The Impact of a Revenue-Neutral Carbon Tax on GDP Dynamics: The Case of British Columbia

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ABSTRACT

We study the impact over time of revenue-neutral-designed carbon taxes on GDP in the Canadian province of British Columbia (B.C.). The tax is broad-based, and all rate hikes and their timings were pre-announced. Our time series approach accounts for these pre-announcement effects, as well as for the possible saliency of the tax. Estimated impulse response functions and statistical comparisons of GDP dynamics in the presence and (counterfactual) absence of carbon taxes lead to the same result. Overall, revenue-neutral carbon taxation has no significant negative impacts on GDP. Our setup also allows us to examine the extent of the carbon tax pass-through into energy prices. We find that pass-through is complete. We conclude that implementing revenue-neutral carbon taxation contributes to lowering harmful greenhouse gases into the atmosphere without hurting the economy.

Keywords: Environmental policies, carbon tax, GDP impacts, tax pass-through, vector autoregression

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1. INTRODUCTION

The effect of environmental taxes on GDP is a major policy concern and it continues to generate heated debates in public squares. Arguments in support of positive and negative net effects are presented. On the one hand, there is the worry expressed by some that environmental taxes increase costs and reduce competitiveness, thus hurting the economy. On the other hand, there is the double-dividend economic argument, whereby not only can environmental taxes reduce negative externalities such as pollution and global warming, but they can also increase income. This can notably happen when the tax is designed to be revenue-neutral; the new tax replaces less efficient duties (such as those applied to personal and business income) ensuring no change in the government budget position.

While theoretical and simulation-based studies have examined the expected effect of revenue-neutral environmental taxation on output,[1] there is little empirical work aimed at quantifying this effect. A possible reason may be the scarcity of real-world such experience, and consequently, of pertinent data. For one thing, the various forms of environmental taxes introduced by governments generally have not been designed to be budget-neutral. In addition, the definition of an environmental tax is not so clear-cut. For example, often governments justify taxes applied to gasoline and to diesel by appealing to environmental considerations. However, when these taxes are collected to also expand and maintain roads, they are really user fees. Alternatively, when the collected monies

1. See, for example, Goulder and Hafstead (2017).

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also serve to fund general government activities, the taxes cannot be qualified as being strictly environmental levies.

In this paper, we rely on a unique policy enacted by the government of the province of British Columbia (B.C.) of Canada to study the effect over time of revenue-neutral environmental taxes on GDP. In 2008, B.C. implemented a carbon tax designed to be revenue-neutral on a broad range of greenhouse gas (GHG) emissions originating from fossil fuel use. The tax rate was set at $10/ton of CO_2 in July 2008 and then raised by $5 in July of every year to reach $30/ton in 2012. The price remained at that level until the end of 2017. In order to fulfill the objective of revenue-neutrality, the government lowered income tax rates to individuals and businesses, and delivered subsidies to low income earners. The two lowest personal income tax rates were thus decreased, providing a tax cut on the first $70,000 earnings of 2% in 2008, and 5.0% in 2009, respectively. The general corporate income tax rate was reduced from 12% to 11% on July 2008, and then to 10% on July 2011. Similarly, the small business income tax rate was reduced from 4.5% to 2.5% over the same period. The income threshold between small businesses and general corporations was lifted from $400,000 to $500,000. In addition, annual tax credits of $100 per adult and $30 per child were granted to low income residents.[2] Note that while the aim is to achieve revenue-neutrality, there exists no actual mechanism to ensure that collected revenues from the tax will exactly equal given tax reductions and credits.

A few studies have examined impacts of this policy initiative on selected aspects of the B.C. economy. Some find declines in GHG emissions or in the demand of fossil fuels in the province.[3] Others focus on tax effects in the labor market and they document changes in employment in specific categories of industries and firms.[4] Welfare effects of the tax have also been examined, with the conclusion that households of varying income levels were impacted differently.[5]

The above show that certain sectors or households gain from a revenue-neutral tax while others lose. But what is the net overall tax impact? Almost all policy actions end up by benefitting some economic agents while being detrimental to others. What matters most is whether a policy has a net positive impact, and by how much. Furthermore, focusing on *average* effects, as is the case with the majority of the above-mentioned studies, may not be enough. Economic agents may face constraints that bind at different points in time, and thus they may adapt to the tax changes in different periods, and by different amounts. In other words, *time-varying* considerations could also be important and thus merit attention. For example, such information can be useful to policymakers for the design of future tax strategies.

Little attention has been given to the big picture, namely the effect of the carbon tax on the province's GDP. An early exception is Elgie and McClay (2013) who observe that, over 2008 to 2011, per capita GDP shrank by an average of -0.15% in B.C. compared to -0.25% in the rest of Canada (ROC), and that, at the same time, per capita GHG emissions fell by 10% in B.C. compared to 1.1% in the rest of Canada.[6] The authors thus conclude that the B.C. carbon tax must have had no

2. See the B.C. Ministry of Finance (2008).

3. See Rivers and Schaufele (2015), Antweiler and Gulati (2016), Lawley and Thivierge (2018), Eruktu and Hildebrand (2018), Xiang and Lawley (2019), Metcalf (2019), Pretis (2019) and Bernard and Kichian (2019). See the latter for a summary on the empirical impacts of the carbon tax on the demand of various fossil fuels in B.C., and Metcalf (2019) for carbon tax impacts in other regions of the world.

4. For example, Yamazaki (2017), Yip (2018), and Azevedo et al. (2018).

5. See, for instance, Beck et al. (2015). See Winter et al. (2019) for another approach to examining environmental tax distributional effects on provincial households of different income quantiles.

6. Per capita consumption of refined petroleum products decreased by 17.4% in B.C. from 2008/09 to 2012/13, while it increased by 1.5% in the rest of Canada. See Table 1 of Elgie and McClay (2013).

negative impact on the province's GDP. More recently, Metcalf (2019) estimates the average effect of the B.C. carbon tax on the province's GDP in the context of a number of static panel models for Canadian provinces. The significance of the estimated impact depends on the particular specification adopted and on the sample period used. Another somewhat relevant paper is Beck et al. (2015) who focus on the distributional household welfare impacts of the tax. Simulations based on their static computable general equilibrium (CGE) model yield an aggregate household welfare loss of 0.08% and show that the tax is progressive.[7]

While useful, the above works measure either average or static effects, and thus they ignore possibly important dynamic considerations. Furthermore, Elgie and McClay (2013) and Beck et al. (2015) do not make use of statistical testing to evaluate their results formally. As for Metcalf (2019), conclusions regarding the importance of the tax effects appear not be robust, given that relatively minor changes in specification (such as using different tax measures, or omitting a province from the analysis) yield different outcomes.

We resort to time series methods to quantify statistically the impact over time of the B.C. carbon tax on the province's GDP. After constructing suitable aggregate energy price and aggregate carbon tax series for B.C., we study the impact of the tax changes on GDP changes in the context of a vector autoregression (VAR) framework. Such models are well suited for our purposes since they can allow for rich interactions amongst variables of interest while remaining parsimonious and easy to implement statistically. Specifically, we build on the canonical VAR framework of Kilian and Vigfusson (2011) by explicitly integrating into our model possible effects of tax saliency, tax pre-announcements, and tax pass-through. To our knowledge, such considerations have not previously been examined in a VAR framework. Finally, our specifications also allow for open economy considerations, which are important for small open economies like British Columbia.

Based on impulse response analysis, and on counterfactual investigations, we find that: (i) the B.C. carbon tax has had no overall statistically significant dynamic effect on monthly GDP changes of British Columbia, (ii) in the few months where carbon taxes do have a statistical impact, GDP changes are mostly positive, and (iii) there is complete pass-through of carbon taxes into energy prices paid by consumers.

