will resemble due to the multiple interconnections and feedbacks among the variables (Borges, 2005). Accordingly, the large amount of data required to create a model that accurately replicates real-world mechanisms, coupled with the somewhat unrealistic assumptions of the General Equilibrium theory (Ackerman et al., 2012) poses a setback for CGE models.

Presently, the domain for the empirical application of growth models encompasses labour (Driffield, 2000), climate change (Bowen et al., 2011), finance (Pasichnyi, 2017) and health (Cylus & Al Tayara, 2021) to mention a few. The model's simplifying assumption of an aggregate (Cobb-Douglas) production function makes the data requirements less stringent compared to other methods. Additionally, research based on the neoclassical approach can be applied to produce results that are accurate yet relatively easy to understand and interpret within a concise timeframe. As Mankiw et al. (1992) state "the Solow model gives the right answers to the questions it is designed to address" (p. 409). Based on its advantages, the growth model provides justification for the theoretical assumptions in this study. Yet, in order to statistically test the neoclassical growth assumptions, an empirical strategy is needed. Accordingly, a vector autoregression model is constructed to locate the determinants of economic growth theorised by the growth model.

2.4. Vector Autoregression Models

The VAR model developed by Christopher Sims (1980) is a linear model where each variable is explained by its lagged values as well as past values of other variables in the system. The relationships between the variables in a VAR model can be disentangled using the conventional “impulse response analysis”. As Sims (1980) proposed, the VAR model offers a credible approach to forecasting economic time series, assessing economic models, and evaluating potential policy changes. VAR models fall into three broad categories; reduced form, recursive and Structural VAR (SVAR) models. The SVAR is useful to identify causal links beyond what can be found using the reduced form or recursive models, such as differentiating across demand-side and supply-side energy price shocks (Kilian, 2014). In many cases, the researchers are particularly interested in the response of the economy over time to unanticipated policy shocks, hence the usefulness of the structural model to interpret the coefficients that make up the lag structure of the model. The structural VAR assumes that disturbances are related to macroeconomic shocks through a matrix, while impulse responses are interpreted under the assumption that all other shocks are held constant. Typically, economic intuition provides the basis to incorporate the appropriate structural restrictions.

Recently, SVAR analysis is increasingly the preferred method to study the economic consequences of oil price shocks (see Kilian, 2014; Rezitis, 2015; Lorusso & Pieroni, 2018 and Beckmann et al., 2020). In the same vein, the SVAR model is the preferred choice to answer the current research question since carbon taxes produce similar outcomes with negative oil price shocks. Although oil price fluctuations are often unexpected and rapid, carbon taxes share its characteristics of increasing the cost of production and decreasing demand.

Moreover, since the carbon tax in BC was announced only five months prior to its implementation, there was insufficient room for the market to adjust, therefore it is considered as being a shock. On the other hand, evidence suggesting that GDP is an autoregressive process (Enders et al., 2007), is another justification for using the SVAR model. Time series analysis is consequently a more accurate way to anticipate GDP growth without sacrificing quantitative data on the estimation, as GDP fluctuations are best explained by the GDP values from the previous period. Additionally, statistical analysis using VARs is less complex and easier to interpret and complete within a short timeframe. To estimate provincial carbon tax impacts, I analyze BC's GDP dynamics from January 1999 to December 2019, which cover the periods before and after the tax implementation, using a multivariate specification to accommodate a variety of shocks relevant to economic growth. To my knowledge, this strategy has not been applied to test the economic impact of carbon tax in British Columbia. Further details of the model specification are presented in subsequent sections.

Chapter 3. Methodology

3.1. Theoretical Framework: The Solow Model

Solow's neoclassical growth model provides a theoretical background to interpret the effects of different shocks to the economy. From the supply side perspective, gasoline is considered an input to production, and therefore, a price increase affects output through increased production costs. To elaborate the transmission mechanism, consider the following aggregate production function:

$$Y_t = A_t f(L_t, K_t, E_t) \tag{1}$$

Where Y_t represents aggregate output in a given time t, K_t is capital stock, L_t stands for labour, E_t is energy input (gasoline), and the variable A_t is Total Factor Productivity, also called the Solow residual which is a measure of technological progress. Note that A_t is Hicks-neutral as it appears as an increasing variable. The logarithm of both sides of equation (1), is totally differentiated then rearranged to get

$$d\ln A_t = d\ln Y_t - \left(\frac{L_t}{Y_t}\frac{\partial Y_t}{\partial L_t}\right) d\ln L_t - \left(\frac{K_t}{Y_t}\frac{\partial Y_t}{\partial K_t}\right) d\ln K_t - \left(\frac{E_t}{Y_t}\frac{\partial Y_t}{\partial E_t}\right) d\ln E_t \tag{2}$$

Considering gasoline to be an intermediate product in the production process, its cost x_t is added to the final price of finished goods. On the other hand, production requires physical work in terms of labour L which grows exogenously through population growth, n and capital K which includes machinery, production equipment and other tangible assets. Capital stock is accumulated through saving and investment adjustment. As in the classic Solow model, labour and capital are subject to diminishing returns and are also paid their marginal products w and r. The level of technology, A determines what combinations of L, K and E are required for production. With these assumptions in place, I turn to the cost function for firms, assuming they are price takers in the input market the cost functions can be written as follows

$$\text{Total Cost: } C_t = w_t L_l + r_t K_t + x_t E_t \tag{3}$$

$$\text{Average Cost: } \frac{C_t}{Y_t}$$

$$\text{Marginal Cost: } \frac{\partial C_t}{\partial Y_t}$$

Also, the cost function can also be expressed in terms of the degree of returns to scale, μ, thus;

$$C_t = \mu \frac{\partial C_t}{\partial Y_t} Y_t \tag{4}$$

Where $\mu \approx \left(\frac{\partial Y_t}{\partial L_t}\frac{L_t}{Y_t}\right) + \left(\frac{\partial Y_t}{\partial K_t}\frac{K_t}{Y_t}\right) + \left(\frac{\partial Y_t}{\partial E_t}\frac{E_t}{Y_t}\right)$

Given the output level Y_t, firms must minimize its cost subject to the production function. As in

$$Min\ (C_t) = w_t L_l + r_t K_t + x_t E_t$$

$$s.t. Y_t = Z_t f(L_t, K_t, E_t)$$

Setting up the Lagrangian

$$\wedge\,(L_t, K_t, E_t, \lambda) = w_t L_l + r_t K_t + x_t E_t - \lambda(f(L_t, K_t, E_t) - Y_t) \tag{5}$$

The following first order conditions with respect to each factor of production are derived as

$$\frac{\partial Y_t}{\partial L_t} = \frac{w_t}{\partial C_t / \partial Y_t} \tag{6.1}$$

$$\frac{\partial Y_t}{\partial K_t} = \frac{r_t}{\partial C_t / \partial Y_t} \tag{6.2}$$

$$\frac{\partial Y_t}{\partial E_t} = \frac{x_t}{\partial C_t / \partial Y_t} \tag{6.3}$$

Combining equations 4 and 6 produces

$$\frac{\partial Y_t}{\partial L_t} = \alpha \frac{Y_t}{L_t} \mu \tag{7.1}$$

$$\frac{\partial Y_t}{\partial K_t} = \beta \frac{Y_t}{K_t} \mu \tag{7.2}$$

$$\frac{\partial Y_t}{\partial E_t} = \theta \frac{Y_t}{E_t} \mu \tag{7.3}$$

Where α, β, and θrepresent the shares of labour, capital, and energy in total cost respectively[3]. Next, the Solow residual is derived by substituting equations 7.1, 7.2 and 7.3 into equation 2 as follows

$$d \ln A_t = d \ln Y_t - \mu \left[\alpha d \ln L_t + \beta d \ln K_t + \theta d \ln E_t\right] \tag{8}$$

The steady state in Solow's model refers to a point where growth is halted. In other words, $\ln L_t$, $\ln K_t$, and $\ln E_t$ = 0. However, the presence of A_t means a steady state associated with balanced growth path where output grows at a constant exogenous rate of technology, that is $d \ln Y_t \equiv d \ln A_t$.

In this context, higher energy price resulting from incremental carbon taxes may negatively affect supply and diminish company's profitability. However, since long-run growth in this model is driven by technological progress, an increase in the Total Factor Productivity, A_t results in higher output even without increasing inputs. This specification of the growth model motivates the construction of the VAR model in the following section. This study proceeds as follow; First, the SVAR model is Specified. Secondly, I conduct unit root tests. Thirdly, the impulse response functions are estimated. Fourthly, I conduct the forecast error decomposition analysis and lastly, the results are interpreted.

3.2. SVAR Model Specification

A structural VAR model allows us to test the impacts of different shocks to the economy while holding other shocks constant. The growth model presented in the previous section identifies the main determinants of growth such as capital, labor, energy, and

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[3] $\alpha = \frac{w_t L_t}{C_t}$, $\beta = \frac{r_t K_t}{C_t}$ and $\theta = \frac{p_t E_t}{C_t}$

technology. To analyze the impact of carbon tax on per capita GDP in British Columbia, this study is mainly interested in assessing energy shocks denoted by gasoline prices E_t, and technology shocks represented by multifactor productivity A_t.

An increase in carbon tax is considered an energy shock because it directly increases the retail price of gasoline. In light of this, it is assumed that the market will react to the shock of the carbon tax in a manner similar to how it will respond to the shock of the energy price increase. Secondly, relying on the assumption that carbon taxes are salient (Rivers & Schaufele, 2015) I expect tax-induced price changes to generate higher a demand response than equivalent market-determined price increases. Additionally, multifactor productivity (MFP) is used as a proxy for Solow's technological advancement since technology is unobservable.

