The Impact of Carbon Taxes on Market Structure: Evidence from British Columbia's Retail Gasoline Industry

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Abstract

As shown by Buchanan (1969), the efficient tax on a monopoly is lower than on a competitive industry (due to market power of the monopolist). I build on this idea by showing that, in oligopoly markets, the market power problem is exacerbated in the long-run, and I estimate short-run and long-run changes in British Columbia's retail gasoline industry resulting from the implementation of a carbon tax. First, I use a theoretical model to illustrate the *direct effect* (in the short-run) and the *market-structure effect* (in the long-run) of a tax. The direct effect is an increase in marginal cost that is partially passed-through to consumers. The market-structure effect is a reduction in the number of firms due to lower margins following the tax, which in turn further increases price. Second, I use panel data on retail and wholesale prices, retail margins, and the number of gasoline stations to empirically estimate the short-run and long-run impacts of a carbon tax. My empirical results are consistent with theory, and suggest that incomplete passthrough of the tax caused some stations to exit resulting in even greater long-run price increases.

1 Introduction

Mitigating the impact of humans' influence on the climate has become an important objective for policy makers. As of 2016, 40 national and 24 subnational jurisdictions have a carbon pricing system in place (World Bank Group, 2016). Carbon taxes have emerged as a main policy tool to reduce emissions throughout the world. Carbon taxes are based on the idea that incorporating the *social cost of carbon* (SCC) in prices for goods and services will eliminate negative externalities.[1] If neither producers nor consumers pay the SCC in market transactions, then output is higher than socially optimal. In competitive markets, setting a carbon tax equal to the SCC can account for the negative externality, and rectify the problem. Introduction of the tax raises firms' marginal cost by the amount of the SCC, and re-optimization causes firms to reduce output until price is equated with marginal cost, or to exit the market if they are unable to achieve positive profit. The result is an increase in the price paid by consumers, and a decrease in the price received by producers. The tax creates a wedge between the two prices so that, in equilibrium, the marginal benefit of consumption is equated with the sum of the marginal cost of production and the SCC; this equilibrium is socially efficient.

In contrast, the same policy applied to an imperfectly competitive market will not yield a socially efficient equilibrium. As noted by Buchanan (1969), in a monopoly environment, setting a tax equal to the SCC will reduce quantity (increase price) past the socially efficient level. This is because market power causes firms to restrict output below the competitive level. It follows from his analysis that, in imperfectly competitive markets with an externality, the efficient tax is less than the marginal damages of the externality (i.e. less than the SCC).[2] However, the monopoly setting that Buchanan analyses is static in the sense that it does not consider changes in the number of firms; if the monopoly firm exits, then the market would cease to exist. But, in an oligopoly setting, a tax could reduce the number of firms in the long-run, and exacerbate the market power problem.

To fix ideas, I distinguish between the *direct effect*, and the *market-structure effect* of a tax in oligopoly markets. The direct effect of the tax is the impact on price and quantity in the short-run, before firms are able to adjust fixed costs. The market-structure effect is the impact on price and quantity due to changes in the number of firms when fixed costs become adjustable. In the short-run, firms may be required to pay fixed costs even if they cease production, and may face exit costs if they choose to close. This means that a tax increase is likely to cause little to no exit in the short-run, but may cause exit in the long-run if firms

[1] The social cost of carbon is a monetary value for the negative externalities associated with carbon emissions. Recent estimates place the SCC at $42.93 as of 2016, with an expected real increase up to $57.49 in 2030 (Environment and Climate Change Canada, 2016).

[2] See also Barnett (1980), who extends Buchanan's work by showing that optimal tax rates may be lower than marginal damages if polluters are imperfectly competitive, and that the difference between the optimal tax and the marginal damages is larger when demand is more inelastic.

are unable to cover fixed costs. As in Buchanan (1969), the effect of a tax in the short-run will be to increase price (reduce output) past the socially efficient level. However, in the long-run, if the tax reduces the number of firms than greater market power will exacerbate the problem described by Buchanan, by further increasing price (reducing output). Overall, the long-run impact of the tax is the combination of the direct and market-structure effects.

In this paper, I use a policy change in the Canadian province of British Columbia (BC) to empirically estimate both short-run and long-run impacts of a carbon tax in the retail gasoline industry, and to capture differences between the direct and market-structure effects. I focus on the retail gasoline industry for two reasons. Firstly, local market power of retail gasoline stations has been attributed to higher prices (Verlinda, 2008; Deltas, 2008). Second, the industry accounts for a sizable portion of emissions. In 2016, passenger cars and passenger light trucks made up 12.09% of Canada's total CO2 equivalent emissions while freight trucks accounted for an additional 8.52% (Environment and Climate Change Canada, 2018a,b).

On July 1st 2008 BC implemented a broad-based carbon tax, which started at \$10 per tonne of carbon dioxide equivalent emissions, and was scheduled to rise at annual intervals of \$5 per tonne up to \$30 per tonne on July 1st 2012.[3] The British Columbia Carbon Tax (BCCT) acts as a good natural experiment for two key reasons. First, the surprise implementation meant that consumers and producers were unable to respond in advance of the policy change.[4] Second, many other Canadian provinces did not see changes in gasoline taxes for many years before or after, and can be used as a control group to identify the impact of the BCCT on retail gasoline markets.

First, I illustrate the direct and market-structure effects in a model of oligopolistic competition between gasoline stations; I start with a symmetric Cournot model and then discuss how firm heterogeneity and differentiated product Bertrand competition affect the results. Next, I use panel data from Statistics Canada and Kent Group Ltd. to empirically analyze the impact of the carbon tax in BC; I observe wholesale prices, retail prices, and retail margins at the city level, as well as the number of gasoline stations by census division. I estimate short- and long-run effects of the tax on BC's retail gasoline markets using a difference-in-difference (DiD) approach where other Canadian provinces act as a control group.

My results suggest that incomplete passthrough in the short-run caused exit and greater market concentration at the station level, which in turn contributed to a long-run price increase that is significantly larger than the short-run price increase. I estimate a short-run decrease in BC's retail margins of 3.76 ¢/ltr. This is a 45% decrease in retail margins, which averaged 8.32 ¢/ltr in BC during the three years prior to the BCCT. Additionally, the

[3]Carbon dioxide equivalent emissions measure the amount of a greenhouse gas that has the same global warming potential as carbon dioxide.

[4]The British Columbia Carbon Tax (BCCT) was first announced on February 19th, 2008, less than five months before it came into effect on July 1st, 2008.

number of stations in BC decreased by 6.49% in the long-run, which I take as confirmation of the hypothesis that the long-run price increase is the result of changes in market structure. However, the long-run retail price increase of 6.65 ¢/ltr is not statistically larger than the tax of 6.67¢/ltr. One possible explanation for this fact is that regulation induced improvements in productivity dampened the effect of market power.

These findings are important in understanding the economic impacts of carbon taxes. Specifically, my results demonstrate that in order for policy makers to select the optimal tax level they need to consider that a long-run decrease in the number of firms will impact both market power and productivity. In oligopoly markets, an optimal tax should be set so that the market price is equal to the marginal cost plus the SCC, which requires knowing the SCC, the short-run passthrough rate, and the size of the market-structure effect as a function of the tax level.

There is a growing literature on the impacts of the BCCT; some initial studies have shown decreases in emissions and/or fuel consumption due to the BCCT (Elgie and McClay, 2013; Beck et al., 2015; Bernard et al., 2014; Rivers and Schaufele, 2015).[5] In a recent paper, Pretis (2019) finds no evidence of a decrease in aggregate CO_2 emissions but finds significant decreases in certain sectors (including transportation). Rivers and Schaufele (2015) estimate demand elasticities and find that the short-run demand response to the carbon tax is significantly larger than the response to non-tax changes in gasoline price; this finding is consistent with Li et al. (2014), who perform a similar analysis on U.S. data. However, an analysis by Erutku and Hildebrand (2018) suggests that the magnitude of this demand response in BC faded over time. Beck et al. (2015) examine income redistribution due to the BCCT and Metcalf (2016) conducts an analysis of the effect on GDP growth. Yamazaki (2017) studies the impact on employment noting that carbon intensive industries lose jobs, but the overall impact is a net gain in employment. Antweiler and Gulati (2016) study the impact on vehicle use and new vehicle purchase.