The paper proceeds as follows. In Section 2 we describe the data, including the details of the construction of the aggregate price and tax series. The analytical framework and model specifications are presented in Section 3. In Section 4 we discuss the results of estimated impulse responses and of a counterfactual exercise. Finally, section 5 concludes.

2. DATA

Our sample consists of monthly data for the province of British Columbia over the period extending from January 1987 to December 2016. These series include domestic sales (in litres or m^3), energy prices (inclusive of all taxes, in cents/litre or cents/m^3), and carbon taxes ($/ ton of CO_2 equivalent emissions) for regular grade gasoline, diesel, and natural gas (for the residential, commercial and industrial sectors). We also obtain the province's consumer price index (CPI) and population. Other monthly series that we make use of are: The Case-Shiller U.S. National Home Price Index, U.S. housing starts, as well as the global measure of economic activity developed in Kilian (2009). Finally, we have quarterly data on real gross domestic product (GDP; 2007$) for

7. See Beck et al. (2015) Table 8. Hicks equivalent income change is used to measure economic welfare. No information on GDP change is reported. We note that economic welfare and GDP change do not necessarily move in the same direction.

British Columbia, which we linearly interpolate to obtain monthly figures. The appendix describes the sources of all these variables.

Our raw series are transformed as follows. We first express carbon taxes for each energy source in comparable price units and subtract these from corresponding total prices to obtain net-of-carbon-tax prices for each of our gasoline, diesel, and natural gas series. The province's CPI is then applied to all of our price and tax series to obtain their real counterparts. In the case of the tax series, and for reasons explained in Section 3, we also generate the real counterparts of the 4-quarter lead series by dividing nominal t+4 tax values by time t CPI values, and which we refer to as real lead-4 carbon taxes, (denoted $\tilde{T}_{t+4}$ in the equations). For sales and GDP data, we obtain per capita terms. Using 2008 conversion factors provided by Statistics Canada, we convert our real prices and carbon taxes into the same energy units (cents/MJ; MJ stands for MegaJoules), and our per capita quantities into units compatible with our prices (MJ).[8] Except for real carbon taxes, we deseasonalize all our series (including per capita quantities) using the ARIMA-X12 filter.[9] Total deseasonalized real prices are constructed by adding together deseasonalized real net-of-carbon-tax prices and corresponding real (non- deseasonalized) carbon taxes.

Final demand of fossil fuels in British Columbia is mostly composed of three energy products, namely gasoline, diesel, and natural gas (the latter is a total comprised of residential, commercial and industrial demand). According to Statistics Canada (2011), their 2008 shares in fossil fuel final demand were 22.2%, 20.0%, and 39.2%, respectively. Together they thus constitute 81.4% of total fossil fuel final demand.[10] Our aggregate series are thus obtained by combining these three energy sources. More precisely, we construct aggregate real net-of-carbon-tax energy prices by weighting individual real energy prices at each point in time by their respective sales quantities. We construct aggregate real carbon taxes in the same manner. In addition, we construct an aggregate real lead-4 carbon tax series, where we weight real lead-4 carbon taxes by the time t sales quantity of the corresponding real energy price.

The figures below show the progress of some of these variables over time. Figure 1 shows the evolution since 1987 of individual real net-of-carbon-tax energy prices in British Columbia. The net-of-carbon-tax prices of gasoline and diesel carry the imprint of the evolution of oil prices in the world market. We observe that, but during the Iraq war, the two prices were relatively stable from 1987 to the late nineties. Afterwards, they moved upwards with increased variability; over this period, world oil price reached an all-time nominal peak of 147$/ barrel in July of 2008, collapsed to 35$ in December of 2008, moved upwards again, and then decreased in early 2014. Except during the Iraq war period, up to 2003, natural gas price followed the same path as the two refined petroleum products. Then paths decoupled due to the shale gas revolution; the prices of the two refined petroleum products moved mostly upwards whereas the price of natural gas decreased.

Figure 2 plots real carbon taxes pertaining to individual energy types while figure 3 shows these series relative to their corresponding net-of-carbon-tax real prices. We see that carbon taxes are very small in magnitude, especially compared with net-of-carbon-tax prices for gasoline and diesel. At the highest rate in the summer of 2012, at 30$/ton, real carbon taxes cost an additional 0.18 cents per MJ for gasoline, 0.19 for diesel, and 0.14 for natural gas. For the former two, these

8. Statistics Canada (2011). Gasoline (1l = 35.0 MJ), diesel (1l = 38.3 MJ), natural gas (m^3 = 38.09 MJ or 1l = 0.03809 MJ).

9. We do not deseasonalize the carbon tax series given that its introduction time and subsequent changes in value always occur on July 1st of the relevant years, which *de facto* creates a seasonal component. Therefore, deseasonalization would eliminate the very tax changes that we are attempting to analyze and is clearly not desirable.

10. The remaining fossil fuel final demand is due to aviation fuel (8.4%), petroleum coke (2.1%), coal (1.9%), natural gas liquids (1.9%), heavy fuel (1.8%), and other products (2.0%).

Figure 1: B.C. Real Prices Net-of-Carbon-Tax for Different Energy Types (Cents/MJ)

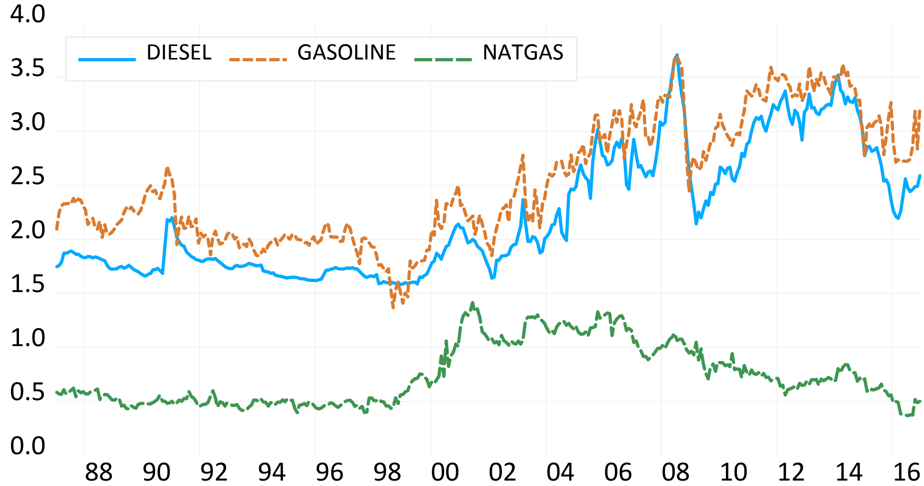
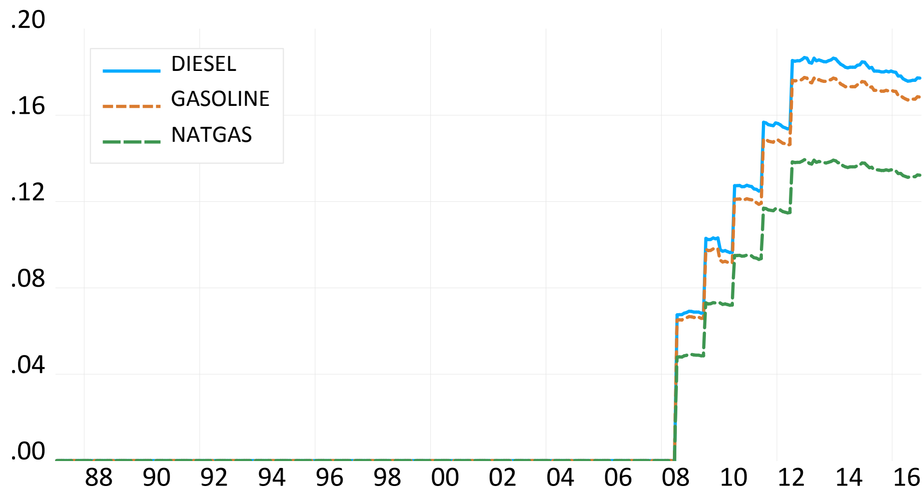


Figure 2: Real B.C. Carbon Taxes Applied to Different Energy Types (Cents/MJ)



correspond to about 5% of net-of-carbon-tax prices paid by users, while for natural gas, they represent about 22%.