Proxies for capital and labour are not included in the analysis for the following reasons: Variables in the SVAR are based on factors that might shock GDP which are the assumed growth determinants according to Solow model. Because this study is mainly interested in the technological progress which is basically the portion of output growth that cannot be attributed to the other factors of production, I chose to focus on the productivity variable. Also, because VARs can become heavily parameterized, having too many parameters relative to observations in the data (i.e., degrees of freedom problem) could result in several difficulties with estimation.

I also introduce inflation I_t in the model which is measured by the Consumer Price Index (CPI). Although traditional growth models do not directly consider inflation, existing literature emphasize the importance of controlling for inflationary pressures in evaluating GDP changes. According to Motley (1998), inflation increases price distortions which might negatively affect supply and imposes considerable deadweight losses on the economy. Since a carbon tax is akin to an increase in gasoline prices, it becomes crucial to account for inflation in the model. On the other hand, given that growth in Solow's model is also dependent upon technological progress and the accumulation of capital, this paper allows for the possibility that inflation may lower the rate of return on both human and physical capital and possibly reduce the rate of technological change.

To understand how the economy of BC responds to its carbon tax, the analysis is carried out in two scenarios. First, a three-variable structural VAR is constructed, consisting of gasoline price E_t, inflation I_t, and per capita GDP Y_t. The aim is to evaluate the instantaneous response of per capita GDP to changes in the price of gasoline. Secondly, to study impact of technological progress in the GDP dynamics, the model is extended to include multifactor productivity A_t. As described in section 3.1, when the economy reaches its long-run equilibrium, economic growth is dependent on the rate of technological advancement. The four-variable model is constructed to test this hypothesis, which is: examine if per capita GDP responds differently to energy shocks in the presence of technological growth. Existence of a positive per capita GDP growth in the four-variable model, would be attributed to technological advancement. This may be expected as carbon pricing motivates the transition to clean technology.

All variables in a VAR are considered to be endogenous, hence it is importance to justify the endogeneity of the variables in the model. Carbon tax is determined within the economy, also policy makers are able to adjust the tax based on economic conditions. In essence, regulatory decisions tend to take economic conditions into account. Based on the assumption that the tax passes through to the price of gasoline, I infer that gasoline prices are also endogenous. Inflation is considered endogenous because it is dependent on factors within the economy including government policies. Since economic growth arises as a direct result of internal processes, GDP is considered endogenous. Lastly, in Solow's exogenous growth model, productivity or technological progress is determined outside the model. Notwithstanding, it is possible to endogenize technological innovations through "learning-by-doing" (See Feasel et al., 2001). Accordingly, productivity is assumed to be endogenous in the second model. The structural VAR model is generally presented as follows;

$$\mathbf{A}_0 K_t = \alpha + \sum_{i=1}^{p} \boldsymbol{A}_i K_{t-i} + \varepsilon_t \tag{9}$$

Where p is the lag order, K_t is a vector of the endogenous variables and $\boldsymbol{A}_i$ is an $N\ X\ N$ matrix of autoregressive coefficients of vector K_{t-i}. ε_t represents the vector of serially uncorrelated structural disturbances and var(ε_t) = Θ; since Θ is a diagonal matrix, the structural disturbances are assumed to be mutually uncorrelated. Assuming that $\mathbf{A}$ is invertible, pre-multiplying equation (9) by $\boldsymbol{A}_0^{-1}$ yields the reduced form of the VAR to be estimated:

$$K_t = \boldsymbol{A}_0^{-1}\alpha + \sum_{i=1}^{p} \boldsymbol{A}_0^{-1}\boldsymbol{A}_i K_{t-i} + e_t \tag{10}$$

Which may re-written as:

$$K_t = \boldsymbol{a} + \boldsymbol{A}(L)K_{t-i} + e_t \tag{11}$$

Where $\boldsymbol{a}$ is the intercept vector and $A(L)$ is the matrix polynomial in the lag operator L, and the error term e_t is the white noise with variance-covariance matrix $\Sigma_e = E(e_t e_t')$. Additionally, $e_t = A_0^{-1}\varepsilon_t$ denotes the relationship between the reduced-form error terms and the uncorrelated structural errors.

3.2.1. The Identification Problem

If A_0^{-1} is known, it would be possible to estimate the structural VAR in equation (9) from the estimated parameters in the reduced form in equation (11). However, since coefficients in A_0^{-1} are unknown, it becomes necessary to identify the structural form. Moreover, a prominent flaw of the reduced-form VAR is that its error terms will likely be correlated. This creates a problem for the impulse-response analysis as we attempt to disentangle the impact of different shocks to the system.

To address this problem, the Cholesky orthogonalization is used to impose restrictions to identify the orthogonal structural components of the error terms which represent the shocks. The aim of an orthogonalized system is to avoid the correlation of error terms in the Impulse Response Functions. Adopting the AB model by Amisano & Giannini (2011), I introduce the structural form parameter matrix $\boldsymbol{B}$ such that the identification problem follows the form:

$$\boldsymbol{A}e_t = \boldsymbol{B}\varepsilon_t \tag{12}$$

Where $\boldsymbol{A}$ and $\boldsymbol{B}$ are the $n\ x\ n$ matrices to be estimated. Imposing $E(\varepsilon_t\varepsilon_t') = I$, yields the following identifying restriction on $\boldsymbol{A}$ and $\boldsymbol{B}$**:**

$$\boldsymbol{A}\Sigma\boldsymbol{A}' = \boldsymbol{B}\boldsymbol{B}'$$

To achieve exact identification, the total number of restrictions needed is $n^2 + n(n-1)/2$, where n is the number of endogenous variables in the system. The series are ordered such that the first variable is not influenced by shocks to other variables in the system however, a shock to the first variable has an instantaneous impact on all the variables, whereas the second shock may only influence subsequent variables and so on. This is realized by setting the upper triangle of the $\boldsymbol{A}$ matrix to zero with 1's on the main diagonal, while $\boldsymbol{B}$ is restricted to be a diagonal matrix. The series are ordered based on the assumptions earlier discussed.

1. Since the effects of gasoline price shock is of primary interest, it is assumed to be independent of contemporaneous disturbances to other variables and is therefore, placed first. Empirical evidence also suggests that oil price changes impact GDP through its effects on inflation and other macroeconomic variables (Awerbuch & Sauter, 2006). This remains the case even when the price increase is gradual and anticipated as in the case of a carbon tax (Yoshino et al., 2021). Since carbon taxes are predetermined, it follows that changes in price of fossil fuel resulting from carbon taxes are also predetermined, which rules out feedback from inflation and GDP to the price on gasoline.
2. Following the theoretical assumptions of the neoclassical growth model, MFP is considered the second most exogenous variable of the system. Research also

indicates that technological advancements could mitigate negative economic impacts of future energy price fluctuations (Lutz & Meyer, 2009). This may be achieved by shifting the attention to cleaner sources of energy thereby reducing the reliance on fossil fuels.

3. Inflation (denoted by CPI) is influenced by shocks to the price of gasoline and MFP. Empirical growth literature highlights that inflation may impact GDP through its effects on savings and reduction of productive capital (Motley, 1992).
4. Lastly, GDP is considered as the most endogenous variable since shocks to all other variables are assumed to affect output growth.

Given the above restrictions the model is presented in matrix form for the trivariate model as:

$$\boldsymbol{A} = \begin{bmatrix} 1 & 0 & 0 \\ a_{21} & 1 & 0 \\ a_{31} & a_{32} & 1 \end{bmatrix} \qquad \boldsymbol{B} = \begin{bmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & 0 \\ 0 & 0 & a_{33} \end{bmatrix}$$

And for the four-variable model as follows:

$$\boldsymbol{A} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 \\ a_{41} & a_{42} & a_{43} & 1 \end{bmatrix} \qquad \boldsymbol{B} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ 0 & a_{22} & 0 & 0 \\ 0 & 0 & a_{33} & 0 \\ 0 & 0 & 0 & a_{44} \end{bmatrix}$$

Missing values in the matrices (a_{ij}) indicate entries to be estimated while entries with assigned values are assumed to be fixed. The next section details the data selection and unit root tests.

3.3. Data

The study uses data for British Columbia across two sample periods: (1) prior to the introduction of the tax; January 1999 – June 2008 and (2) after its introduction; July 2008 –December 2019. The sample is cut off in the year 2019 to avoid the compounding economic impacts of the Covid-19 pandemic experienced in 2020 and beyond.

I also note that the recession that occurred between 2008-2009 may have confounding impacts on the results derived from the analysis. To account for this impacts Bernard & Kichian (2021) include dummy variables to represent the recessionary periods. However, they find that inclusion of the dummy terms does not change their overall conclusions. Therefore, to keep the exposition simple, the impact of the recession is ignored in the present study. All data are obtained from the Statistics Canada website, sources are detailed in the appendix. Data plots for the variables of interest are shown in figures 3.1 to 3.4. The raw data consists of provincial annual real GDP in 2012 chained dollars, average monthly retail prices for gasoline, quarterly population estimates, monthly Consumer Price Index (CPI – Seasonally adjusted), and yearly multifactor productivity (MFP) index for business sector industries. All prices are in Canadian dollars. The series are transformed as follows;

1. **Gasoline** – Refined petroleum products – which includes gasoline and diesel – contribute to roughly 38% of total end-use demand in British Columbia[4]. Out of these two, gasoline is most commonly used. Average final retail prices for regular gasoline in Vancouver are used since it is the province's largest city by economy and geography. The nominal price series are expressed in cents per litre.
2. **Multifactor Productivity (MFP)** – A proxy for the Solow residual in this study. The MFP index is computed as a ratio of real GDP to aggregate labour and capital inputs. As reported by Statistics Canada, the MFP index gauges the effectiveness

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[4] https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-british-columbia.html#:~:text=About%2087%25%20of%20electricity%20in,Peace%20River%20in%20the%20northeast.

of all inputs in the production process. Annual MFP is disaggregated to monthly series by the Denton linear interpolation method using CPI as the indicator variable.