This paper is also related to the literature on regulation and market structure. The literature in this area is vast; I list some that focus on environmental policies or regulations of gasoline markets. For example, List et al. (2003) show that air quality regulation reduced entry of pollution intensive plants in regulated parts of New York State (relative to unregulated areas), and Berman and Bui (2001) show that regulatory changes to oil refineries in California led to investment in productivity improving technology. Abito (2018) provides evidence that price regulations on U.S. electric utilities led to lower fuel efficiency and uses a structural model to estimate welfare gains under a counterfactual policy. Specific to gasoline markets, Carranza et al. (2015) study the impact of price floors on retail gasoline markets in Quebec, Canada, and Anderson and Johnson (1999) study the effect of sales-below-cost laws on retail gasoline margins in the U.S. Eckert and West (2005) study retail station rationalization (specifically in the Toronto area), and Eckert and West (2006) study the response

[5]Murray and Rivers (2015) provide a review of early work in this area.

of incumbent stations following a new entrant.

Two closely related papers are Ryan (2012), and Fowlie et al. (2016). Ryan (2012) estimates a dynamic model of competition between cement producers to evaluate the impact of a regulation that increased firms' sunk entry costs. Ryan's analysis shows that lower entry rates led to greater market power which increased the cost to consumers in the product market; he argues that these costs should be included in the overall cost of the policy. Fowlie et al. (2016) then use a similar model on the same dataset to estimate the impact of a number of counterfactual policies for pricing emissions. Their analysis accounts for market dynamics, including exit, in estimating the impact of carbon pricing on trade exposed cement markets. One difference between their setting and the one in this paper is that retail gasoline markets have minimal trade exposure. Given the costs associated with purchasing from unregulated markets, only retailers that are very close to BC boarders could be substituted for unregulated ones. Additionally, I construct a theoretical model which clearly illustrates the short-run and long-run impacts of the carbon tax and use a DiD estimation strategy to check the predictions of the theoretical model. My estimation strategy relies on the use of an unaffected control group as a baseline, while the procedure used by Fowlie et al. (2016) is to estimate a structural model and simulate counterfactual outcomes.

The remainder of this paper is organized as follows: section 2 presents an overview of the retail gasoline sector, and BC's carbon tax; section 3 introduces a theoretical model to characterize the expected impacts of the BCCT on retail gasoline markets; sections 4 and 5 describe the data and estimation procedure; results are discussed in section 6; and section 7 provides concluding remarks.

2 Industry Structure and the Carbon Tax

The retail gasoline industry in Canada is made up of many small geographic markets that vary in the degree of competition. Isolated rural markets may be local monopolies, while urban markets are likely to have more competitors. Houde (2012) accounts for commuting patterns in estimating retail gasoline demand in Quebec City and notes that the average consumer faces 10 stores within one minute of their optimal commuting route. Carranza et al. (2015) define neighbourhood retail gasoline markets using a clustering algorithm; their median market size is 3 stations. These papers give a sense of the number of competitors in a market.

Given the sizes of retail gasoline markets, it should be expected that stations will hold some market power. Moreover, research on price dynamics in retail gasoline markets suggests that market power does contribute to higher prices. For example, a number of researchers have identified asymmetric price changes in response to transitory marginal cost fluctuations

(Verlinda, 2008; Deltas, 2008; Borenstein et al., 1997; Borenstein and Shepard, 1996; Duffy-Deno, 1996). Asymmetric pricing increases average retail margins over a given time period and is associated with market power at the station level.

2.1 Overview of BC's Gasoline Taxes

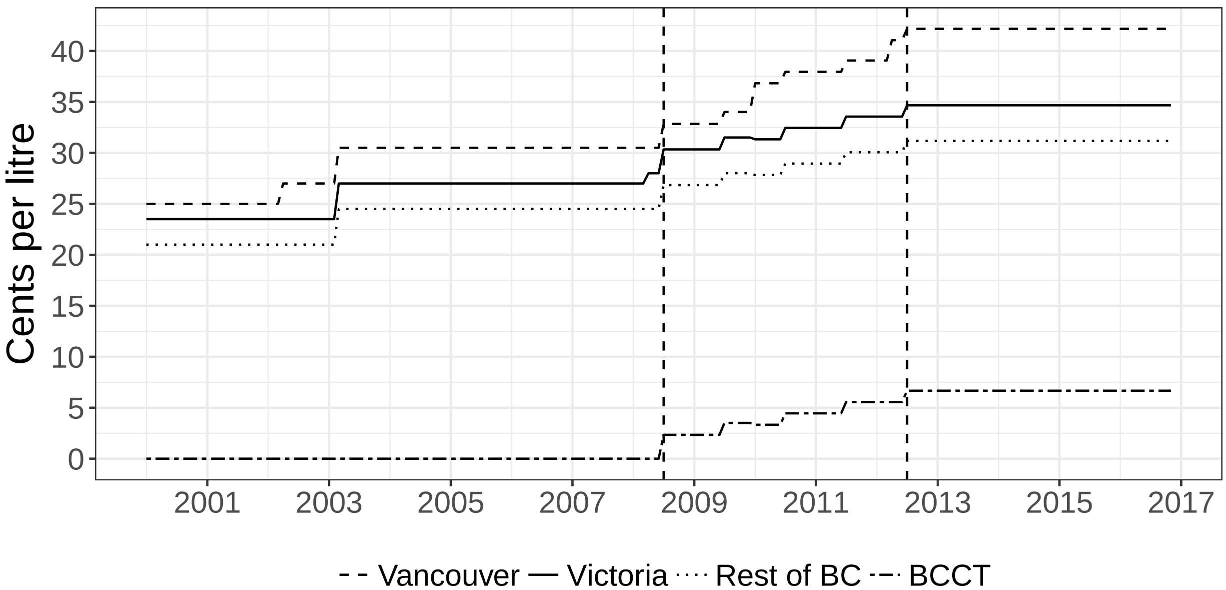
The BCCT was originally introduced at a rate of $10 per tonne of CO_2 equivalent emissions, and was scheduled to rise at $5 per tonne each year until it reached $30 per tonne on July 1st 2012. It was then held constant until April 1st 2018. For clear gasoline sold, the initial rate was 2.34¢/ltr. It increased to 3.51¢/ltr on July 1st 2009, there was an unscheduled decrease of 0.2¢/ltr on January 1st 2010, and then three more scheduled increases; it rose to 4.45¢/ltr on July 1st 2010, 5.56¢/ltr on July 1st 2011, and finally 6.67¢/ltr on July 1st 2012.

In addition to the BCCT, gasoline sales in BC are subject to provincial, regional and federal taxes. These include a provincial tax on motor fuel throughout BC, regional taxes for the Vancouver area and Victoria areas, and a federal motor fuel tax. At the provincial and regional levels, there are three transportation authorities that collect taxes as part of their funding. The British Columbia Transportation Financing Authority collects gasoline taxes throughout the province; at the regional level gasoline taxes are collected by the South Coast British Columbia Transportation Authority (TransLink) in the Vancouver area, and by the British Columbia Transit Authority in the Victoria area. There are also additional taxes administered by the provincial government and the federal government.

Regional and provincial taxes in BC have experienced various changes in recent years; the federal tax however, which is set at 10¢/ltr, has not changed since 1995. Figure 1 shows historic gasoline tax rates in BC at the regional level as well as the value of the carbon tax for gasoline. Rates in the figure are the sum of all regional, provincial and federal taxes. The dashed vertical lines correspond to the introduction and the last rate increase of the BCCT.