Moreover, and as figure 3 shows, while this relative importance is more or less constant for the refined petroleum products, it varies considerably in the case of natural gas. This implies that, based on the type of fossil fuels consumed, carbon tax impacts likely differ from one sector of the economy to another.[11] Moreover, it is important to consider the evolution over time of aggregate energy tax impacts on GDP.

Figure 4 depicts the movements of the resulting aggregate real net-of-carbon-tax energy price series. We also plot the evolution of real aggregate energy prices inclusive of carbon taxes

11. See Bernard, Islam and Kichian (2018) for a comparative analysis of carbon tax impacts on GDP when they are applied to gasoline (household sector) versus diesel (industrial-commercial sector). In contrast, the current paper examines the aggregate GDP impact due to the application of the carbon tax jointly to gasoline, diesel, and natural gas.

Figure 3: Real Carbon Tax Relative to Real Net-of-Carbon-Tax Price (Different Energy Types)

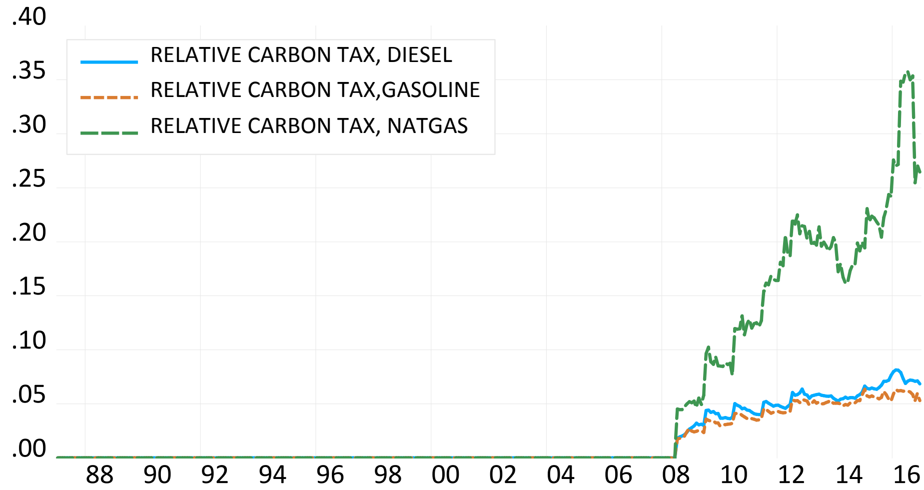
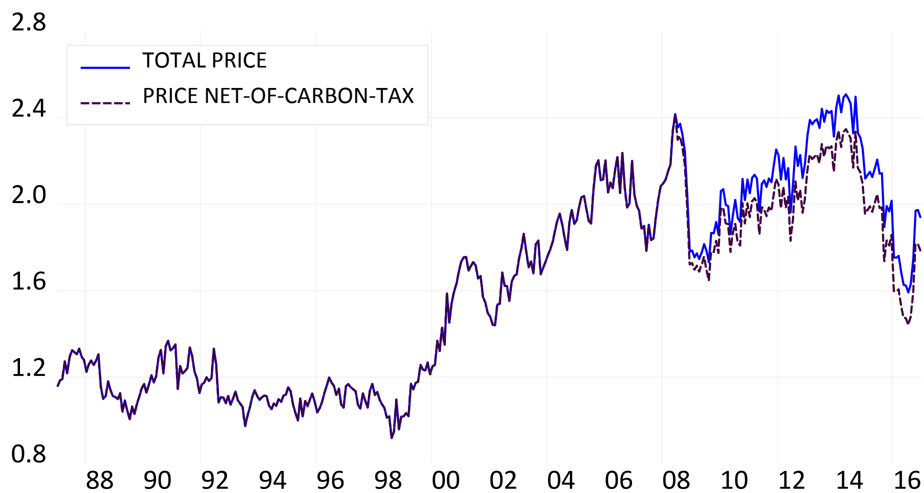


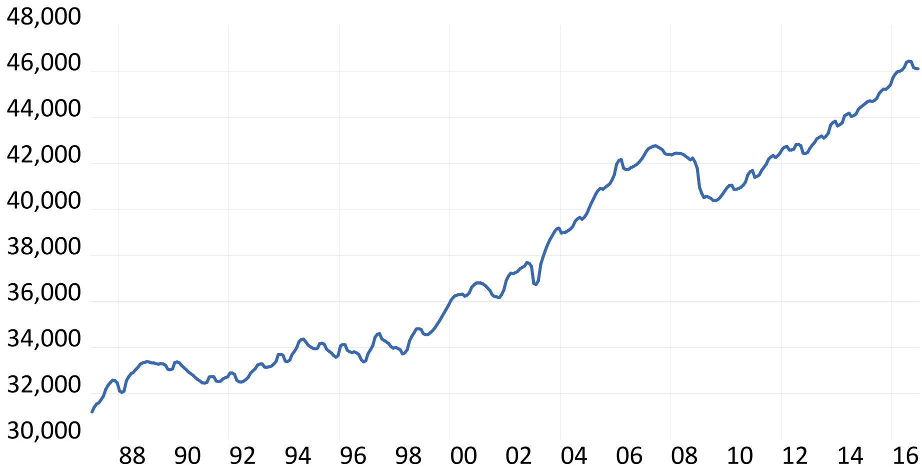
Figure 4: B.C. Real Aggregate Energy Price, Total and Net-of-Carbon-Tax (Cents/MJ)



(which we refer to as total price in the figure). We see that the two series diverge starting in July of 2008 (when the carbon tax was introduced in the province), with the total price series at slightly higher values compared to its non-tax counterpart. Since July of 2012, and at the highest cost per CO_2 ton, the difference between the two series has been of the order of 0.16 cents/MJ, while during the same period net-of-tax real aggregate prices have averaged 2.0 cents/MJ.

Figure 5 shows that per capita GDP (2007$) was mostly trending upwards over the sample period, except during the Great Recession (GR) in late 2008 and early 2009. Annualized real per capita income reached 43,000 in July 2012 when the last increment of the carbon tax was implemented; at that time, the monthly aggregate energy cost net-of-carbon-tax and the monthly aggregate carbon tax represented per capita expenses of $175, and $14.5, respectively, which correspond to 4.9%, and 0.41%, of per capita (monthly) income.

Figure 5: Per capita B.C. GDP (2007 Dollars)



3. MODEL SPECIFICATIONS

The literature on the impact of oil price shocks on the economy is vast, with considerable attention having been devoted to impacts on GDP.[12] While several types of models have been used to study this relationship, vector autoregression (VAR) type models have proven more popular in recent periods.[13] This is partly because asymmetries were thought to be present in the data, and standard VAR frameworks are well-suited to test for and accommodate such effects. On the other hand, interest in the impact of different types of oil shocks (e.g., demand, supply, policy-induced, etc.) on the economy led to the formulation of appropriate structural VAR models.