3. **Consumer Price Index (CPI)** – Since the aim of including CPI is to proxy for inflation, the seasonally adjusted federal CPI is the preferred option. The national monthly CPI for all-items (2002=100) is used. The provincial CPI reported by statistics Canada is not seasonally adjusted which could potentially cause a problem of non-stationarity.
4. **Gross Domestic Product (GDP)** – Annual GDP is also disaggregated to monthly values using the Denton procedure. Where available, quarterly GDP data is the preferred option, however at the provincial level, statistics Canada reports only annual GDP data. These were further converted to per capita terms using monthly population estimates[5].

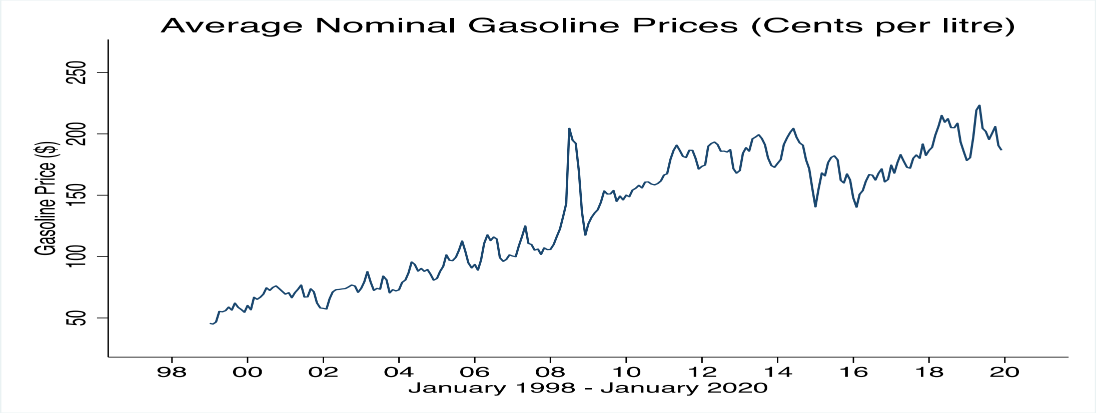

Figure 3.1: Average nominal gasoline prices in Vancouver (1999-2019)

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[5] To obtain monthly series, quarterly population estimates are divided by three, a robust smoothing is then applied to check for outliers.

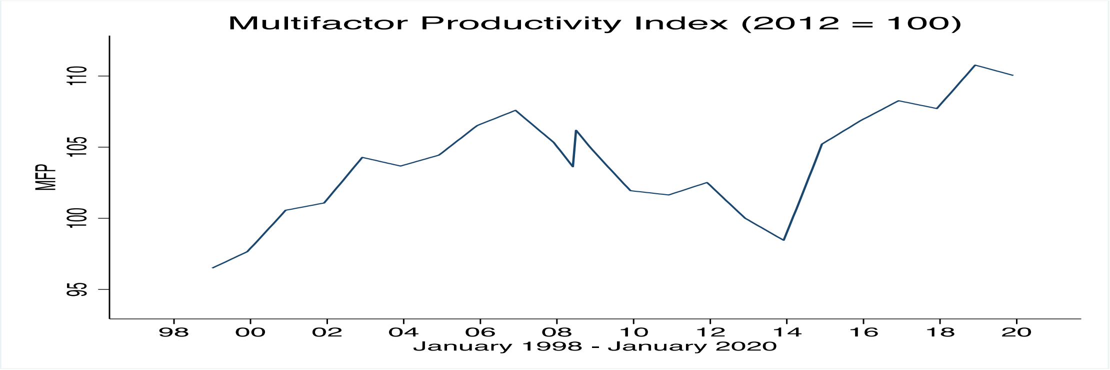

Figure 3.2: Provincial Multifactor Productivity index (2012 = 100)

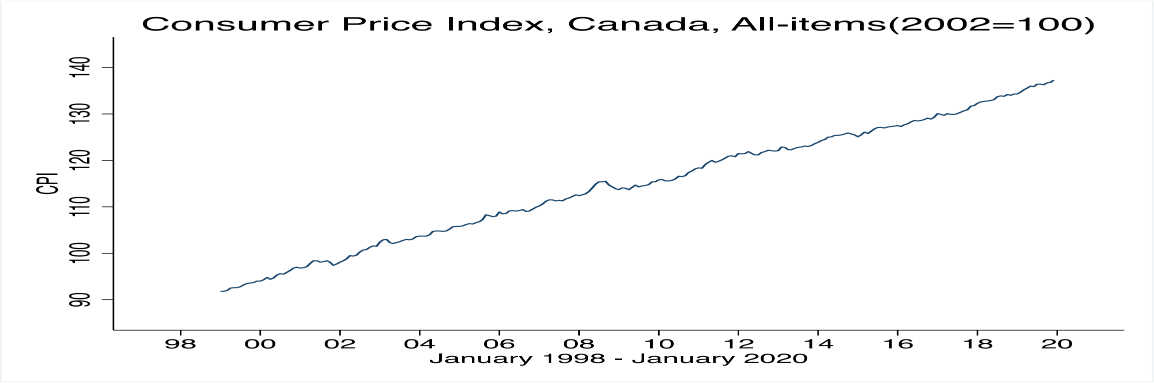

Figure 3.3: Consumer Price Index, Federal (2002=100)

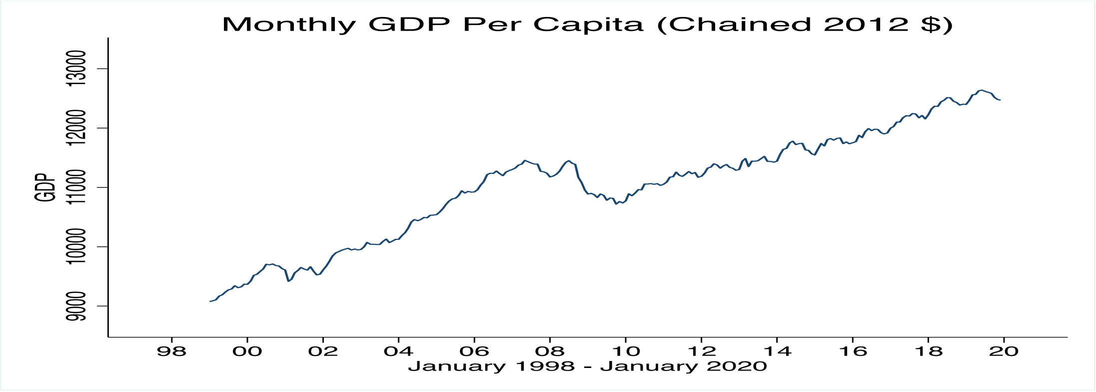

Figure 3.4: GDP Per Capita for British Columbia (Chained 2012 dollars)

3.3.1. Unit root Tests

The unit root or stationarity test is a prerequisite for VAR analysis. In essence, non-stationary series could lead to statistically spurious relationships from which meaningful inferences cannot be drawn. A series is said to be stationary if the mean and autocovariances of the series are time independent; this is called “strict stationarity”. However, because strict stationarity tends to be too strong an assumption, we rely on the alternative “weak stationarity”. The assumption therefore is that the series has a constant mean and variance throughout the time. Statistically, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests are standard approaches to check for stationarity when there is serial correlation among variables - a common case for macroeconomic time series data.

For both tests, rejection of the null hypothesis of the presence of unit root implies that the series are stationary. A common approach to address a unit root problem would be to difference the variable(s) of interest. However, Sims et al. (1989) argues that differencing to address unit root may be unnecessary and could yield inconsistent estimates and a loss of vital information regarding interrelationships among variables.

Table 3.1 summarizes the results of the ADF and PP unit root tests for all variables in natural log forms. The trend option is used since the graphs in figures 3.1-3.4 indicate that the data exhibits an upward trend overtime. The null hypothesis of the existence of a unit root is rejected for all variables with the exception of the pre-tax per capita GDP. However, suppressing the constant term in the PP test confirms stationarity for the pre-tax per capita GDP variable. Therefore, the model is estimated without further transformation.

Table 3.1: Unit Root Tests

	January 1999 - June 2008 **(Pre-tax)**		**July 2008 - December 2019** **(Post-tax)**	
Variables	ADF	PP	ADF	PP
lnA_t	-5.050***	-2.827**	-3.202*	-3.161*
lnE_t	-4.823***	-4.221***	-4.524***	-3.817**
lnI_t	-4.054***	-3.489**	-3.425**	-3.349**
lnY_t	-2.185	0.683	-5.975***	-5.652***
lnY_t*	-	5.774***	-	-

Note: *, **, and *** indicate significant at 10%, 5%, and 1% levels respectively

*P-Perron test with no constant

Chapter 4. SVAR Estimation

The SVARS are estimated by maximum likelihood, beginning with the trivariate model for the post-tax period. For the optimal lag selection, Schwarz Information Criterion (SIC) and Hannan-Quinn Information Criterion (HQIC) suggest 1 and 2 lags respectively while the Akaike Information Criterion (AIC) and Final Prediction Error (FPE) both suggest 4 lags. The optimal lag order of 2 is selected as this specification clears the error structure of the model. In the case of the four-variable model which includes MFP, all lag selection criteria recommend a lag order of 4. However, using the Lagrange multiplier statistics, the null hypothesis of no serial correlation among residuals is rejected for the four-variable model. Yet, since both models satisfy the stability condition that all eigenvalues lie inside the unit circle, I proceed with the impulse response analysis.