Both Vancouver and Victoria had gasoline tax changes that coincide with the introduction of the carbon tax. In Victoria there was a small increase of 1 ¢/ltr in April 2008 (only three months before the BCCT started), but in Vancouver there was a larger increase of 5 ¢/ltr between the first and last BCCT changes. If these cities are included in the empirical analysis, then the results should be interpreted as the cumulative effect of these tax changes and the BCCT. However, the changes in Vancouver and Victoria do not drive my empirical results. I discuss this issue in more detail in the empirical section, and in the appendix I include a robustness check where I drop Vancouver and Victoria and the estimated coefficients are very similar.

Figure 1: Historical gasoline tax rates in British Columbia.



3 Theory

Gasoline companies often own stations in many different markets. However, individual stations compete against only a few rivals in small geographic markets. Given the size of retail markets, it is not likely that firms will have multiple retail outlets in the same market, thus cannibalization effects are expected to be small or non-existent. This allows me to investigate the impact of a tax by focusing on one representative market.

Suppose that n retail gasoline stations, indexed by $i \in \{1, ..., n\}$, simultaneously choose quantities q_i in order to maximize profits

$$\pi_i = (P - c_i - \tau)q_i - F_i. \tag{1}$$

c is the marginal cost of production, F is fixed cost, τ is a per unit tax, and the market demand curve is

$$P = P(Q) = A - BQ, \tag{2}$$

where $Q = \sum_i q_i$. Firm i's first order condition with respect to q_i is

$$\underbrace{A - BQ - Bq_i}_{mr_i} = c_i + \tau, \tag{3}$$

where the left hand side is firm i's marginal revenue. Assuming that all firms maximize profits, we can add up equation (3) over firms and divide by n to get $A - \frac{n+1}{n}BQ^* = \bar{c} + \tau$.

Rearranging gives the equilibrium aggregate quantity of

$$Q^* = \frac{A - \bar{c} - \tau}{B} \frac{n}{n+1}. \tag{4}$$

It follows that the market price is

$$P^* = \frac{1}{n+1} A + \frac{n}{n+1} (\bar{c} + \tau), \tag{5}$$

firm i's output is

$$q_i^* = \frac{A - \tau - (n+1)c_i + n\bar{c}}{B(n+1)}, \tag{6}$$

and firm i's profit is

$$\pi_i^* = \left[\left(\frac{1}{n+1} \right) (A - \tau - (n+1)c_i + n\bar{c}) \right]^2 \frac{1}{B} - F_i. \tag{7}$$

I first show the impacts of a carbon tax with symmetric firms. This simplification facilitates a simple graphical illustration for the direct and market-structure effects of the tax. Next, I discuss how these effects can change with asymmetric firms or differentiated product Bertrand competition.

3.1 Symmetric Firms

With symetric firms ($c_i = c$ and $F_i = F$), we can write

$$q^*(n) = \frac{1}{n+1} \frac{A - c - \tau}{B} \tag{8}$$

$$\pi(q^*(n)) = \frac{1}{B} \left(\frac{A - c - \tau}{n+1} \right)^2 - F, \tag{9}$$

where the i subscript has been dropped because firms are symmetric.

Allowing for free entry and exit, the number of firms should satisfy: $\pi(q^*(n)) \geq 0$ and $\pi(q^*(n+1)) < 0$. So, the equilibrium number of firms can be concisely written as

$$n^* = \text{floor} \left(\frac{A - c - \tau}{\sqrt{BF}} - 1 \right) \tag{10}$$

where the function floor$(\cdot)$ rounds down to the nearest integer.

To illustrate the effect of taxing an externality it will be useful to express equation (3) in terms of aggregate output, rather than individual quantity. With symmetric firms, $q_i = q = \frac{Q}{n}$, and equation (3) can be written as

$$\underbrace{A - B\frac{n+1}{n}Q}_{mr(n)} = c + \tau \tag{11}$$

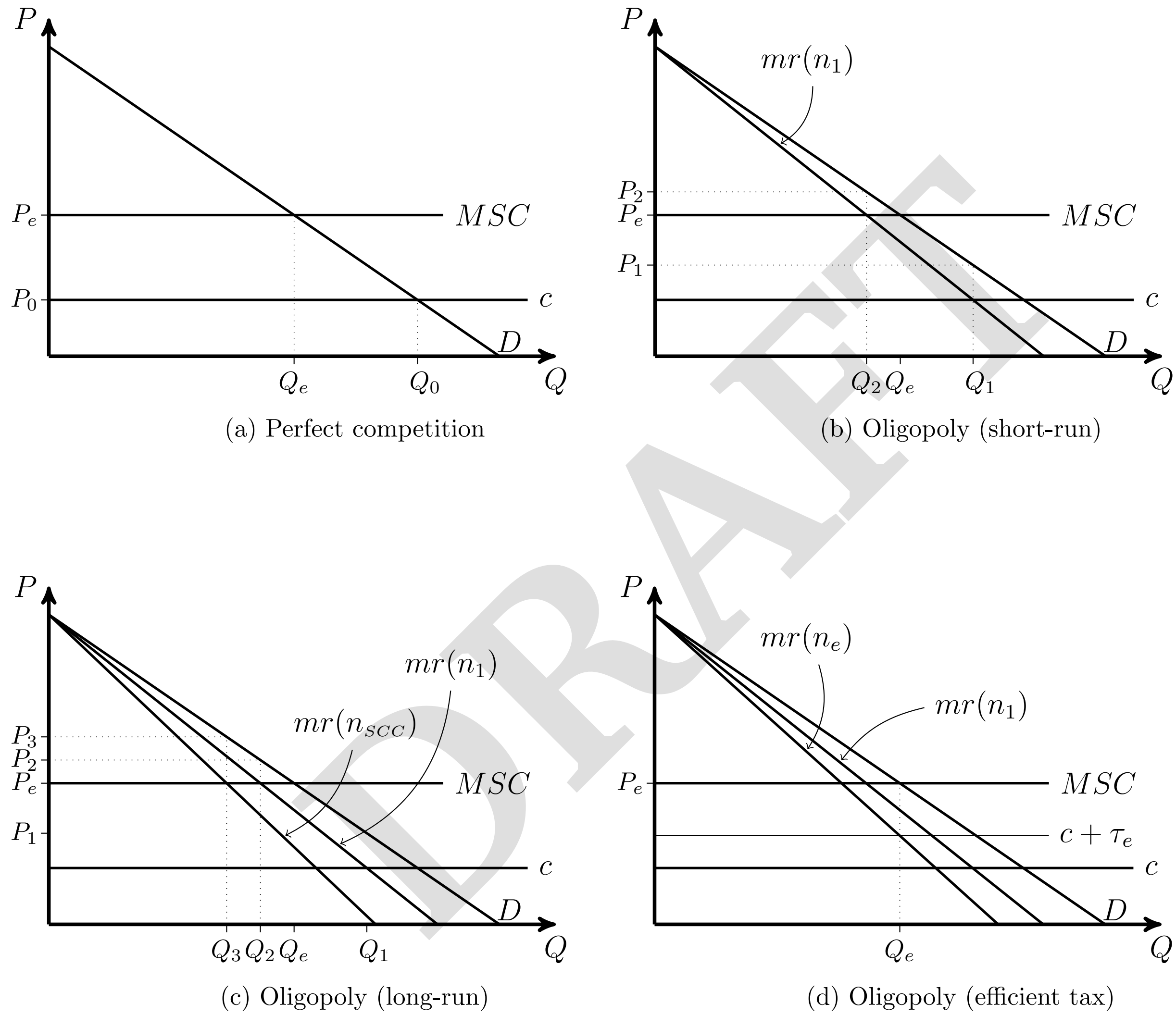
where $mr(n)$ is the marginal revenue with n firms that all produce Q/n.