Since our interest is in measuring tax impacts, and in order to keep the exposition simple, we choose the standard VAR specification to describe the relationship between B.C. aggregate real energy price and per capita monthly GDP changes.[14] We adopt the bivariate specification of Kilian and Vigfusson (2011), originally applied to U.S. data, which we extend by including some exogenous variables to account for open economy considerations that are especially important in the case of B.C. The model specification is thus given by:

$$\Delta \overline{P}_t = a_{10} + \sum_{i=1}^{L} a_{11,i} \Delta \overline{P}_{t-i} + \sum_{i=1}^{L} a_{12,i} \Delta y_{t-i} + \sum_{i}^{L^*} a_{13,i} \Delta x_{t-i} + \varepsilon_{1,t}$$

$$\Delta y_t = a_{20} + \sum_{i=0}^{L} a_{21,i} \Delta \overline{P}_{t-i} + \sum_{i=1}^{L} a_{22,i} \Delta y_{t-i} + \sum_{i}^{L^*} a_{23,i} \Delta x_{t-i} + \varepsilon_{2,t}, \quad (1)$$

where $\overline{P}_t$ is aggregate real energy price inclusive of carbon tax, y_t is per capita GDP in the province, x_t is the vector of exogenous variables, Δ is the first difference operator, L and L^* are lag orders, and $\varepsilon_{j,t}$, $j = 1, 2$ are error terms. The vector of exogenous variables includes the global real economic activity index of Kilian (2009), based on ocean bulk dry cargo freight rates. The variable aims to

12. See, for example, Herrera, Karaki and Rangaraju (2019) for a recent survey on this topic.

13. In the case of VARs, see, for instance, Kilian and Vigfusson (2011, 2013) and Karaki (2018) for U.S. data, and Schaufele (2016) for a Canadian example. For structural VAR models, examples include Kilian and Murphy (2014) and Baumeister and Hamilton (2019).

14. Unit root tests confirm the stationarity of the above variables in first differences. Results are available upon request.

capture world business cycle conditions which can notably affect commodity markets. The other two exogenous variables are U.S. housing starts and U.S. house prices, both reflecting conditions in the U.S. housing sector. These are important to include given that lumber shipments to the U.S. constitute a major share of the province's exports. For later reference, we also note that aggregate real total energy price is the sum of aggregate real net-of-carbon-tax energy price, P_t, and of aggregate real carbon tax, T_t, so that $\overline{P}_t = P_t + T_t$.

We consider two data subsamples over which we conduct our analyses: one covers the period from January 1987 to December 2007 and corresponds to the phase prior to the arrival of carbon taxes; we denote this as "the pre-tax period". The other extends from March 2008 to December 2016 and is denoted "the post-tax period". The proposed model in (1) is applicable to the period prior to the existence of the carbon tax. For the post-tax period, we extend the basic framework in several different dimensions.

First, we add a third equation to the model, one that describes the dynamics of the aggregate real carbon tax. Since our aggregate tax measure has been obtained by summing quantity-weighted individual taxes, and that the weights are endogenous, it is endogenous; the weights reflect choices by households and firms regarding how much natural gas, diesel, or gasoline they want to consume in each period, and the fact that these choices are based on their incomes, the relative prices of the different energy types, the announced carbon tax changes, and on available substitution possibilities.

While the taxes were actually imposed only in July of 2008, their advent was declared ahead of time in the provincial government budget, towards the end of February of that year. The March 2008 starting point of the second subsample (which is a 4-period lead with respect to the actual implementation date) accommodates the possibility that agents may have reacted to the tax in anticipation, that is, as early as 4 months ahead, but also in any month during this interval.[15]

Second, we allow for the possible saliency of taxes, whereby tax changes may induce different (larger) effects than net-of-tax price changes of the same magnitude. This phenomenon has been documented in the literature notably on B.C. gasoline demand by Rivers and Schaufele (2015), Lawley and Thivierge (2018), and Eruktu and Hildebrand (2018), on B.C. residential demand for natural gas by Xiang and Lawley (2019), and on B.C. diesel demand by Bernard and Kichian (2019)). We therefore permit tax coefficients to be different from price coefficients in the three equations of the post-tax model.

Third, the separate treatment of net-of-tax price and carbon tax allows us to analyze the extent to which the latter is passed through to the former. In all the papers referenced in footnote 2, the maintained assumption is that there is perfect pass-through. To the best of our knowledge, Gittens (2019), who focused on the gasoline sector, is the first study to admit that the B.C. carbon tax pass-through into retail and wholesale gasoline prices might not be perfect.[16]

Fourth, to capture the effects of the Great Recession, we include a dummy variable in the vector of exogenous variables of our modified model. This serious recession that originated in the U.S. in 2007 affected Canada primarily over the 2008-2009 period, coinciding with the first two years of the carbon tax implementation in B.C. It is thus important to adequately disentangle its effect from that of the tax. While the lags of changes in the activity index and in the two U.S. housing variables

15. According to google trends, the highest interest in the BC carbon tax occurred in July of 2008. It was preceded by a period of milder interest in the tax over the period March-June of the same year. Far fewer searches were undertaken in the comparable months of the subsequent years. Combined to the fact that that the size of the tax was twice as important in 2008 as in subsequent years, any anticipatory reactions would have been highest in 2008. Thus, we do not think it necessary to consider leads greater than four.

16. Erutku (2019) estimates the effect of carbon price on wholesale gasoline price in the Canadian provinces of Quebec and Ontario; these provinces were participants in the Western Climate Initiative (cap-and-trade) launched by California.

help to capture some of this effect, we found that including the additional dummy term for this period further alleviated the heteroscedasticity of the residuals of the model.

The model proposed thus far does not yet incorporate possible impacts on GDP due to the announcement of the tax 4 months ahead of its implementation. Replacing aggregate real tax changes throughout with their corresponding 4th lead terms makes it possible to capture movements in GDP not only after the tax was put in place, but also contemporaneously, as well as 3 months ahead of the enactment date.[17]

The resulting VAR model for the post-tax period, where $e_{j,t},\ j = 1,2,3$ are error terms, is given by:

$$\Delta\tilde{T}_{t+4} = b_{10} + \sum_{i=1}^{K} b_{11,i}\Delta P_{t-i} + \sum_{i=1}^{K} b_{12,i}\Delta y_{t-i} + \sum_{i=-3}^{K-3} b_{13,i}\Delta\tilde{T}_{t-i} + \sum_{j=1}^{M} b_{14,j}\Delta x_{t-j} + e_{1,t}$$

$$\Delta P_t = b_{20} + \sum_{i=1}^{K} b_{21,i}\Delta P_{t-i} + \sum_{i=1}^{K} b_{22,i}\Delta y_{t-i} + \sum_{i=-3}^{K-3} b_{23,i}\Delta\tilde{T}_{t-i} + \sum_{j=1}^{M} b_{24,j}\Delta x_{t-j} + e_{2,t}$$

$$\Delta y_t = b_{30} + \sum_{i=1}^{K} b_{31,i}\Delta P_{t-i} + \sum_{i=1}^{K} b_{32,i}\Delta y_{t-i} + \sum_{i=-3}^{K-3} b_{33,i}\Delta\tilde{T}_{t-i} + \sum_{j=1}^{M} b_{34,j}\Delta x_{t-j} + e_{3,t}. \qquad (2)$$

We estimate the models developed in this section for each of our subsamples and discuss the obtained results next.