For the pre-tax data, three lags are selected based on AIC. The LM autocorrelation test indicate no residual autocorrelation for the model with three lags and the model satisfies stability condition. The eigen values are reported in figures 4.1 and 4.2, while autocorrelation tests are reported in tables 4.1 and 4.2.

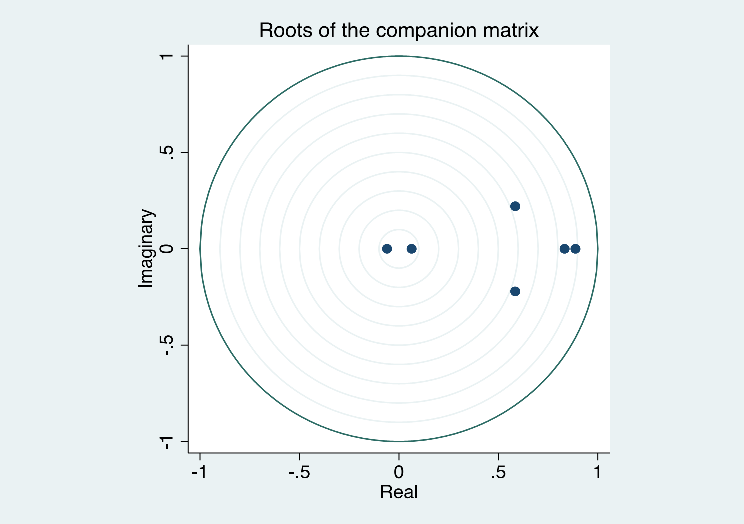

Figure 4.1: Stability Test for post-tax trivariate model

Table 4.1: LM test for post-tax trivariate model

Lagrange-multiplier test

lag	chi2	df	Prob > chi2
1	15.7	9	0.07404
2	13.7	9	0.13287

H0: no autocorrelation at lag order

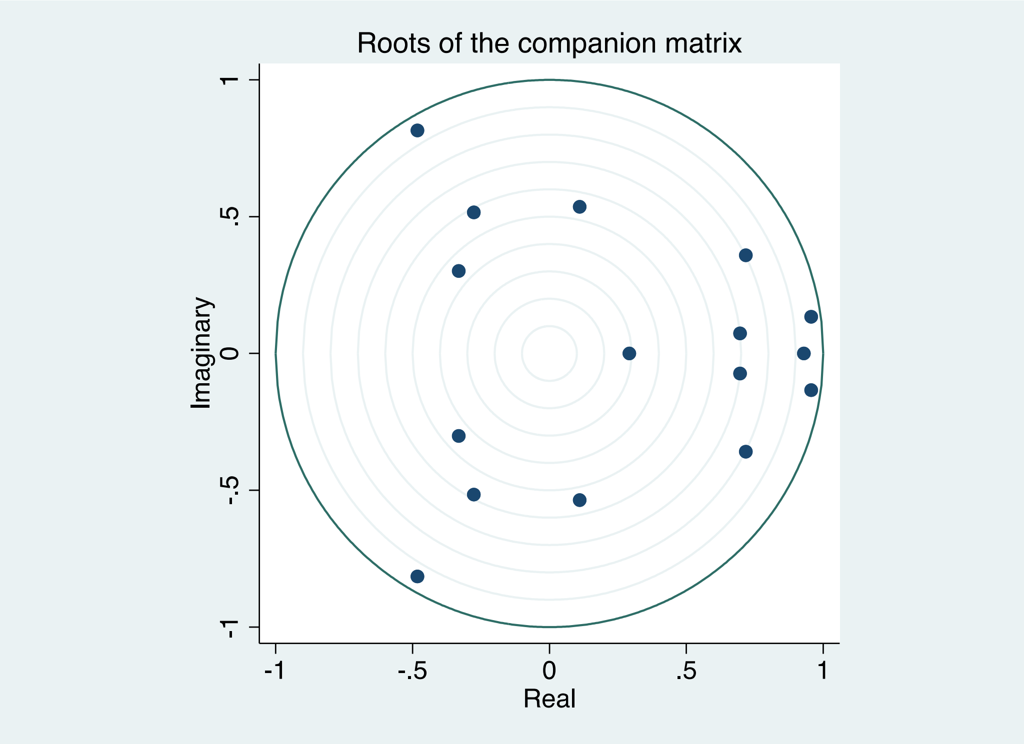

Figure 4.2: Stability Tests for post-tax four-variable model

Table 4.2: LM test for post-tax four-variable model

Lagrange-multiplier test

lag	chi2	df	Prob > chi2
1	27.7	16	0.03418
2	43.5	16	0.00024
3	46.1	16	0.00009
4	22.2	16	0.13577

H0: no autocorrelation at lag order

4.1. Impulse Response Analysis

This section evaluates the estimated responses of BC's per capita GDP to both carbon tax and productivity shocks. This is done by examining the impulse-response functions of GDP to a one standard deviation (sd.) shock to the price of gasoline and MFP over a range of 12-month period. It also examines the response of MFP to gasoline price shocks. Results are shown in figures 4.3 – 4.6. The red lines represent the boundaries of the 90 percent confidence bands.

Starting with the trivariate VAR (2) model, figure 4.1 shows that a one sd. positive shock to the price of gasoline has an initial positive effect on GDP which translates to a 0.25% increase in per capita GDP. The increase peaks in the first month, and thereafter steadily declines as the impulse response converges to zero. This reaction is consistent with the studies surveyed in section 2: while the carbon tax disturbs economic growth, this effect diminishes overtime. In this case, the effects of the shock die out in the fifth month where the lower bound of the confidence interval is zero.

However, inclusion of MFP in the second model yields a slightly different result. Figure 4.2 shows that the instantaneous positive shock quickly declines but starts to appreciate after the seventh month. Likewise, a shock to MFP produces similar effect on GDP (figure 4.3): an instantaneous 0.29% rise in per capita GDP followed by subsequent decline which upturns in the eighth month. While this confirms the results of Dong et. al (2018) that despite the negative impact of a carbon tax, technological progress eventually stirs economic growth, we also observe that these effects become statistically insignificant from months five and six in figures 4.2 and 4.3 respectively. Also noteworthy is that in all cases, an MFP shock has a higher immediate statistically significant positive effect on GDP than a gasoline price shock.

Regarding the impulse response of MFP to a sd. shock in gasoline price, one can see in figure 4.4 an instantaneous positive effect which steadily drops and diminishes by the third month. The result is surprising as one would expect BC's revenue-neutral carbon tax to have the opposite effect on productivity. Yet, a possible explanation is offered by Yamazaki (2021). The study predicts that although BC's tax positively affects productivity by lowering corporate income taxes, the tax also leads to the redirection of productive resources to energy-saving activities which are typically not cost efficient.

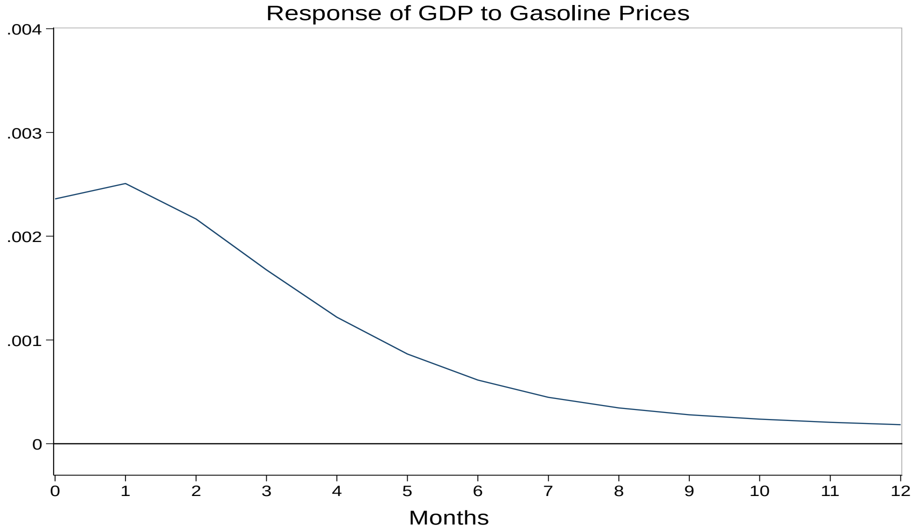

Figure 4.3: Impulse response of per capita GDP to gasoline price shocks for trivariate VAR(2) model

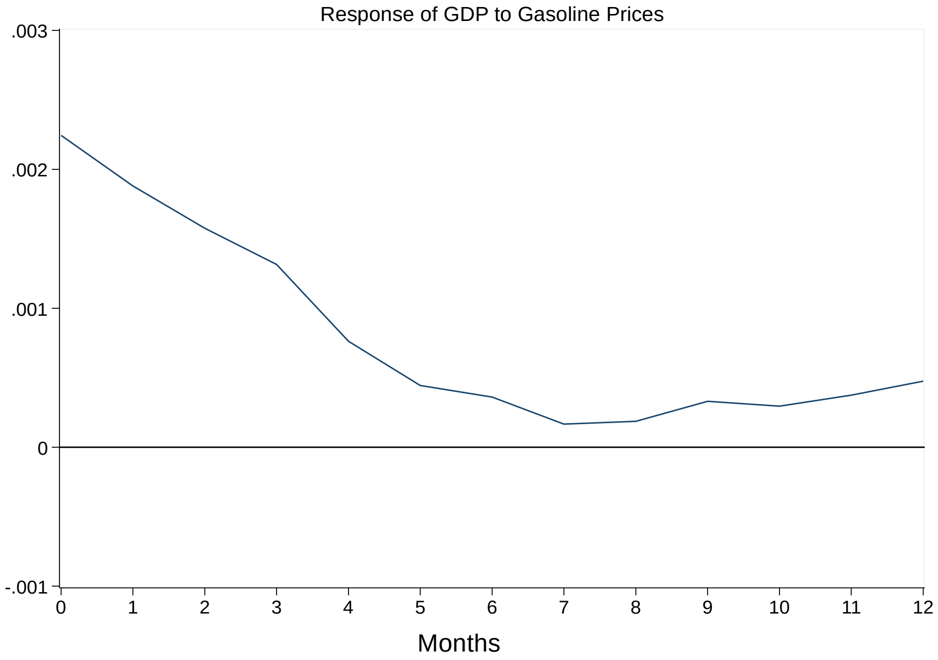

Figure 4.4: Impulse response of per capita GDP to gasoline price shocks for four-variable VAR(4) model