Equation (11) defines the equilibrium aggregate output (Q^*). Since externalities are determined by aggregate output, equation (11) enables a comparison of allocative efficiency in the presence of a market externality. Two important points to note from equation (11) are (i) higher taxes reduce equilibrium output, and (ii) a decrease in the number firms makes $mr(n)$ steeper, which reduces equilibrium output.

Figure 2 outlines the impact of a tax in the presence of a market externality. A perfectly competitive market is shown as a baseline in panel 2a. The market demand curve is D, and there is a negative externality so the marginal social cost of production (MSC) is greater than the marginal cost for firms (c). The difference $MSC - c$ is the marginal damage from the externality. If the competitive market is unregulated then $P = c$ and the resulting output is Q_0. Setting a tax equal to the marginal damages of the externality ($MSC - c$) would correct the externality and yield the socially efficient quantity Q_e and price $P_e = MSC$. Next, consider the oligopoly market in panel 2b, with n_1 firms and average marginal revenue given by $mr(n_1)$. Without a tax, firms will choose quantity so that $mr(n_1) = c$, which results in the unregulated oligopoly outcome of (Q_1, P_1). Holding the firms constant at n_1, if a regulator imposed a tax of $\tau_{SCC} = MSC - c$, then firms would choose quantity according to $mr(n_1) = MSC$, which would result in a market equilibrium at (Q_2, P_2). Price would be too high and quantity too low; the policy would overshoot its target.

The fact that an optimal tax on an externality should be less than marginal damages is a well known result that was originally discussed by Buchanan (1969). However, Buchanan's analysis does not consider how changes in the the tax affect market structure in a dynamic oligopoly. As can be seen in equation (10), if the tax increase is large enough, it will reduce the number of firms that the market can support in the long-run. This will exacerbate the negative impact of market power. In panel 2c, the long-run number of firms is assumed to fall to n_{SCC} when the tax is τ_{SCC}. The decrease in the number of firms increases market power and moves the market from the short-run equilibrium at (Q_2, P_2) to the long-run equilibrium at (Q_3, P_3). In order to set an allocatively efficient tax in an oligopoly market, the long-run changes in market structure need to be considered; this means setting the tax lower than $MSC - c$. An example is shown in panel 2d, where the tax τ_e reduces the number of active firms to n_e, and $mr(n_e) = c + \tau_e$. Note that $0 < \tau_e < MSC - c$ implies that $n_1 > n_e > n_{SCC}$.

In general, the direct effect of the tax is determined by the short run passthrough rate. As long as the aggregate demand curve is not perfectly inelastic, it will lead to higher price and lower output. However, the market-structure effect is determined by long-run changes in the number and composition of surviving firms, which means potential differences between exiting and surviving firms needs to be considered.



(a) Perfect competition

(b) Oligopoly (short-run)

(c) Oligopoly (long-run)

(d) Oligopoly (efficient tax)

Figure 2: Tax in an oligopoly market

3.2 Heterogeneous Firms

With heterogeneous firms, the long-run equilibrium number of firms,n^*, can is defined as

$$n^* = n : \pi_i^* \geq 0 \ \ \forall i \in \{1, ..., n\} \ \text{ and } \ \pi_i^* < 0 \ \ \forall i \notin \{1, ..., n\}. \tag{12}$$

In words, n^* is such that profit is positive for all active firms, and would be less than zero for any potential entrant. As shown in proposition 1, n^* is decreasing in the tax.

Proposition 1. *Denote the long-run equilibrium number of firms given tax level τ as n^*_τ, then*

$$\tau_2 > \tau_1 \Rightarrow n^*_{\tau_2} \leq n^*_{\tau_1}$$

Proof. Note from equation (6), that positive output implies $A - \tau - (n+1)c_i + n\bar{c} > 0$, and from (7) that $\frac{\partial \pi_i^*}{\partial \tau} < 0$ whenever $A - \tau - (n+1)c_i + n\bar{c} > 0$. So, if $\tau_2 - \tau_1$ is large enough, then profit will become negative for some firm (or firms) causing exit. □

Using subscripts to denote the number of firms and the tax level, the direct effect of an increase in taxes from τ_1 to τ_2 on the price is $P_{n,\tau_2} - P_{n,\tau_1}$, and the market-structure effect, if k firms exit in the long-run, is $P_{n-k,\tau_2} - P_{n,\tau_2}$. It is clear from equation (5), that the direct effect will increase price. But, with firm asymmetry, we need to consider the characteristics of exiting firms in order to determine the market-structure effect. Without loss of generality, suppose that we start with n active firms and denote the sets of surviving and exiting firms respectively as $\{1, ..., n-k\}$ and $\{n-k+1, ..., n\}$. Then using equation (5) the change in price when k firms exit can be written as

$$P^*_{n-k,\tau} - P^*_{n,\tau} = \frac{1}{n+1}\left[\left(\frac{k}{n-k+1}\right)(A - \tau + (n-k)\bar{c}_{n-k}) - k\bar{c}_k\right], \tag{13}$$

where $\bar{c}_{n-k} = \frac{1}{n-k}\sum_{i=1}^{n-k} c_i$ is the average marginal cost of surviving firms, and $\bar{c}_k = \frac{1}{k}\sum_{i=n-k+1}^{n} c_i$ is the average marginal cost of exiting firms. Notice that $P^*_{n-k,\tau} - P^*_{n,\tau}$ is decreasing in $\bar{c}_k$ and increasing in $\bar{c}_{n-k}$; if surviving firms have lower marginal cost than exiting firms, then the price increase due to the market-structure effect will be dampened by an increase in average productivity.

Proposition 2. *Exit increases equilibrium price ($P^*_{n-k,\tau} - P^*_{n,\tau} > 0$) if and only if*

$$\left(\frac{1}{n-k+1}\right)(A - \tau) + \left(\frac{n-k}{n-k+1}\right)\bar{c}_{n-k} > \bar{c}_k$$

Proposition 2 follows directly from equation (13), and it says that, in order for the market-structure effect to increase price, the average marginal cost of exiting firms has to be less than a weighted average of consumers' *net of tax maximum willingness to pay* $(A-\tau)$ and the average marginal cost of surviving firms. It is natural to assume that firms with the lowest profits will exit first (the high cost ones), which suggests that the increase in productivity could actually lead to lower prices. However, exiting firms' costs can be bounded, relative to surviving firms' costs, by assuming that all firms make positive profits before the tax increase.

Lemma 1. *In a long-run equilibrium with tax level* τ*, and free entry and exit, positive profits for all active firms implies that*

$$\left(\frac{A-\tau}{n-k+1}\right)+\left(\frac{n-k}{n-k+1}\right)\bar{c}_{n-k}-\left(\frac{n+1}{n-k+1}\right)\frac{1}{k}\sum_{i=n-k+1}^{n}\sqrt{BF_i}\geq \bar{c}_k$$

Proof. Plug $n\bar{c}=(n-k)\bar{c}_{n-k}+k\bar{c}_k$ into the profit function from equation (7), and simplify $\pi_i^*\geq 0$ to get

$$A-\tau+(n-k)\bar{c}_{n-k}-(n+1)\sqrt{BF_i}\geq (n+1)c_i-k\bar{c}_k.$$

Averaging over the k firms in $\{n-k+1,...,n\}$ gives

$$A-\tau+(n-k)\bar{c}_{n-k}-(n+1)\tfrac{1}{k}\textstyle\sum_{i=n-k+1}^{n}\sqrt{BF_i}\geq (n+1)\bar{c}_k-k\bar{c}_k,$$

and dividing by $n-k+1$ gives the result. □

Proposition 3. *Starting from a long-run equilibrium with* n^* *firms, as in* (12)*, and tax level* τ_1*, if increasing the tax level to* $\tau_2>\tau_1$ *causes the* k *firms indexed by* $\{n^*-k+1,...,n^*\}$ *to exit then*

$$\frac{n^*+1}{k}\sum_{i=n^*-k+1}^{n^*}\sqrt{BF_i}>\tau_2-\tau_1 \qquad \Rightarrow \qquad P^*_{n^*-k}-P^*_{n^*}>0$$