4. ESTIMATION RESULTS AND ANALYSIS

The model represented by the system of equations (1) is estimated using our pre-tax data sample and allowing for a maximum of 8 lags for the endogenous variables and 18 lags for the exogenous Δx_t variables.[18] The Akaike criterion then selects an optimal lag order of 7 for the endogenous variables and lags of different orders for the exogenous variables. The results indicate a fairly good model fit, with an adjusted R-square value of 0.60 for the GDP equation and 0.24 for the price equation, and with no evidence, at the 5% level, of remaining autocorrelation in the model residuals, from 1 up to 8 lags.[19,20]

Figures 6 and 7 demonstrate the fit of changes in GDP and aggregate net-of-carbon-tax prices, respectively. We see that the model is able to replicate quite well actual GDP changes over time. On the other hand, and as expected, it is less successful in capturing real net-of-tax aggregate price changes; commodity prices are fairly volatile and difficult to predict.[21]

We next estimate our proposed three-equation VAR specification over the post-tax period. In this case, the Akaike criterion selects an optimal lag order of 6 for the endogenous variables. Once again, we find a good model fit, with adjusted R-squares of 0.66 for the GDP equation, 0.14

17. As explained in the data section, to construct the aggregate real lead-4 carbon tax series, the (exogenous) nominal tax at time t+4 for each fuel source is first normalized by the CPI value at time t. These real lead terms are then weighted by their respective time t sales quantities to obtain the (resulting endogenous) aggregate $\tilde{T}_{t+4}$ measure. The normalization and the weighting by time t values ensures that when lags of this aggregate are used as regressors in the VAR, they are indeed pre-determined.

18. The maximum lag allowances are made to strike a balance between the need to incorporate sufficient relevant information from the regressors and degrees of freedom losses.

19. A dummy term is included in the model to capture an outlier in the residuals of the GDP change equation in January of 2003. Coefficient estimates are not reported to save space but are available upon request.

20. Tests based on impulse-response comparisons (as in Kilian and Vigfusson (2011, 2013)) revealed no evidence of asymmetry at the 5% level. Results are available upon request.

21. Indeed, in some studies they are represented as random walk processes.

Figure 6: Fit of per capita GDP changes, pre-tax period (2007 Dollars)

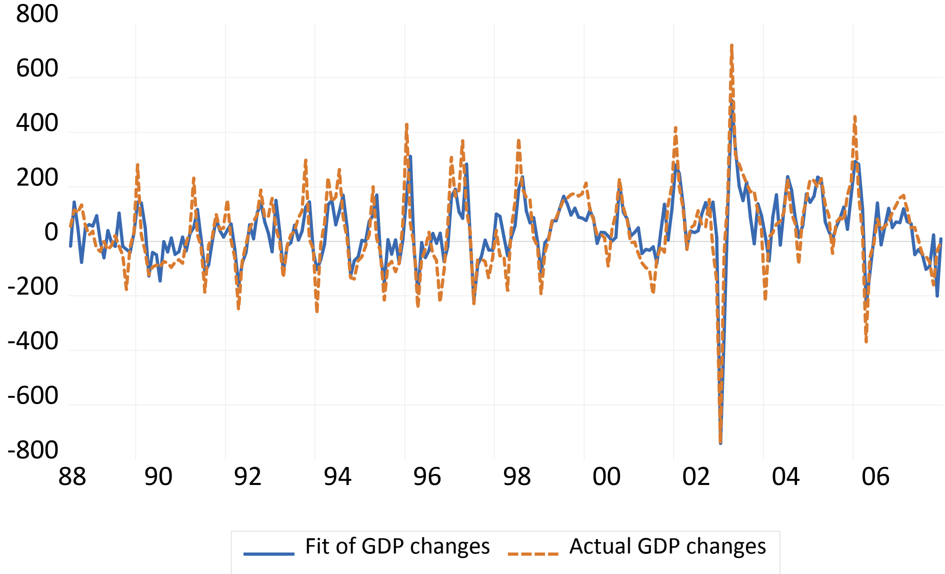
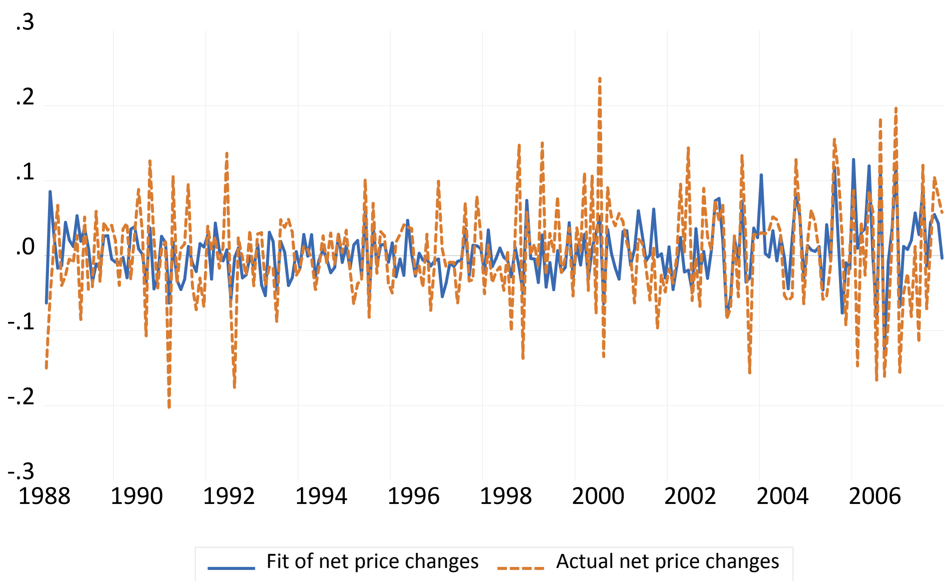


Figure 7: Fit of real aggregate net-of-carbon-tax energy price changes, pre-tax period (Cents/MJ)



for the real aggregate net price equation, and 0.52 for the real aggregate tax equation. In addition, diagnostic tests applied to the residuals reveal no evidence of remaining systematic information in these series.[22]

22. Applied tests include a White test for no heteroscedasticity and LM tests of no autocorrelation of 1 up to 8 lags. These hypotheses are not rejected at the 5% level. Coefficient estimates and detailed test results are available upon request.

Figure 8: Fit of real per capita GDP changes, post-tax period (2007 Dollars)

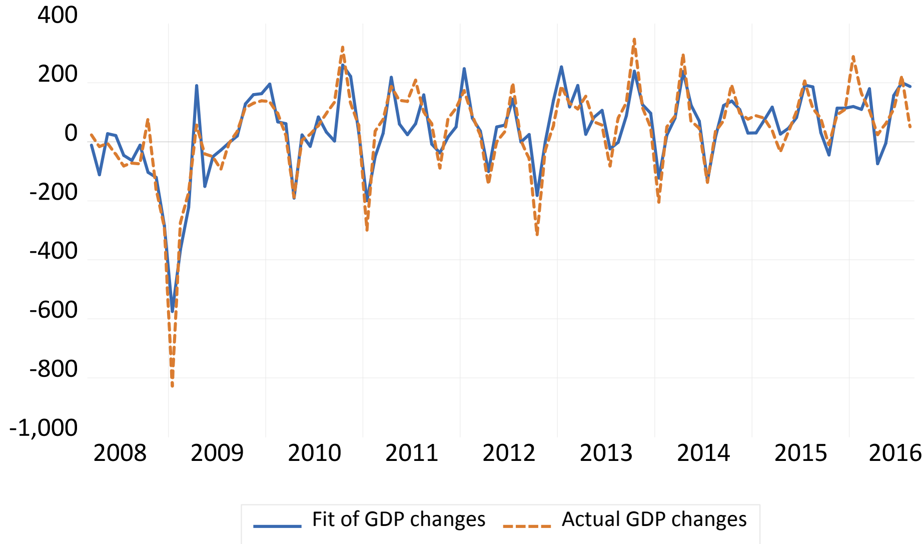
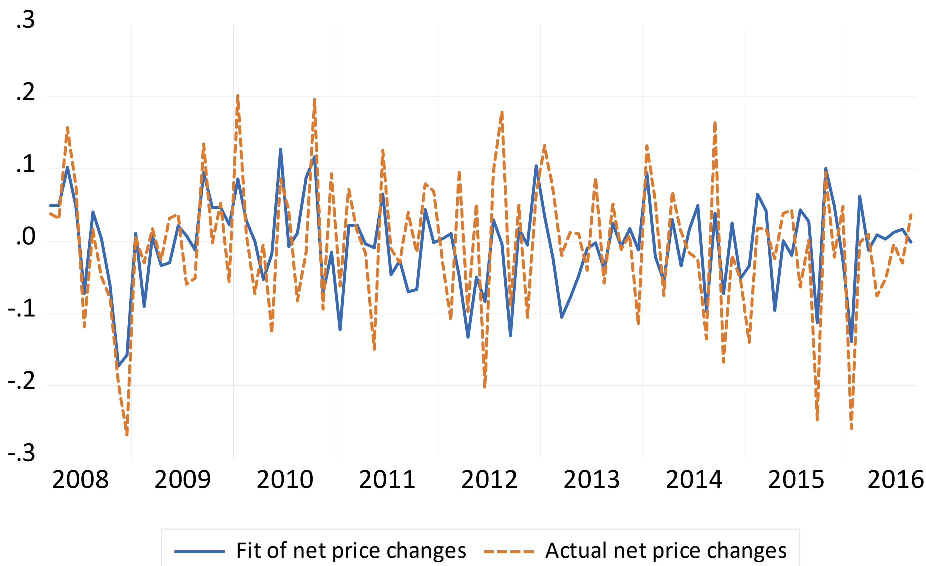