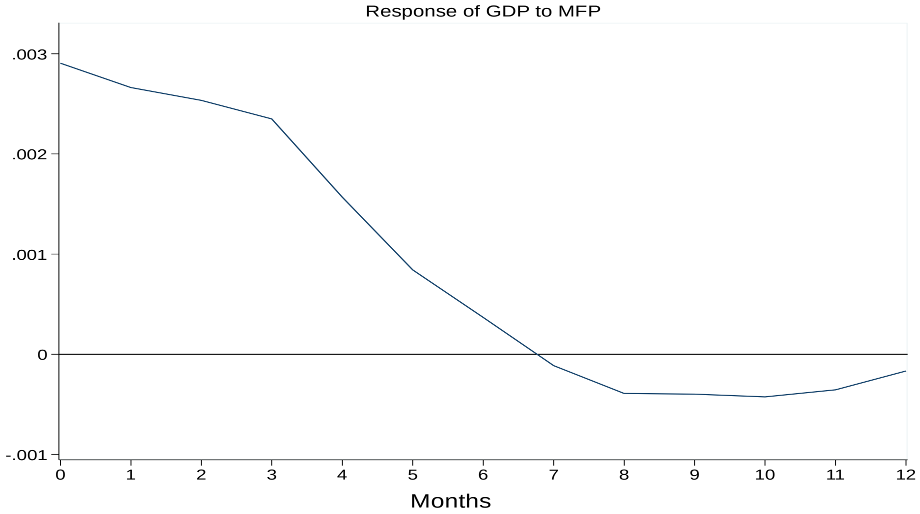

Figure 4.5: Impulse response of per capita GDP to MFP shocks

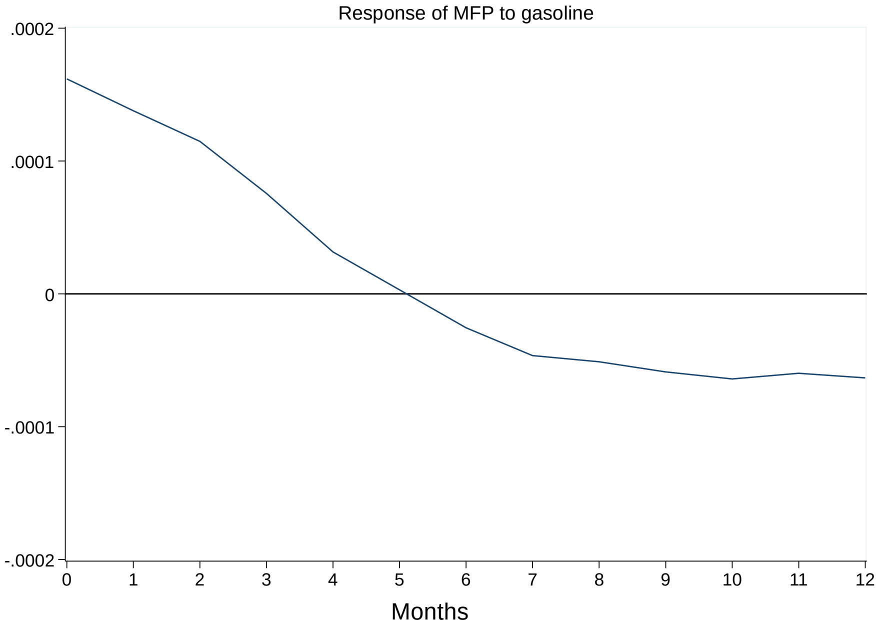

Figure 4.6: Impulse response of MFP to gasoline price shocks

4.2. Variance Decomposition Analysis

To determine how important each shock is in explaining fluctuations in per capita GDP a Forecast Error Variance Decomposition is computed based on the estimated structural VAR model. It is also worth reemphasizing that the VAR was estimated based on the contemporaneous structural restrictions for each equation. Of particular interest are the decompositions of per capita GDP and MFP. The first section of table 4.7 contain the variance decomposition of per capita GDP to each variable in the VAR system. From the second column, it can be seen that the carbon tax shock transmitted through gasoline prices contributed 34% to the changes in per capita GDP in the first month and then dropped to 26% by the 12th month. On the other hand, MFP accounted for 58% of the variation in per capita GDP within the same period, more than double the effect of gasoline price changes on per capita GDP. We also find that inflation only explained about 4% of the variation in per capita GDP.

Evaluating the variance decomposition of MFP, the second section of table 4.3 shows in column 1 that carbon tax shock initially accounted for 33% variation in MFP but by the 12th month this significantly decreased to 13%. Interestingly, column 3 and 4 of the same section indicates that inflation and per capita GDP account for very little of the variation in productivity. In a way, this finding supports the hypothesis of the neoclassical economic growth model, that GDP growth is explained by productivity and not vice versa. Additionally, these findings are quite consistent with the evidence found in the examined literature. Many of these studies have determined that carbon pricing may not have a significant impact on economic outcomes.

Table 4.3: Forecast error variance decomposition

Period	GAS	MFP	INF	GDP
Variance Decomposition of per capita GDP				
1	0.341459	0.572555	0.002356	0.08363
4	0.287505	0.617978	0.008156	0.086362
8	0.265875	0.596672	0.020254	0.117198
12	0.258404	0.575963	0.038402	0.127232
Variance Decomposition of Productivity				
1	0.333687	0.666313	0	0
4	0.20282	0.770982	0.016896	0.009302
8	0.140499	0.774684	0.018932	0.065885
12	0.136746	0.705879	0.027771	0.129604
Variance Decomposition of Inflation				
1	0.342914	0.081868	0.575218	0
4	0.400269	0.036065	0.563241	0.000425
8	0.423081	0.032284	0.54406	0.000574
12	0.42457	0.049502	0.524627	0.0013
Variance Decomposition of Gasoline prices				
1	1	0	0	0
4	0.963152	0.032637	0.001123	0.003087
8	0.874284	0.086853	0.035488	0.003374
12	0.721068	0.205135	0.070375	0.003423

4.3. Pre-tax Comparison

In this section, the post-tax GDP for British Columbia is compared to the GDP forecasted using the pre-tax data, under the assumption that the carbon tax is non-existent. The goal of this exercise is to see if there is a significant difference between the actual change in per capita GDP growth and the changes that may have existed without the tax.

Figure 4.7 depicts the actual per capita GDP from 1998 to 2008 in log terms and the 24months forecast from 2008 to 2010. In figure 4.8 the actual time path of per capita GDP within a 2year period (2008-2010) is compared against the predicted evolution of per capita GDP in the absence of carbon taxes. The forecast is presented along with its 90% confidence bands.

It can be seen from the graph that the variation between the actual path and the forecasted growth path is negligible. Also, the 24months forecast captures the 2008 GDP decline due to the economic recession. Similar to the reality, in the no-tax scenario, the economy is predicted to shrink in 2008 but rise again by the middle of 2010. What can be deduced from this analysis is that the carbon tax had no significant effect on GDP fluctuations in the post-tax period.