Proof. Note that lemma 1 implies proposition 2 if

$$\left(\tfrac{A-\tau_2}{n-k+1}\right)+\left(\tfrac{n-k}{n-k+1}\right)\bar{c}_{n-k}>\left(\tfrac{A-\tau_1}{n-k+1}\right)+\left(\tfrac{n-k}{n-k+1}\right)\bar{c}_{n-k}-\left(\tfrac{n+1}{n-k+1}\right)\tfrac{1}{k}\textstyle\sum_{i=n-k+1}^{n}\sqrt{BF_i}.$$

Simplifying this inequality gives $\frac{n^*+1}{k}\sum_{i=n^*-k+1}^{n^*}\sqrt{BF_i}>\tau_2-\tau_1$. □

The intuition behind proposition 3 is that the market-structure effect will increase prices as long as demand is not *too* inelastic and/or fixed cost are not *too* small relative to the tax increase. In the case of gasoline retailing, fixed costs are much larger than the per litre price of gasoline, and hence the per litre tax, so exit should be expected to increase price, even with heterogeneous firms.

3.3 Other Theoretical Complications

Another point to consider is how the tax impacts profits if, rather than choosing quantity, firms compete on prices in a differentiated product Bertrand setting. In this case, for exit to occur, it must be that profit becomes negative for at least one active firm after the tax is imposed. While it seems natural that an increase in tax should decrease firms' profits, this is not guaranteed theoretically. Anderson et al. (2001) study this issuse in a differentiated product Bertrand model with symmetric demand functions and constant marginal cost. They show that the impact of a tax on profits depends on the curvature of demand, which suggests that the impact on station exit is an empirical question.[6] However, they also show that incomplete short-run passthrough is a sufficient condition for a decrease in profits. This is an intuitive result because, with incomplete passthrough, firms' profit margins decrease and, since prices are higher, they also sell less.

A final point to consider is the role of vertical structure. The models considered so far illustrate the direct and market-structure effects on a particular level of a vertically separated industry. However, in gasoline retailing integration with the upstream sector is common. Due to the added complication I only discuss main points here, but in the appendix I consider a case where upstream-only and integrated firms compete in a first stage followed by downstream-only and integrated firms in a second stage. The model reaches similar conclusions regarding the downstream sector, but it also gives predictions about changes in wholesale prices. In the model, integrated firms have an incentive to increase wholesale price past the oligopoly level in order to increase the marginal cost for their non-integrated downstream rivals. This incentive is magnified when there are fewer retail outlets in the downstream market, which means the the wholesale price increases when retail outlets exit. This only happens when integrated firms exist.

4 Data

For the empirical analysis I construct two panel datasets. In the first, the unit of observation is a Canadian city in a given month and the outcomes of interest are retail and wholesale gasoline prices and retail margins. KENT Marketing Ltd. publishes records of the monthly average retail and wholesale gasoline prices for select Canadian cities. I calculate retail margins as the net of tax retail price minus the wholesale price. However, wholesale gasoline terminals are only located in some cities. So, to calculate retail margins, I match cities with retail price data to cities with wholesale prices based on proximity; I limit matching to cities that are at most 300 kilometers apart. I also add a number of control variables, which are

[6] In the appendix, I present a similar model and derive a condition on demand functions that guarantees a fall in short-run profits following the tax.

discussed in the next section.

The second dataset is from Statistics Canada's Business Register program, which tracks the number of establishments by North American Industry Classification System (NAICS). The cross sectional unit is a Canadian census division, and for each geographic unit I observe the number of businesses by industry twice per year.[7] [8] The outcome of interest is the number of gasoline stations, but I use business counts for other NAICS groups as control variables; these are discussed in the next section.

Summary statistics for the number of stations, the prices, and the retail margins are shown in table 1. In the table, the mean number of stations is larger than the typical market. This is because the data show the total number of stations within a census division at a point in time, and most census divisions will contain multiple distinct retail gasoline markets. Also, the margin does not equal retail price minus wholesale price because the retail price is tax inclusive. The numbers of geographic units for each outcome variable are shown in table 2.

Table 1: Summary Statistics

Province		Stations per census division	Wholesale price (¢/ltr)	Retail price (¢/ltr)	Retail margin (¢/ltr)
British Columbia	Mean	45.58	70.74	115.80	7.68
	St. dev.	70.33	12.57	14.42	3.47
	Obs.	546.00	396.00	783.00	528.00
Alberta	Mean	77.12	68.76	101.15	7.71
	St. dev.	107.91	12.95	13.38	2.50
	Obs.	336.00	264.00	651.00	519.00
Nova Scotia	Mean	22.08	66.48	115.65	8.84
	St. dev.	21.29	13.28	15.83	1.49
	Obs.	336.00	132.00	774.00	774.00
Ontario	Mean	54.78	69.24	110.38	6.42
	St. dev.	51.61	12.91	16.66	3.34
	Obs.	672.00	1162.00	1689.00	1678.00
Saskatchewan	Mean	29.59	68.94	109.10	9.68
	St. dev.	27.22	12.91	13.97	2.46
	Obs.	336.00	132.00	396.00	396.00

Notes: All statistics are calculated over the period July 2005 through June 2016.

[7] June and December are the two reference months for the Business Register program.
[8] Industry groups are at the 6 digit NAICS level.

Table 2: Number of geographic units

	Gasoline stations	Wholesale price	Retail price	Retail margin
	Census divisions	Cities		
British Columbia	26	3	4	6
Control provinces	80	13	20	21

5 Empirical Model

My empirical approach is based on comparing market outcomes in BC with outcomes in a non-BC control group, and estimating SR and LR outcomes relative to a common base period. Specifically, I use Difference-in-Difference (DiD) regressions to estimate the impact of the BCCT on retail prices, wholesale prices, retail margins, and the number of gasoline stations. I use four Canadian provinces as a control group (Alberta, Ontario, Nova Scotia and Saskatchewan), and I restrict my sample to observations between July 2005 and June 2016. This allows me to define a pre-treatment period in which no gasoline tax changes took place. Of the control provinces, only Alberta had a small change in gasoline tax in the post-treatment period, but not until March of 2015, almost 3 years after the BCCT reached its full level.[9]

My estimating equation is

$$y_{gt} = \alpha_0 + \gamma_t + \gamma_g + X_{gt}\beta + \delta \times \mathtt{I}(t \in \hat{T} \text{ and } g \in \text{BC}) + \epsilon_{gt} \tag{14}$$

y_{gt} is one of the outcome variables; g denotes the geographical unit, and t denotes the time period. For number of gasoline stations, g is the CD, and t is the biannual reference month (June or December). For the other outcome variables (retail prices, wholesale prices, and retail margins), g is the city, and t is the month. $\mathtt{I}(\cdot)$ is the indicator function, $\hat{T}$ denotes the treatment period, BC is the treatment group, and ϵ_{gt} is an idiosyncratic error term. The parameter δ estimates the impact of the BCCT on the outcome variable. X_{gt} is a vector of controls. Including the controls means that δ can be interpreted as the impact of the BCCT net of any changes due to the control variables. I estimate equation (14) by OLS, and cluster standard errors at the geographical unit (either CD or city).

In the price equation, I include controls for the wholesale price and other taxes. Other taxes are made up of gasoline taxes, excluding the BCCT, and sales taxes. Since sales taxes are percent of the final retail price, fluctuations in the price cause temporary changes in the

[9]Dropping Alberta after March 2015 does not qualitatively change the results (results without Alberta are shown in section C of the appendix).

tax amount. Wholesale price and other taxes account for changes in retailer costs and have significant explanatory power over retail prices. For both retail and wholesale prices and the retail margin equations, I also include controls for the log of the value of building permits, the average wage for retail employees, and the unemployment rate.[10] Building permits and the unemployment rate are included to account for demand side shocks, while the retail wage will account for supply side shocks.