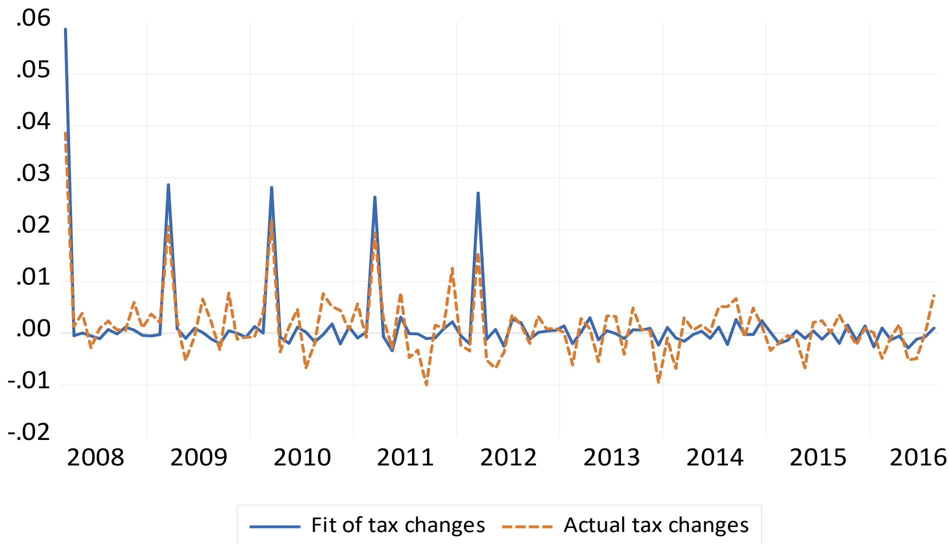
Figure 9: Fit of real aggregate net-of-carbon-tax energy price changes, post-tax period (Cents/MJ)



Figures 8 to 10 plot actual and fitted changes for the three series included in our model. From the first figure we can see that the dynamics of GDP changes is well matched by the estimated model.

In particular, the model is able to capture the downturn of the 2008-2009 Great Recession and the subsequent upswing. The model is also fairly successful in capturing the five July increases in aggregate real carbon taxes (Figure 10), especially the second to the fourth tax hikes. Finally, while the fit of aggregate net-of-carbon-tax price change is less satisfactory than that of the other two series, the model is able to replicate relatively well net price changes in the early part of the subsample (Figure 9).

Figure 10: Fit of real aggregate tax changes, post-tax period (Cents/MJ)



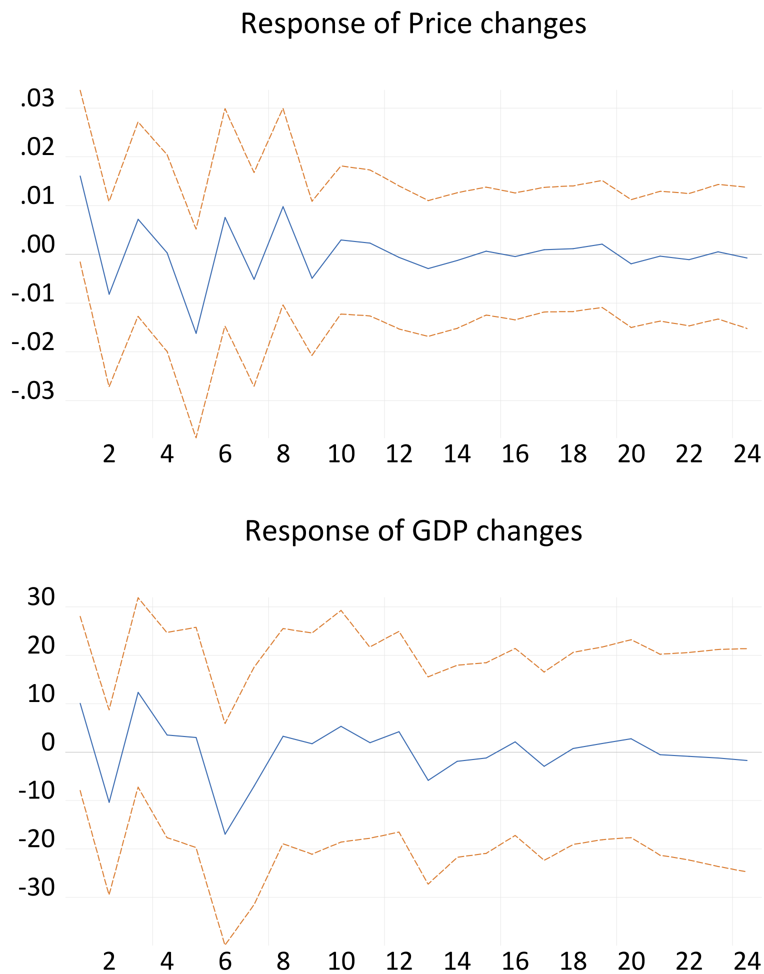
4.1 Impulse Response Analysis

To evaluate the impact of the carbon tax changes on GDP dynamics, we impose a contemporaneous recursive structure on the variance-covariance of our VAR(2) residuals. That is, we apply a Cholesky factorization to this variance-covariance, and we calculate impulse responses. The VAR ordering places real aggregate tax changes first since nominal taxes are exogenously decided and that these are normalized by prices that are lagged 4 periods. Real aggregate net-of-carbon-tax energy price changes are placed second; although refiners and distributors do have small profit margins and can adjust prices, for example, to temporarily absorb tax shocks, commodity prices are primarily driven by world trends in these prices. We place GDP changes of the province last since they may be influenced contemporaneously by both real tax and real energy price changes.