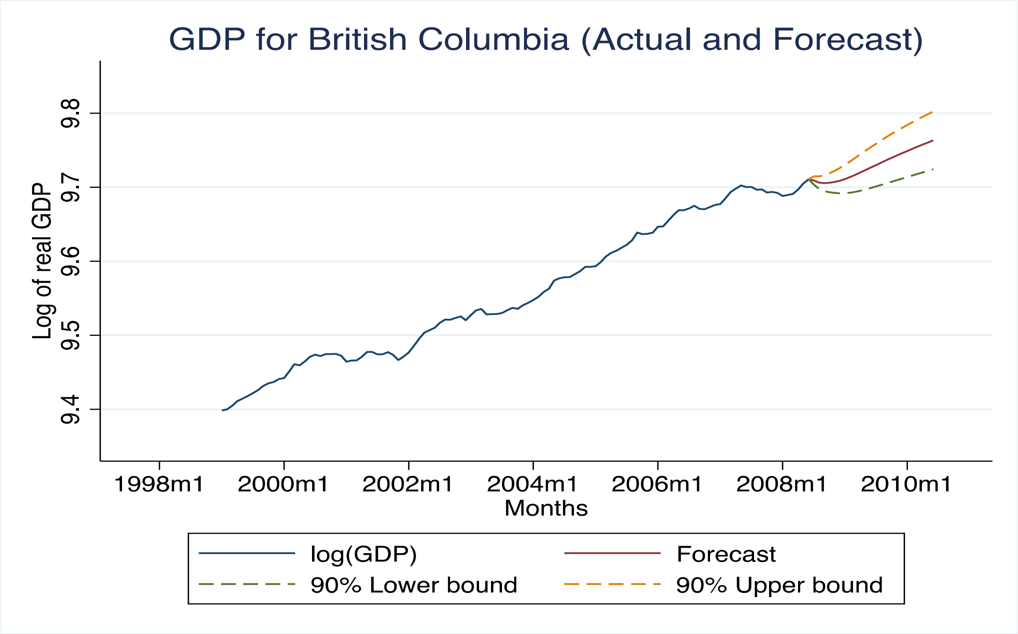

Figure 4.7: GDP Forecast for British Columbia

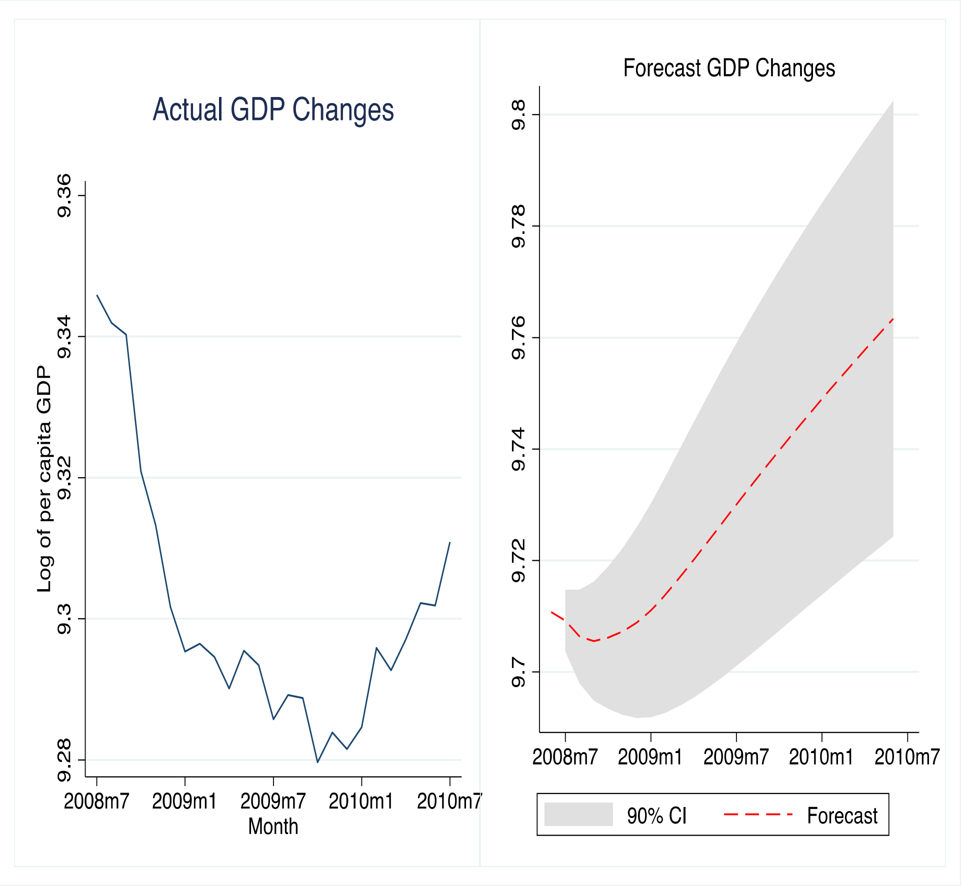

Figure 4.8: Actual and Forecasted per capita GDP trends (2008-2010)

Chapter 5. Discussion and conclusion

British Columbia was the first province to introduce a comprehensive revenue-neutral carbon tax policy in Canada. The policy has largely been hailed for its success in mitigating carbon emissions, and various studies have generally dismissed its short-term economic impact as negligible. This paper evaluates the economic impact of BC's carbon tax using a SVAR framework under two settings. Under the assumption that carbon tax effects are translated through gasoline price increases, a trivariate model is first constructed to trace the response of per capita GDP to gasoline price shocks. Impulse response analysis as well as variance decomposition analysis confirm no significant impact of the tax on provincial per capita GDP from the July 2008 – December 2019 post tax period. Particularly, the results show that the response is mostly prominent in the first month of its implementation after which the shock declines and eventually dissipates within a twelve-month period. Forecast comparisons of pre-tax and post-tax models also indicate no significant variation in estimated and actual per capita GDP trends.

In an extended four-variable model which incorporates technology shocks, some interesting findings emerge. The main reason for inclusion of MFP in the second model is to accentuate the impact of technological progress on economic growth during the period the tax was imposed. As in the trivariate model, per capita GDP responds instantaneously to the carbon tax shock, albeit at a lower percentage. Also, rather than the initial effects dying out within a year, per capita GDP is estimated to appreciate from the seventh month after the shock is imposed. This second finding suggests that environmental regulations can stimulate technological improvements which then lead to economic growth. Overall, these results can be summarised as the short-run and expected long-run consequences of the carbon tax since the impact of technological progress may be more significantly experienced in the long-run.

In the short-run, the immediate impact of a carbon tax is an increase in the price of gasoline which consequently raises the costs of production as gasoline is considered an input to production. This in turn escalates final retail prices, producing a positive response on per capita GDP. However, as consumers begin to react to the price increase, demand is expected to drop which then adversely affects per capita GDP. This effect is seen to die out as society adjust to the price changes, coupled with the revenue-neutrality of the tax, the net effect on per capita GDP in this case moves closer to zero (figure 4.2) within a year. On the other hand, the carbon tax which is set at a relatively high rate induces companies to switch to renewable technology that are less emissions intensive. In the short-run this high-cost transition negatively affects productivity (figure 4.4) and per capita GDP, but as time evolves, the economy adjusts, and as growth becomes less responsive to the carbon tax in the long-run, per capita GDP begins to increase.

This result is in line with the proposition of Fouquet et al (2016) that economies will become more resilient to energy price shocks as they transition to renewable energy sources. In the second model, this transition starts in the eighth month (figure 4.4). However due to the short-time span considered, it is important to note that this analysis is only suggestive for the long-term response. Realistically, the long-run reaction may depend on how quickly firms are able to seek out more eco-friendly alternatives. The lacking empirical evidence on the link between carbon pricing and technological changes makes it difficult to pinpoint the exact time frame for the long-run response, however, due to the nature of investment required to acquire zero-carbon assets, one could expect such transition to occur in five years (Yuan & Zuo, 2011). Moreover, policies that are available to induce innovation would also speed up such transitions as the level of innovation required differs across industries (Hubacek et al., 2018).

Justifying the trade-off between the economic cost and social benefits of an environmental policy is a challenging task. The 2019 nationwide implementation of carbon pricing in Canada has been met with mixed reactions from relevant stakeholders. A common concern of policy makers relates to the economic implications of the tax. Using British Columbia as a case study, this paper uses a trivariate structural VAR model to show that while the tax produces a negative response from GDP in the short-run, the effect is negligible and short-lived. On the other hand, the four-variable model suggests that by encouraging lower-emitting technologies, carbon pricing may ultimately stimulate productivity and economic growth in the long-run. In conclusion, successfully achieving the objectives of the Paris agreement to eliminate CO_2 emissions would require the replacement of carbon emissions agents with other forms of energy. This study shows evidence that economic growth is sustainable with such technological transformations. Yet, due to the nature of environmental externalities, economic agents are likely to attain suboptimal levels of innovation, hence policies addressing these issues are vital to stimulate faster transitions.

Chapter 6. Limitations & Further Research

I acknowledge the existence of some limitations arising from this study. First, the original data used were provided indifferent frequencies, therefore the analysis relied on various data generating processes such as the denton procedure to estimate the unobserved data. Possible inconsistencies arising from these data transformation methods may pose a bias to the validity of the results. Secondly, the study does not control for the economic recessions that occurred in 2008 and 2014. Figure 3.2 shows declines in MFP in these two years. These factors may have also contributed to the negative response of GDP to MFP shocks (figure 4.3). Possibly, testing for structural breaks could provide more insights to the robustness of the results. Nonetheless, it is beyond the scope of this research to isolate the main factors responsible for the economic fluctuations during those years. This study is mainly interested in presenting the impulse responses of the relevant variables given the restrictions identified within the models. Although it is possible that the recessions contributed to the macroeconomic trends, it does not take away the conclusion derived from this analysis. The overall effects of carbon taxes on the economy remained trivial. Additionally, it is possible that the neutralizing impact on GDP in the long run may be as a result of the revenue recycling. Yet, this hypothesis has not been tested in this study.

Further, it is not possible to quantitatively measure technological progress, but this study relies on the Solow residuals as a proxy. Therefore, in accordance with standard practice, the multifactor productivity (MFP) variable was used to measure technological progress. Finally, the evidence presented in this paper suggests that putting a price on emissions could potentially lead to a redirection of the economy towards more emissions-friendly investments, nevertheless, I do not conclude that carbon pricing by itself triggers technological advancements. If anything, relying solely on the tax without intentional investment in decarbonization initiatives could harm the economy. Further research would benefit from the effect of decarbonization incentive schemes on emissions reduction and economic sustainability. Additionally, it would be insightful to study how the carbon tax affects consumption.

Bibliography

Ackerman, F., & Heinzerling, L. (2002). Pricing the Priceless: Cost-Benefit Analysis of Environmental Protection. *University of Pennsylvania Law Review*, *150*(5), 1553. https://doi.org/10.2307/3312947

Ackerman, F., & Munitz, C. (2012). Climate damages in the FUND model: A disaggregated analysis. *Ecological Economics*, *77*, 219–224. https://doi.org/10.1016/j.ecolecon.2012.03.005

Aldy, J. E., & Pizer, W. A. (2015). The Competitiveness Impacts of Climate Change Mitigation Policies. *Journal of the Association of Environmental and Resource Economists*, *2*(4), 565–595. https://doi.org/10.1086/683305

Allan, G., Lecca, P., McGregor, P., & Swales, K. (2014). The economic and environmental impact of a carbon tax for Scotland: A computable general equilibrium analysis. *Ecological Economics*, *100*, 40–50. https://doi.org/10.1016/j.ecolecon.2014.01.012

Amisano, G., & Giannini, C. (2011). *Topics in Structural VAR Econometrics* (2nd ed. 1997. Softcover reprint of the original 2nd ed. 1997). Springer.