For the gasoline stations equation, I include controls for the number of businesses in other industry groups (6 digit NAICS groups). I select the NAICS control groups using a lasso regression in which the shrinkage parameter is chosen by 10 fold cross-validation.[11] I also exclude some sectors that are likely to be directly affected by the carbon tax (automobile and other fuel and gas industries). The selected control groups are shown in table 3.

In order to increase similarity between BC and the control group, I create a matched sample based on the number of gasoline stations per capita. Specifically, for every control group census division, I calculate the percentage distance of stations per capita from each BC census division. Then, I remove control census divisions that are not in the top 10% match for at least one BC ones. Table 4 shows summary statistics for the number of stations per 10,000 persons during the pre-treatment period in BC, the matched control group, and the unmatched control group.

I use three years before the start of the BCCT as the pre-treatment base period, and I estimate the DiD model using eight separate post treatment periods.[12] Each post treatment period is one year in length and starts in July, the month that tax changes took place. Figure 3 shows the base and post treatment periods along with the BCCT level. The BCCT was introduced and then increased increased in the first five post-treatment periods, but then it was held fixed until the end of the eighth post-treatment period. Therefore, changes in earlier periods include the short-run effect of recent tax increases, while changes in later periods capture more of the long run effect of past tax changes. Specifically, periods six, seven, and eight have no short-run effect at all.

Following the theoretical model from section 3, the tax should first increase the retail price and reduce the retail margin in the short-run. But, once stations exit, the retail margin should also go back up, and the retail price should go up even more.

[10]The value of building permits and the unemployment rate are measured at the city level for most cities, but not for all. I use the provincial average for cities without measurements. The average wage for retail employees is recorded at the provincial level.

[11]The shrinkage parameter is chosen as the largest value such that the cross validation error is within 1 standard error of its minimum.

[12]As noted previously, the BCCT was announced only 5 months before it was implemented so anticipatory behaviour in the pre-treatment period is not expected. However, I also estimate the model excluding the six months before the BCCT from the pre treatment period (these results are shown in section D of the appendix).

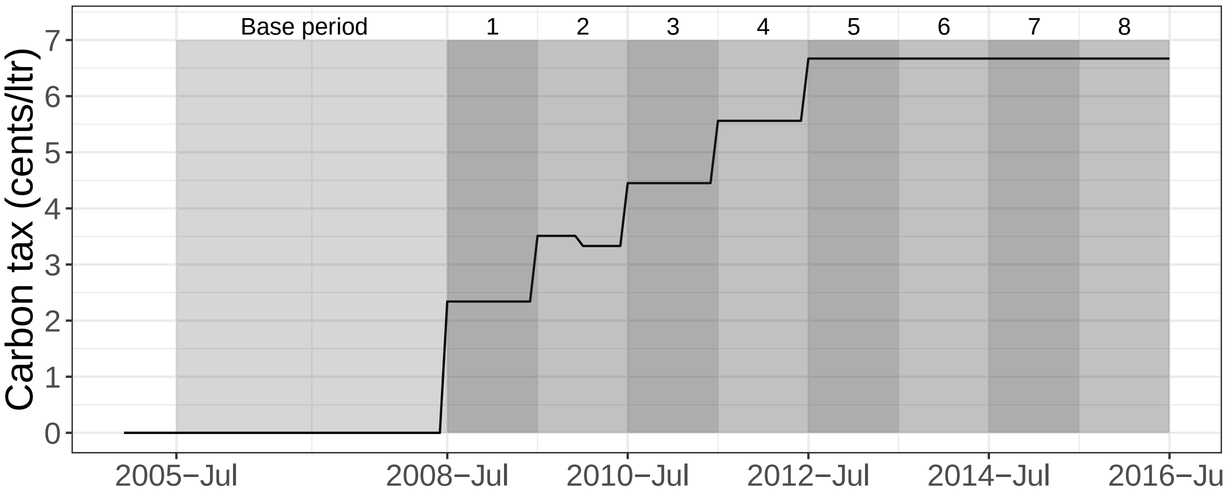
Table 3: NAICS control industires

Number	Name
442210	Floor covering stores
442291	Window treatment stores
442292	Print and picture frame stores
442298	All other home furnishings stores
444110	Home centres
444190	Other building material dealers
445110	Supermarkets and other grocery (except convenience) stores
445120	Convenience stores
445210	Meat markets
445220	Fish and seafood markets
445291	Baked goods stores
445299	All other specialty food stores
445310	Beer, wine and liquor stores
446199	All other health and personal care stores
448130	Children's and infants' clothing stores
448191	Fur stores
448210	Shoe stores
451120	Hobby, toy and game stores
451140	Musical instrument and supplies stores
452110	Department stores
452999	All other miscellaneous general merchandise stores
453110	Florists
453220	Gift, novelty and souvenir stores
453910	Pet and pet supplies stores
453920	Art dealers
453992	Beer and wine-making supplies stores
454210	Vending machine operators
454390	Other direct selling establishments

Table 4: Stations per 10,000 persons

	Obs.	Mean	Min	Max	St. dev.
British Columbia	156	5.218	1.566	12.870	2.068
Controls (matched)	480	5.075	1.659	13.106	2.225
Controls (unmatched)	1,356	5.126	0	15.961	2.405

Figure 3: Pre and post treatment periods



Another point to consider is the fact that Vancouver and Victoria had regional gasoline tax changes near/during the base period. As noted before, this slightly impacts the interpretation of the results. The parameter δ captures the average change in outcome y in BC but includes the effect of the additional tax change in Vancouver and Victoria. This means that δ will overestimate the impact of the BCCT alone. My reason for including these cities is to reduce bias in the estimated standard errors. However, I preform a robustness check where I exclude Vancouver and Victoria, and the estimated coefficients are very similar (results without Vancouver Victoria are shown in section D of the appendix). Moreover, the results with Vancouver and Victoria still illustrate the mechanism by which the increase in gasoline taxes drives some stations out of the market and leads to greater long-run passthrough.