Figure 11 plots the responses of real aggregate net-of-tax energy price changes and of GDP changes to a one standard deviation shock to the pre-announced real aggregate carbon tax, along with corresponding standard error bands. In the lower panel we observe that, after a swing up and then back down (to the starting GDP level) in the first two months after the tax announcement, there is an increase in GDP in the third month (i.e., one month ahead of the actual tax shock). This can be explained by the purchase of fuels at cheaper prices, either to advance planned energy-intensive future production or for storage. Negative GDP changes are observed a few months later (i.e., in the 2nd and 3rd months after the implementation of the tax increase), in line with a decrease in the rate of advanced production and the depletion of fuel inventories. However, we also note that, despite being intuitive, none of the monthly impacts are significant; zero is present in the estimated 95% confidence bands.[23]

23. We take considerable care in our analysis to ensure that 2008-2009 tax effects are not confounded with the effect of other factors, notably the Great Recession. In particular, we include a recession dummy term that extends from October 2008 to June 2009. Since the first tax implementation occurred in July of 2008 while the second tax hike happened in July 2009, if there were any collinearity between the dummy and the 2008-2009 taxes, this would definitely not be perfect. To check whether the inclusion of the dummy term changes our conclusions, we also obtain impulse responses from a model that ex-

Figure 11: Impulse Reponses due to real aggregate tax changes, post-tax period (Top panel: cents/MJ; Bottom panel: 2007 dollars)

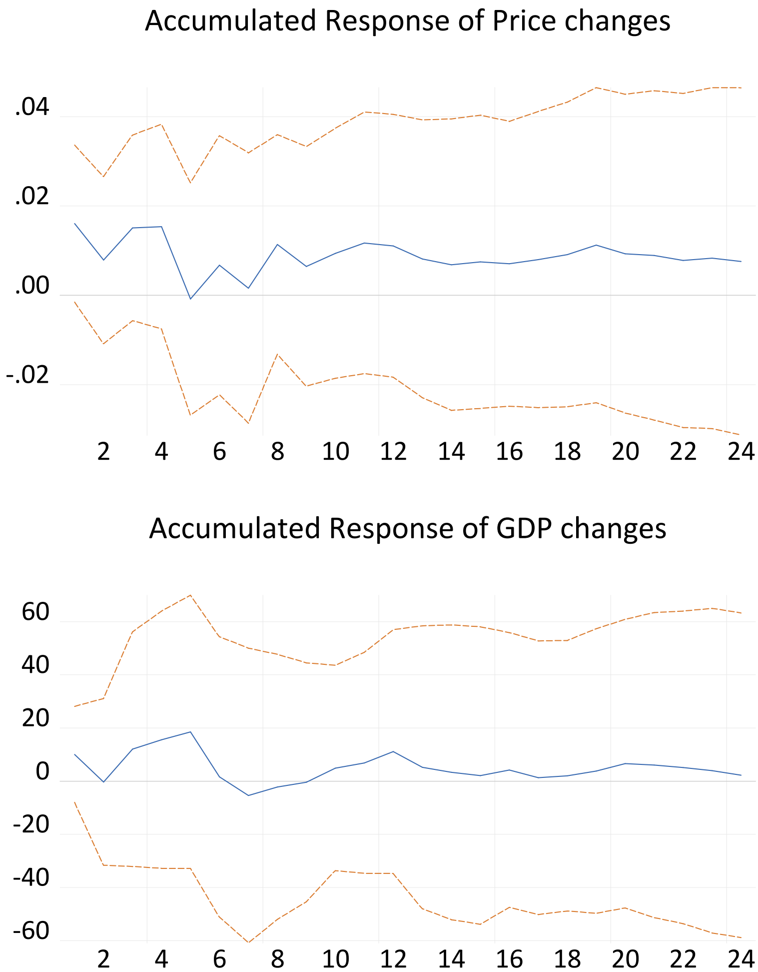


As for aggregate real net-of-carbon-tax energy prices, responses are similar to that of GDP change. Prices increase ahead of the tax hike and decrease in the month following the tax change. However, once again, responses are not significant. Thus, wholesalers and retailers jointly pass on tax changes fully into final prices.

We next examine the possibility that responses are cumulatively statistically relevant. Figure 12 plots the accumulated impulse responses of the variables of interest to a one standard deviation increase in the aggregate real tax. These show that even when we consider accumulated effects, carbon tax changes have no significant impact, either on changes in net energy prices, or on changes

cludes the dummy term. We find that impulse responses and accumulated impulse responses from models with and without the recession dummy term exhibit similar profiles. Differences are that the no-dummy model produces significant positive responses in the first and third periods after the shock, and in the first and fifth periods after the shock for the accumulated response. These outcomes uphold our conclusion that the B.C. carbon tax has produced no significant negative GDP impacts over time.

Figure 12: Accumulated Impulse Reponses to real aggregate tax changes, post-tax period (Top panel: cents/MJ; Bottom panel: 2007 dollars)



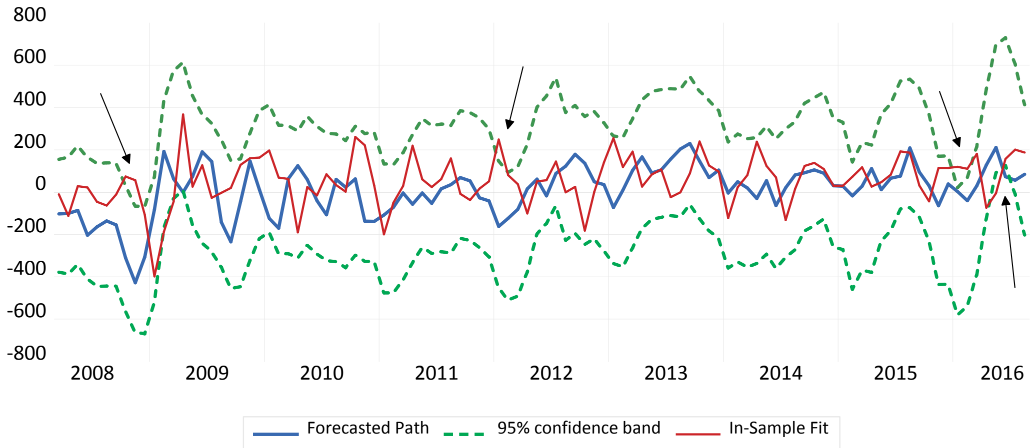
in GDP. In other words, we confirm full pass-through into prices and reinforce the result that GDP dynamics is not affected by carbon taxes.

4.2 A Counterfactual Comparison Exercise

In this section, we consider a different approach to determining whether carbon taxes have changed GDP dynamics in the province: we compare the GDP forecast path from the pre-tax period to GDP movements in the post-tax period. More specifically, fixing the parameters of the pre-tax VAR to their estimated values, and the exogenous variables to their actual values, we generate dynamic forecasts for the endogenous variables of the system over the period January 2008 to December 2016, along with corresponding 95% confidence bands.

The resulting path of GDP changes describes what the evolution of GDP would have been in a world without carbon taxes. The idea is to statistically compare this path to actual GDP changes in the post-tax period. However, since the post-tax era also witnessed the Great Recession that coincided with the advent of the tax, we first need to remove its effects on the province's GDP dynamics.

Figure 13: Pre-tax period forecast of per capita GDP changes versus post-tax fit of GDP changes (2007 Dollars)



For this purpose, we rely on our model for the post-tax period, which estimates the distinct effects of the carbon taxes and of the Great Recession. The latter impacts operate via three channels in the model: the Great Recession dummy term, the exogenous variables, and (indirectly) through the lags of the endogenous variables.

The exogenous variables are present in both the pre-tax and post-tax periods, conveying the impact of foreign supply and demand conditions on domestic GDP. Since the actual values of these exogenous variables are used when generating the dynamic out-of-sample forecasts, this channel is accounted for in the forecasted series as well as in the in-sample fit of GDP changes. Once the recession is transmitted to the domestic economy, its influence is additionally captured by the endogenous lags of the post-tax model. Given that our pre-tax specification also includes endogenous lags, these additional influences should also be accounted for in the forecasted path of GDP changes. In contrast, supplementary important effects entering through the dummy term in our post-tax model is clearly not present in the forecasted series. To make our comparisons meaningful, we remove the estimated impact of the latter from our post-tax in-sample fit of GDP changes and use this as our post-tax series.