Asafu-Adjaye, J., & Mahadevan, R. (2013). Implications of CO2 reduction policies for a high carbon emitting economy. *Energy Economics*, *38*, 32–41. https://doi.org/10.1016/j.eneco.2013.03.004

Awerbuch, S., & Sauter, R. (2006). Exploiting the oil–GDP effect to support renewables deployment. *Energy Policy*, *34*(17), 2805–2819. https://doi.org/10.1016/j.enpol.2005.04.020

Bagheri, M., Guevara, Z., Alikarami, M., Kennedy, C. A., & Doluweera, G. (2018). Green growth planning: A multi-factor energy input-output analysis of the Canadian economy. *Energy Economics*, *74*, 708–720. https://doi.org/10.1016/j.eneco.2018.07.015

Beck, M., Rivers, N., Wigle, R., & Yonezawa, H. (2015). Carbon tax and revenue recycling: Impacts on households in British Columbia. *Resource and Energy Economics*, *41*, 40–69. https://doi.org/10.1016/j.reseneeco.2015.04.005

Beckmann, J., Czudaj, R. L., & Arora, V. (2020). The relationship between oil prices and exchange rates: Revisiting theory and evidence. *Energy Economics*, *88*, 104772. https://doi.org/10.1016/j.eneco.2020.104772

Bergman, L. (1991). General Equilibrium Effects of Environmental Policy: A CGE-Modeling Approach. *Environmental and Resource Economics*, *1*(1), 43–61. https://doi.org/10.1007/bf00305950

Bernard, J. T., & Kichian, M. (2021). The Impact of a Revenue-Neutral Carbon Tax on GDP Dynamics: The Case of British Columbia. *The Energy Journal*, *42*(3). https://doi.org/10.5547/01956574.42.3.jber

Bistline, J. E. T., Merrick, J., & Niemeyer, V. (2020). Estimating Power Sector Leakage Risks and Provincial Impacts of Canadian Carbon Pricing. *Environmental and Resource Economics*, *76*(1), 91–118. https://doi.org/10.1007/s10640-020-00421-4

Blanchard, O., & Perotti, R. (2002). An Empirical Characterization of the Dynamic Effects of Changes in Government Spending and Taxes on Output. *The Quarterly Journal of Economics*, *117*(4), 1329–1368. https://doi.org/10.1162/003355302320935043

Böhringer, C., & Alexeeva-Talebi, V. (2012). Unilateral Climate Policy and Competitiveness: Economic Implications of Differential Emission Pricing. *The World Economy*, *36*(2), 121–154. https://doi.org/10.1111/j.1467-9701.2012.01470.x

Borges, A. M. (2005). Applied General Equilibrium Models : An Assessment Of Their Usefulness For Policy Analysis. *OECD*.

Bovenberg, A., & Goulder, H. (2001). Environmental Taxation and Regulation. *National Bureau of Economic Research*.

Bowen, A., Cochrane, S., & Fankhauser, S. (2011). Climate change, adaptation and economic growth. *Climatic Change*, *113*(2), 95–106. https://doi.org/10.1007/s10584-011-0346-8

Burfisher, M. E. (2021). *Introduction to Computable General Equilibrium Models*. Cambridge University Press.

Carbone, J. C., & Rivers, N. (2017). The Impacts of Unilateral Climate Policy on Competitiveness: Evidence From Computable General Equilibrium Models. *Review of Environmental Economics and Policy*, *11*(1), 24–42. https://doi.org/10.1093/reep/rew025

Chan, H. S., Li, S., & Zhang, F. (2012). Firm Competitiveness and the European Union Emissions Trading Scheme. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2167298

Chen, J., Gao, M., Mangla, S. K., Song, M., & Wen, J. (2020). Effects of technological changes on China’s carbon emissions. *Technological Forecasting and Social Change*, *153*, 119938. https://doi.org/10.1016/j.techfore.2020.119938

Cylus, J., & Al Tayara, L. (2021). Health, an ageing labour force, and the economy: Does health moderate the relationship between population age-structure and economic growth? *Social Science &Amp; Medicine*, *287*, 114353. https://doi.org/10.1016/j.socscimed.2021.114353

de Miguel, C., Manzano, B., & Martin-Moreno, J. M. (2003). Oil Price Shocks and Aggregate Fluctuations. *The Energy Journal*, *24*(2). https://doi.org/10.5547/issn0195-6574-ej-vol24-no2-2

Dietzenbacher, E., & Mukhopadhyay, K. (2006). An Empirical Examination of the Pollution Haven Hypothesis for India: Towards a Green Leontief Paradox? *Environmental and Resource Economics*, *36*(4), 427–449. https://doi.org/10.1007/s10640-006-9036-9

Dong, B., Wei, W., Ma, X., & Li, P. (2018). On the impacts of carbon tax and technological progress on China. *Applied Economics*, *50*(4), 389–406. https://doi.org/10.1080/00036846.2017.1316826

Driffield, N. (2000). FDI and the labour market: a review of the evidence and policy implications. *Oxford Review of Economic Policy*, *16*(3), 90–103. https://doi.org/10.1093/oxrep/16.3.90

Elgie, S., & McClay, J. (2013). Policy Commentary/Commentaire BC's Carbon Tax Shift Is Working Well after Four Years (Attention Ottawa). *Canadian Public Policy*, *39*(Supplement 2), S1–S10. https://doi.org/10.3138/cpp.39.supplement2.s1

Erutku, C. (2019). Carbon pricing pass-through: Evidence from Ontario and Quebec's wholesale gasoline markets. *Energy Policy*, *132*, 106–112. https://doi.org/10.1016/j.enpol.2019.05.026

Feasel, E. M., Kim, Y., & Smith, S. M. (2001). Investment, Exports, and Output in South Korea: A VAR Approach to Growth Empirics. *Review of Development Economics*. https://doi.org/10.1111/1467-9361.00133

Fischer, C., & Fox, A. K. (2007). Output-Based Allocation of Emissions Permits for Mitigating Tax and Trade Interactions. *Land Economics*, *83*(4), 575–599. https://doi.org/10.3368/le.83.4.575

Folmer, H., & Gabel, H. L. (2000). *Principles of environmental and resource economics: a guide for students and decision-makers*. Edward Elgar Publishing Ltd.

Freire-González, J., & Ho, M. S. (2019). Carbon taxes and the double dividend hypothesis in a recursive-dynamic CGE model for Spain. *Economic Systems Research*, *31*(2), 267–284. https://doi.org/10.1080/09535314.2019.1568969

Gamtessa, S., & Olani, A. B. (2018). Energy price, energy efficiency, and capital productivity: Empirical investigations and policy implications. *Energy Economics*, *72*, 650–666. https://doi.org/10.1016/j.eneco.2018.04.020

Hubacek, K., Meunier, G., & Hallegatte, S. (2018). When starting with the most expensive option makes sense: Optimal timing, cost and sectoral allocation of abatement investment. *Journal of Environmental Economics and Management*, *88*, 210–233. https://doi.org/10.1016/j.jeem.2017.12.001

Hwang, K. (2015). Cost-benefit analysis: its usage and critiques. *Journal of Public Affairs*, *16*(1), 75–80. https://doi.org/10.1002/pa.1565

Kesicki, F. (2013). What are the key drivers of MAC curves? A partial-equilibrium modelling approach for the UK. *Energy Policy*, *58*, 142–151. https://doi.org/10.1016/j.enpol.2013.02.043

Kilian, L. (2014). Oil Price Shocks: Causes and Consequences. *Annual Review of Resource Economics*, *6*(1), 133–154. https://doi.org/10.1146/annurev-resource-083013-114701

Koks, E. E., Carrera, L., Jonkeren, O., Aerts, J. C. J. H., Husby, T. G., Thissen, M., Standardi, G., & Mysiak, J. (2016). Regional disaster impact analysis: comparing input–output and computable general equilibrium models. *Natural Hazards and Earth System Sciences*, *16*(8), 1911–1924. https://doi.org/10.5194/nhess-16-1911-2016

Lawley, C., & Xiang, D. (2019). The impact of British Columbia's carbon tax on residential natural gas consumption. *Energy Economics*, *80*, 206–218. https://doi.org/10.1016/j.eneco.2018.12.004

Leontief, W. (1941). The Structure of American Economy 1919-39: An Empirical Application of Equilibrium Analysis. *The Economic Journal*, *53*(210/211), 213. https://doi.org/10.2307/2226319

Liu, C., Zhang, H., & Wang, Z. (2019). Study on the Functional Improvement of Economic Damage Assessment for the Integrated Assessment Model. *Sustainability*, *11*(5), 1280. https://doi.org/10.3390/su11051280

Lorusso, M., & Pieroni, L. (2018). Causes and consequences of oil price shocks on the UK economy. *Economic Modelling*, *72*, 223–236. https://doi.org/10.1016/j.econmod.2018.01.018

Malik, A., Lenzen, M., Ely, R. N., & Dietzenbacher, E. (2014). Simulating the impact of new industries on the economy: The case of biorefining in Australia. *Ecological Economics*, *107*, 84–93. https://doi.org/10.1016/j.ecolecon.2014.07.022

Mankiw, N. G., Romer, D., & Weil, D. N. (1992). A Contribution to the Empirics of Economic Growth. *The Quarterly Journal of Economics*, *107*(2), 407–437. https://doi.org/10.2307/2118477

Marron, D. B., & Morris, A. C. (2016). How to Use Carbon Tax Revenues. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2737990

Mascher, S. (2018). Striving for equivalency across the Alberta, British Columbia, Ontario and Québec carbon pricing systems: the Pan-Canadian carbon pricing benchmark. *Climate Policy*, *18*(8), 1012–1027. https://doi.org/10.1080/14693062.2018.1470489

Maslin, M. (2021). *Climate Change: A Very Short Introduction (Very Short Introductions)* (4th ed.). Oxford University Press.