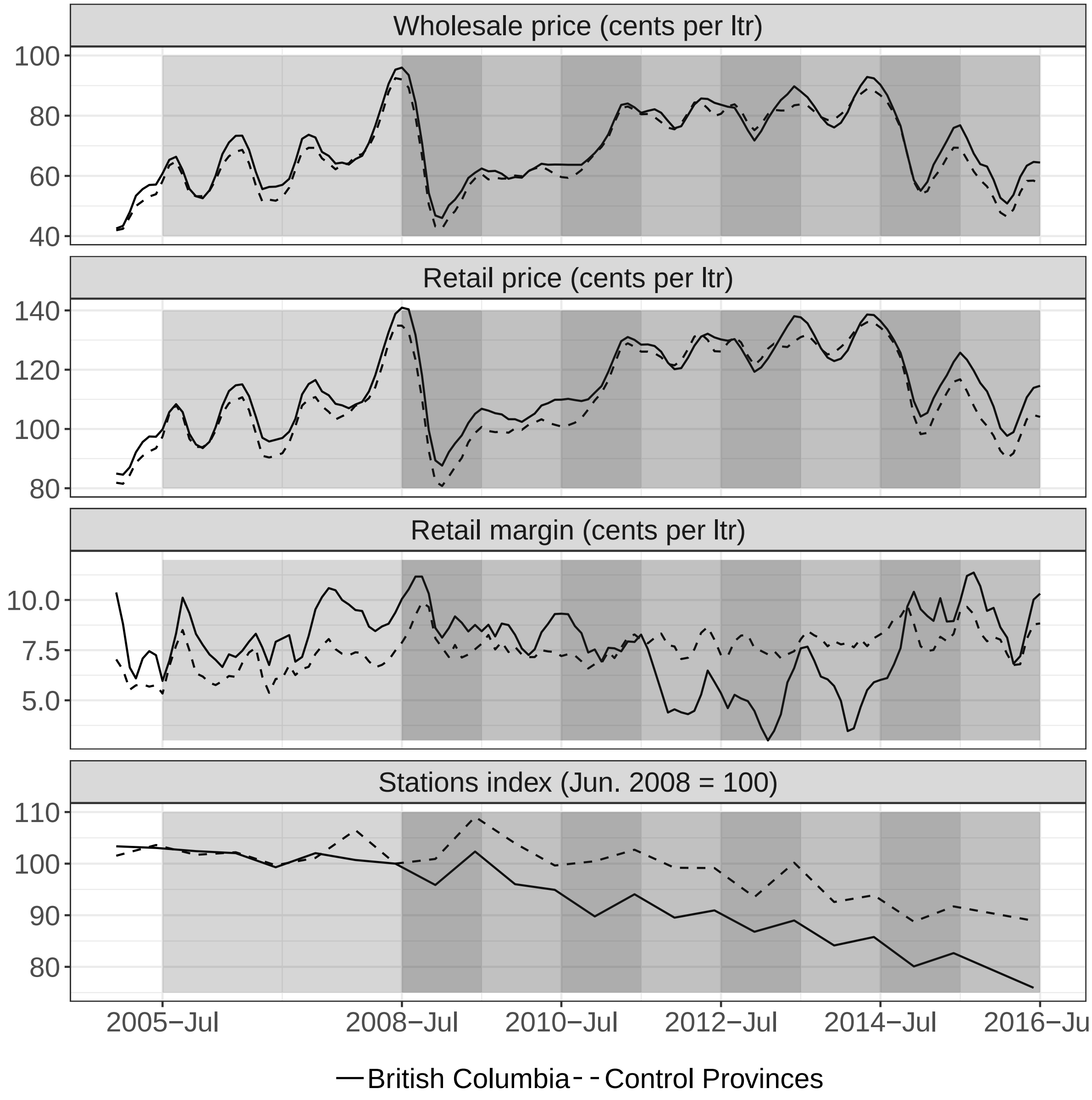
5.1 Identification

Following a potential outcomes framework, the average effect of the policy (the average treatment effect) on units in group G can be written as

$$ATE(G) = \sum_{g \in G} \left[\sum_{t \in \hat{T}} y^1_{gt} - \sum_{s \notin \hat{T}} y^0_{gs} \right] \tag{15}$$

where the superscript indicates whether or not the unit g received treatment in the treatment period (1 indicates treatment in $\hat{T}$, 0 indicates no treatment). Of course, we do not observe BC without the treatment in the post treatment period ($y^0_{gt} | t \in \hat{T}, g \in BC$) or the control group with the treatment in the treatment period ($y^1_{gt} | t \in \hat{T}, g \notin BC$); we cannot calculate

Figure 4: Outcome variable trends



Notes: Wholesale price, retail price and retail margins are shown in three month rolling mean due to volatility of the raw data. The number of stations are shown as indexes in order to compare values in BC with the Control provinces.

the quantity in (15). However, the parameter δ is an unbiased estimator of $ATE(BC)$ if, in addition to the standard OLS assumptions, a *parallel trends* assumption is also satisfied. Formally, this assumptions can be written as

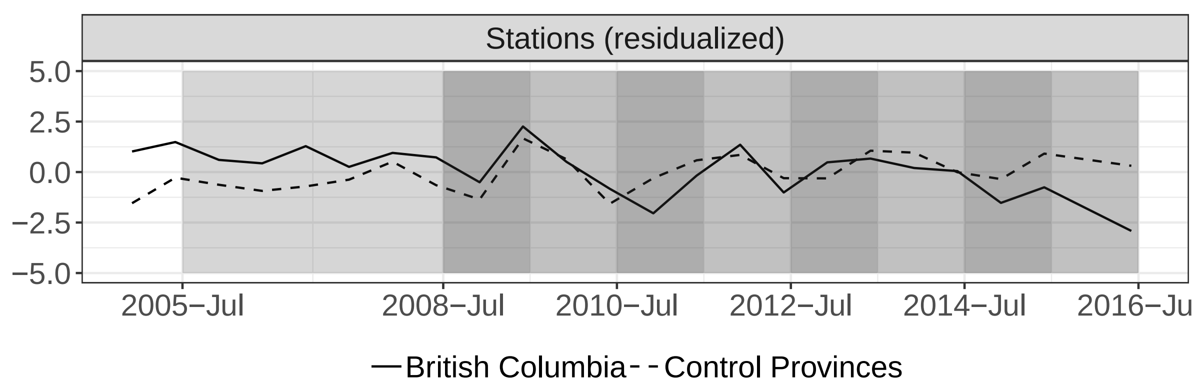
$$E(y^0_{gt} - y^0_{gt'} | t \in \hat{T}, t' \notin \hat{T}, g \in BC) = E(y^0_{g't} - y^0_{g't'} | t \in \hat{T}, t' \notin \hat{T}, g' \notin BC) \qquad (16)$$

The parallel trends assumptions states that in the absence of treatment, both the treatment group and the control group would have followed the same trend. One way to check that this assumption holds is to compare trends in the pre-treatment period.

Figure 4 shows time trends for the outcome variables over the sample period. The shaded areas are the pre-treatment (base) period, and the two post-treatment periods. Note that during the base period, the trends in BC are similar to the average over the control provinces. This suggests that the control provinces will act as a good counterfactual for the outcome in BC in lieu of the policy change.

Also, the retail margin drops by a large amount near the end of the of the treatment, and stays low for about two years before returning to pre BCCT levels. Furthermore, the number of stations decreases in BC relative to the control provinces and the difference between the two groups grows over time. This is consistent with higher cost causing lower short-run profits, but greater long-run revenue due to less competition. However, in figure 4, stations in BC start to fall before the retail margin hits its low point. One possibility is that this is due to changes in the control variables that are unrelated to the policy change; including the NAICS group controls will account for this issue. Including the controls means that the DiD coefficient is interpreted as the impact of the BCCT net of any changes due to the control variables. To visualize this effect, I plot the *residualized* number of stations in BC and averaged over the control provinces in figure 5. The residualized values are the predicted error terms from a regression of the number of stations on a date trend, census division fixed effects, and the NAICS group controls.[13] The change in the residualized values shows the change in the number of stations that is not attributed to changes in included controls.

Figure 5: Station count trends (residualized)