Figure 13 presents the forecasted path of GDP changes over 2008-2016, along with its 95% confidence bands. It also plots the fitted in-sample GDP change series from the post-tax model (with the estimated dummy term removed). We observe that, except for a few instances (indicated by arrows in the figure), the series representing the in-sample fit is well within the forecast path confidence bands. This implies that the two series are generally not statistically different from each other.[24]

In the cases where the fitted series exceeds the forecast bounds, we notice three occasions (October-November 2008, January 2012, and January 2016) where the GDP change in the presence of carbon taxes is statistically greater than its counterpart scenario of no carbon taxes. In particular, while according to the no-tax scenario, the GDP change would have been strongly negative in the

24. To check the robustness of our results to our particular forecasted path (which is conditional on the fit of our 2-variable VAR model over the pre-tax period), we compare the post-tax GDP path to an average forecast obtained from six different unconstrained specifications, and related 95% confidence bands. These vary in the lag orders for the endogenous, and the exogenous variables, respectively, and are given by (4,4), (4,12), (4,18), (8,4), (8,12), and (8,18). We find very similar results to the ones that we have reported. We are grateful to an anonymous referee for suggesting this robustness check.

fourth quarter of 2008 (the non-reported estimated coefficient on the dummy term is large and negative), it is positive in the presence of the carbon tax. This may be due to the re-distributional impact of the collected carbon tax funds which appear to have stimulated the economy during this period, and which are masked by the advent of the Great Recession.

Despite the occasional and minor significant effects, the results in this sub-section largely corroborate the results from our response analysis section, confirming that revenue-neutral carbon taxes, overall, have no significant negative effects on GDP changes. Hence, these conclusions concord with the findings by Elgie and McClay (2013) and Metcalf (2019). They are also in line with works such as Abdullah and Morley (2014); the latter tests, for a panel of OECD countries, the Granger-causality of average per unit taxes (across countries and across time) on GDP growth. Note that these taxes were not necessarily introduced only for environmental reasons, nor were they revenue-neutral.

The absence of negative carbon tax impacts might be specific to the features of the B.C. policy. First, even if revenue-neutrality is the intended aim of the policy, actual tax amounts collected differed from the designated tax reductions and credits. For instance, according to the B.C. Ministry of Finance (2013), during the 2012-2013 fiscal year (which witnessed the final tax increase), carbon tax revenues amounted to $ 1.12 billion compared to $1.3 billion spent in subsidies and rebates. Revenue shortfalls also happened in previous years, implying that the policy has been somewhat expansionary.

Second, and as supported by the findings of Beck et al. (2015), tax changes were designed to also be progressive. Since low-income earners save less in general than higher income households, such income transfers may also have contributed to higher GDP. Finally, the fact that we observe no significant negative tax impacts could be due to the tax component being a relatively small part of the monthly total energy price paid by B.C. consumers.

5. CONCLUSION

Environmental taxes were implemented in various forms by several industrialised countries during the last three to four decades, and the impact of such taxes on country GDP is a major policy concern. Since these tax strategies vary significantly from one jurisdiction to another, and that the collected taxes are often not all strictly devoted to environmental purposes, there is little empirical evidence that bears directly on this contentious issue. The introduction of a broad-based revenue-neutral carbon tax by the government of the province of British Columbia in 2008 thus provides an exceptional natural experience in this respect.

Relying on a VAR framework, we studied the impact of aggregate carbon taxes on provincial GDP. Impulse response analysis, as well as statistical comparisons of the post-tax fit of GDP changes with the forecasted path of GDP changes from the pre-tax period overall revealed no evidence of carbon tax impacts on GDP dynamics. In the few instances where statistical effects were detected, the monthly GDP changes were found to be mostly positive (and small). Our results on the time-varying impacts concord with findings from previous studies that measure average and static B.C. carbon tax impacts on GDP, and together they show that carbon taxation is a viable way to tackle CO2 emissions without negative consequences on the economy.

Our finding of no significant carbon tax effects on per capita GDP changes should be interpreted as a lower bound estimate. Further changes, in the spirit of the so-called Porter hypothesis, if they exist, would yield additional positive benefits for the economy, but over horizons that extend beyond our analysis period. The Porter hypothesis (Porter and van der Linde (1995)) contends that environmental taxes and regulations can spur innovation, which in turn leads to gains in productivity thus also accelerating growth. Such positive impacts are likely to be both spread out over time and to evolve at fairly long horizons. As more data becomes available, future work should be able to examine the presence of such effects for the B.C. carbon tax case.

In Canada, surveys show that there is large public support for policies addressing climate change. In view of this fact, and to honour Canada's commitment to the 2015 Paris Accord, the federal government introduced in January 2019 a revenue-neutral carbon tax in those provinces that do not already have their own GHG-reducing programs. Some politicians have been claiming that this will hurt the economy badly.[25] Our analysis on the B.C. experience does not support such claims.

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25. The following quote on January 22, 2019 by Doug Ford, the Premier of the Ontario (the largest province of Canada) is an example: "A carbon tax will be a total economic disaster".

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APPENDIX: DATA SOURCES

Regular gasoline average final prices in Vancouver (¢/litre)	Kent Group Ltd, Canada; http://www.kentgroupltd.com/
Diesel average final prices in Vancouver (¢/litre)	Kent Group Ltd., Canada; http://www.kentgroupltd.com/
Natural gas, unit price by sector (¢/m^3)	Jan 1987 to Dec 2015, Statistics Canada, Table 25-10-0055-01, *Natural Gas Monthly Sales.* Jan 2016 to Dec 2016, Statistics Canada, Table 18-10-0004-11, *CPI by Geography, monthly percentage change, not seasonally adjusted*.
Gasoline domestic sales (litres)	Statistics Canada, Table 25-10-0044-01, Supply and Disposition of Refined Petroleum Products, monthly**.**
Diesel domestic sales (litres)	Statistics Canada, Table 25-10-0044-01, *Supply and Disposition of Refined Petroleum Products, monthly.*
Natural gas sales (m^3)	Jan 1987 to Dec 2015, Residential and Commercial: Statistics Canada, Table 25-10-0032-01, *Natural Gas Utilities, Monthly Receipts and Disposition*. Industrial = Total local delivery—(residential + commercial): Statistics Canada, Table 25-10-0047-01, *Natural Gas, Monthly Supply and Disposition*. Jan 2016 to Dec 2016, Statistics Canada, Table 25-10-0055-01, *Supply and Disposition of Natural Gas, monthly*.
B.C. GDP ($2007)	Conference Board of Canada, quarterly
B. C. Consumer Price Index (2007=100.0)	Statistics Canada. Table 18-10-0004-07: Consumer Price Index (CPI), 2011 basket, monthly (2002=100).
B.C. population	Statistics Canada. Table 17-10-0009-01: Estimates of population, Canada, provinces and territories, quarterly (persons).
Case-Shiller U.S. National Home Price Index	Federal Reserve Bank of St. Louis, Jan 2000=100, seasonally adjusted, https://fred.stlouisfed.org/
U.S. housing starts	Federal Reserve Bank of St. Louis https://fred.stlouisfed.org
Global activity index (Kilian 2009)	https://web.archive.org/web/20180725151325/http://www-personal.umich.edu/~lkilian/reaupdate.txt
U.S. Consumer Price Index (2010=100.0)	Federal Reserve Bank of St. Louis Consumer Price Index: Total All Items for the United States (CPALTT01USM661S) https://fred.stlouisfed.org

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IAEE wishes to congratulate and thank all those involved including authors, editors, peer-reviewers, the editorial boards of both publications, and to you, our readers and researchers, for your invaluable contributions in making 2019 a strong year. We count on your continued support and future submission of papers to these leading publications.