Masoumzadeh, A., Möst, D., & Ookouomi Noutchie, S. C. (2016). Partial equilibrium modelling of world crude oil demand, supply and price. *Energy Systems*, *8*(1), 217–226. https://doi.org/10.1007/s12667-016-0196-6

Metcalf, G. E. (2014). A Conceptual Framework for Measuring the Effectiveness of Green Fiscal Reforms. *International Journal of Green Growth and Development*, *2*(2), 87–126.

Metcalf, G. E. (2019). On the Economics of a Carbon Tax for the United States. *Brookings Papers on Economic Activity*, *2019*(1), 405–484. https://doi.org/10.1353/eca.2019.0005

Metcalf, G. E., & Stock, J. H. (2020). Measuring the Macroeconomic Impact of Carbon Taxes. *AEA Papers and Proceedings*, *110*, 101–106. https://doi.org/10.1257/pandp.20201081

Mildenberger, M., Lachapelle, E., Harrison, K., & Stadelmann-Steffen, I. (2022). Limited impacts of carbon tax rebate programmes on public support for carbon pricing. *Nature Climate Change*, *12*(2), 141–147. https://doi.org/10.1038/s41558-021-01268-3

Motley, B. (1998). Growth and inflation: a cross-country study. *Econometric Reviews*, 15–28. https://econpapers.repec.org/article/fipfedfer/y_3a1998_3ap_3a15-28_3an_3a1.htm

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

Nordhaus, W. D. (2017). Revisiting the social cost of carbon. *Proceedings of the National Academy of Sciences*, *114*(7), 1518–1523. https://doi.org/10.1073/pnas.1609244114

Nordhaus, W. D. & Zili Yang. (1996). A Regional Dynamic General-Equilibrium Model of Alternative Climate-Change Strategies. *The American Economic Review*, *86*(4), 741–765.

Olale, E., Yiridoe, E. K., Ochuodho, T. O., & Lantz, V. (2019). The Effect of Carbon Tax on Farm Income: Evidence from a Canadian Province. *Environmental and Resource Economics*, *74*(2), 605–623. https://doi.org/10.1007/s10640-019-00337-8

Pasichnyi, M. (2017). Empirical study of the fiscal policy impact on economic growth. *Problems and Perspectives in Management*, *15*(3), 316–322. https://doi.org/10.21511/ppm.15(3-2).2017.01

Ramsey, F. P. (1928). A Mathematical Theory of Saving. *The Economic Journal*, *38*(152), 543. https://doi.org/10.2307/2224098

Ren, X., liu, Z., Jin, C., & Lin, R. (2023). Oil price uncertainty and enterprise total factor productivity: Evidence from China. *International Review of Economics &Amp; Finance*, *83*, 201–218. https://doi.org/10.1016/j.iref.2022.08.024

Rezitis, A. N. (2015). The relationship between agricultural commodity prices, crude oil prices and US dollar exchange rates: a panel VAR approach and causality analysis. *International Review of Applied Economics*, *29*(3), 403–434. https://doi.org/10.1080/02692171.2014.1001325

Rivers, N., & Schaufele, B. (2014). The Effect of Carbon Taxes on Agricultural Trade. *Canadian Journal of Agricultural Economics/Revue Canadienne D'agroeconomie*, *63*(2), 235–257. https://doi.org/10.1111/cjag.12048

Scholtens, B., & Yurtsever, C. (2012). Oil price shocks and European industries. *Energy Economics*, *34*(4), 1187–1195. https://doi.org/10.1016/j.eneco.2011.10.012

Seung, C. K. (2013). MEASURING SPILLOVER EFFECTS OF SHOCKS TO THE ALASKA ECONOMY: AN INTER-REGIONAL SOCIAL ACCOUNTING MATRIX (IRSAM) MODEL APPROACH. *Economic Systems Research*, *26*(2), 224–238. https://doi.org/10.1080/09535314.2013.803039

Sims, C. A. (1980). Macroeconomics and Reality. *Econometrica*, *48*(1), 1. https://doi.org/10.2307/1912017

Sims, C. A., Stock, J. H., & Watson, M. W. (1989). Inference in Linear Time Series Models with some Unit Roots. *Econometrica*, *58*(1), 113. https://doi.org/10.2307/2938337

Smith, V. K. (1986). A Conceptual Overview of the Foundations of Benefit-Cost Analysis. *Benefits Assessment*, 13–34. https://doi.org/10.1007/978-94-009-4524-1_2

Solow, R. M. (1956). A Contribution to the Theory of Economic Growth. *The Quarterly Journal of Economics*, *70*(1), 65. https://doi.org/10.2307/1884513

Suerkemper, F., Thema, J., Thomas, S., Dittus, F., Kumpaengseth, M., & Beerepoot, M. (2015). Benefits of energy efficiency policies in Thailand: an ex-ante evaluation of the energy efficiency action plan. *Energy Efficiency*, *9*(1), 187–210. https://doi.org/10.1007/s12053-015-9357-z

Tol, R. S. (2001). Equitable cost-benefit analysis of climate change policies. *Ecological Economics*, *36*(1), 71–85. https://doi.org/10.1016/s0921-8009(00)00204-4

Tol, R. S. (2003). Is the Uncertainty about Climate Change too Large for Expected Cost-Benefit Analysis? *Climatic Change*, *56*, 265–289. https://doi.org/10.1023/A:1021753906949

Tol, R. S. (2013). Targets for global climate policy: An overview. *Journal of Economic Dynamics and Control*, *37*(5), 911–928. https://doi.org/10.1016/j.jedc.2013.01.001

Tuinstra, J., Wegener, M., & Westerhoff, F. (2014). Positive welfare effects of trade barriers in a dynamic partial equilibrium model. *Journal of Economic Dynamics and Control*, *48*, 246–264. https://doi.org/10.1016/j.jedc.2014.06.015

Verbruggen, A., Laes, E., & Woerdman, E. (2019). Anatomy of Emissions Trading Systems: What is the EU ETS? *Environmental Science &Amp; Policy*, *98*, 11–19. https://doi.org/10.1016/j.envsci.2019.05.001

Wang, K., Wang, J., Hubacek, K., Mi, Z., & Wei, Y. (2019). A cost–benefit analysis of the environmental taxation policy in China: A frontier analysis-based environmentally extended input–output optimization method. *Journal of Industrial Ecology*, *24*(3), 564–576. https://doi.org/10.1111/jiec.12947

Weyant, J. (2017). Some Contributions of Integrated Assessment Models of Global Climate Change. *Review of Environmental Economics and Policy*, *11*(1), 115–137. https://doi.org/10.1093/reep/rew018

Withey, P., Sharma, C., Lantz, V., McMonagle, G., & Ochuodho, T. O. (2021). Economy-wide and CO_2 impacts of carbon taxes and output-based pricing in New Brunswick, Canada. *Applied Economics*, *54*(26), 2998–3015. https://doi.org/10.1080/00036846.2021.2001422

Wooldridge, J. M. (2019). *Introductory Econometrics: A Modern Approach*. Cengage Learning.

Xiang, H., & Kuang, Y. (2020). Who benefits from China's coal subsidy policies? A computable partial equilibrium analysis. *Resource and Energy Economics*, *59*, 101124. https://doi.org/10.1016/j.reseneeco.2019.101124

Yamazaki, A. (2017). Jobs and climate policy: Evidence from British Columbia's revenue-neutral carbon tax. *Journal of Environmental Economics and Management*, *83*, 197–216. https://doi.org/10.1016/j.jeem.2017.03.003

Yamazaki, A. (2021). Environmental taxes and productivity: Lessons from Canadian manufacturing. *Journal of Public Economics*, *205*, 104560. https://doi.org/10.1016/j.jpubeco.2021.104560

Yoshino, N., Rasoulinezhad, E., & Taghizadeh-Hesary, F. (2021). Economic Impacts of Carbon Tax in a General Equilibrium Framework: Empirical Study of Japan. *Journal of Environmental Assessment Policy and Management*, *23*(01n02). https://doi.org/10.1142/s1464333222500144

Yuan, X., & Zuo, J. (2011). Transition to low carbon energy policies in China—from the Five-Year Plan perspective. *Energy Policy*, *39*(6), 3855–3859. https://doi.org/10.1016/j.enpol.2011.04.017

Zhang, K., Xue, M. M., Feng, K., & Liang, Q. M. (2019). The economic effects of carbon tax on China's provinces. *Journal of Policy Modeling*, *41*(4), 784–802. https://doi.org/10.1016/j.jpolmod.2019.02.014

Appendix: Data Sources

B.C. Provincial GDP ($ 2012)	Statistics Canada. Table 36-10-0402-01 Gross domestic product (GDP) at basic prices, by industry, provinces, and territories (x 1,000,000). DOI: https://doi.org/10.25318/3610040201-eng
Average retail prices for gasoline (cents/litre)	Statistics Canada. Table 18-10-0001-01 Monthly average retail prices for gasoline and fuel oil, by geography. DOI: https://doi.org/10.25318/1810000101-eng
B.C. population estimates	Statistics Canada. Table 17-10-0009-01 Population estimates, quarterly. DOI: https://doi.org/10.25318/1710000901-eng
Canada Consumer Price Index (2002 = 100), All items excluding food and gasoline	Statistics Canada. Table 18-10-0006-01 Consumer Price Index, monthly, seasonally adjusted. DOI: https://doi.org/10.25318/1810000601-eng
B.C. Multifactor productivity (2012 = 100)	Statistics Canada. Table 36-10-0211-01 Multifactor productivity and related variables in the aggregate business sector and major sub-sectors, by industry. DOI: https://doi.org/10.25318/3610021101-eng

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