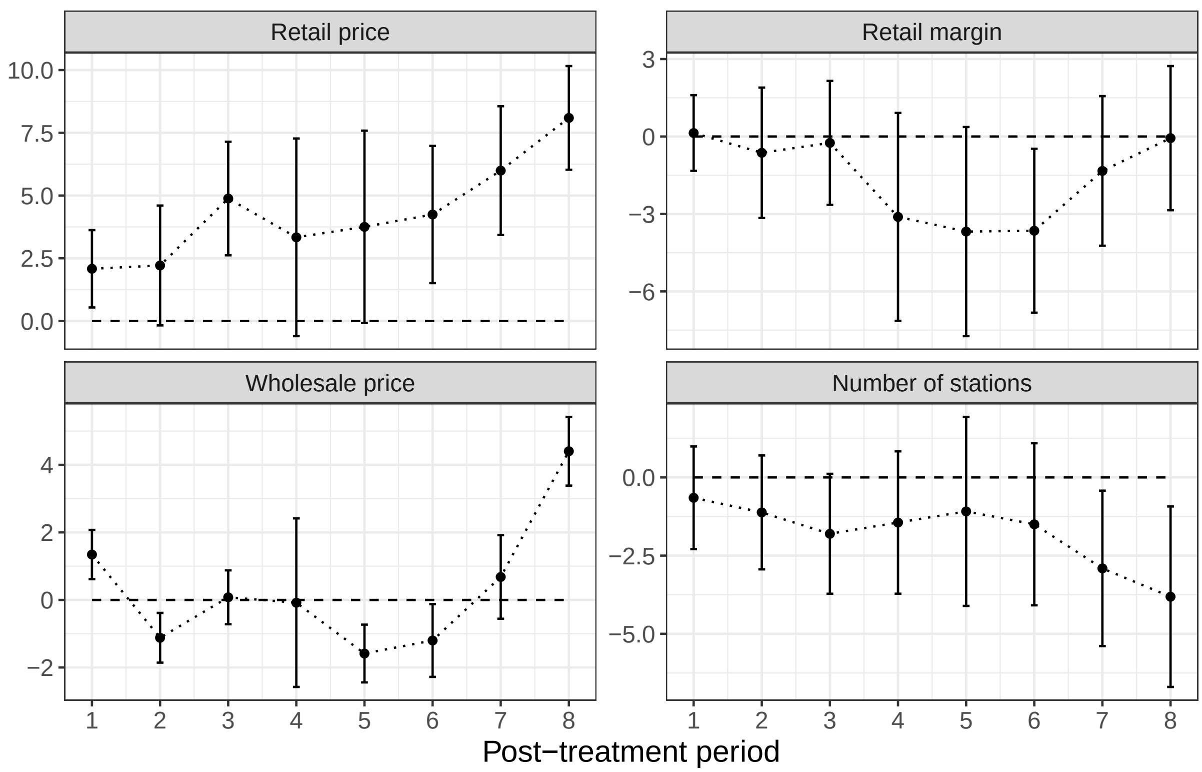
Notes: Residualized values for the number of stations in BC and averaged over the control provinces.

[13]The regression uses the full sample for control provinces but restricts BC observations to those before the BCCT was introduced.

6 Results

DiD estimates for the change in wholesale prices, retail prices, retail margins, and the number of stations are shown in tables 5, 6, 7, and 8 respectively; the column numbers correspond to the eight post-treatment periods. All regressions include both geographic unit and time period fixed effects. The NAICS group controls are not shown in the number of station regressions to save space, but are included in the appendix. All the DiD estimates are summarized in figure 6.

Figure 6: DiD estimates of δ



Notes: The error bounds are 95% confidence intervals with standard errors clustered by geographic unit.

There are a number of important points to note in 6. Firstly, the BCCT has a positive impact on the retail price and the magnitude is increasing over time. Moreover, the impact on the retail price continues to rise in post-treatment periods 6, 7, and 8 even though there was tax increase in these periods. Second, the retail margin begins to fall in period 4, and stays low until period 7 where it starts to return to the pre-BCCT level. Third, the BCCT has no significant impact on the number of stations in the short-run, but has a negative impact on the number of stations in periods 7 and 8. These results are consistent with the theoretical model from section 3.

Following the theory, it is expected that the retail price increases by less than the tax in the short-run, and retail margins fall. In the long-run, this causes stations to exit, which further increases retail price and raises margins above their short-run level. The low point for the retail margin is in periods 5 and 6 where the DiD estimates are 3.68¢/ltr and 3.65¢/ltr respectively. This is almost a 50% decrease in the retail margin, which averaged 8.32¢/ltr during the pre-treatment period in BC. Then, following the low point of the retail margin, the BCCT starts to have a significant effect on the number of stations. In periods 7 and 8, when the retail margin returns to pre-BCCT levels, the DiD estimates for the decrease in stations are 2.91 and 3.81. Respectively, these represent a 5.85% and 7.66% decrease in the number of stations in BC relative to the base period. Moreover, in period 8, the DiD estimate for the long-run increase in the retail price in BC is 8.09¢/ltr, which is larger than the tax of 6.67¢/ltr. The p-value for the one tail test that the retail price in period 8 is larger than the BCCT is 0.09 , suggesting that long-run passthrough is even larger than the tax.

While the empirical estimates do not show an immediate decrease in the retail margin, they do show that it starts to fall as the BCCT reaches its highest level, and it goes back up as stations exit the market. Moreover, the timing of the exit and the increase in margins is consistent with the story that lower profits due to incomplete passthrough caused stations to exit. These results suggests that the market-structure effect contributed significantly to the long-run price increase.

Table 5: Difference-in-Difference estimates for wholesale price

	Dependent variable:							
	Wholesale price (¢/ltr)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	1.344***	−1.120***	0.079	−0.081	−1.586***	−1.201**	0.680	4.403***
	(0.372)	(0.376)	(0.407)	(1.273)	(0.436)	(0.550)	(0.631)	(0.519)
log(building permits)	0.671**	0.730***	0.721***	0.500**	0.412	−0.146	0.378	1.224***
	(0.243)	(0.257)	(0.272)	(0.245)	(0.260)	(0.378)	(0.280)	(0.470)
Retail wage	0.571***	0.242	0.305	0.017	0.422	0.018	−0.313	0.526*
	(0.272)	(0.319)	(0.196)	(0.462)	(0.467)	(0.216)	(0.428)	(0.298)
Unemployment rate	−0.135	−0.037	−0.079	−0.009	0.343	0.141	−0.134	−0.362**
	(0.140)	(0.238)	(0.207)	(0.342)	(0.313)	(0.311)	(0.298)	(0.176)
Constant	48.695***	54.417***	53.567***	58.467***	48.747***	57.172***	65.672***	50.923***
	(5.655)	(6.961)	(4.432)	(9.976)	(9.970)	(4.018)	(9.340)	(6.296)
Observations	742	742	742	741	742	741	742	741
R^2	0.985	0.969	0.974	0.973	0.965	0.977	0.974	0.962

Notes: Standard errors are clustered at the city level. All regressions include a full set of city and time period dummies. The average wholesle price in BC during the base period is 66.35. *p<0.1; **p<0.05; ***p<0.01.

Table 6: Difference-in-Difference estimates for retail price

	Dependent variable:							
	Retail price (¢/ltr)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	2.081***	2.213*	4.881***	3.335*	3.752*	4.244***	5.993***	8.093***
	(0.786)	(1.218)	(1.155)	(2.009)	(1.956)	(1.395)	(1.309)	(1.054)
log(building permits)	0.172	0.144	0.332***	0.496**	0.177	0.383***	0.017	−0.219
	(0.138)	(0.091)	(0.121)	(0.246)	(0.212)	(0.130)	(0.133)	(0.191)
Retail wage	0.560***	0.341*	0.453***	0.307	0.255*	0.144	−0.103	0.478***
	(0.165)	(0.176)	(0.121)	(0.225)	(0.151)	(0.181)	(0.224)	(0.152)
Unemployment rate	−0.052	−0.078	−0.052	−0.212	−0.333*	−0.181	−0.292**	−0.013
	(0.114)	(0.125)	(0.117)	(0.153)	(0.173)	(0.136)	(0.141)	(0.189)
Other taxes	1.772***	1.929***	1.223***	1.177***	1.213***	1.323***	1.233***	1.449***
	(0.184)	(0.285)	(0.096)	(0.102)	(0.107)	(0.084)	(0.101)	(0.141)
Wholesale price	1.003	0.985***	0.964***	0.947***	0.929***	0.947***	0.981***	0.969***
	(0.031)	(0.032)	(0.034)	(0.040)	(0.039)	(0.041)	(0.028)	(0.031)
Constant	−25.009***	−23.519***	−6.612**	−0.915	0.551	−1.194	4.472	−13.339***
	(4.433)	(7.417)	(3.359)	(5.298)	(4.227)	(4.534)	(5.209)	(4.474)
Observations	1,134	1,134	1,134	1,130	1,134	1,132	1,134	1,136
R^2	0.991	0.982	0.985	0.985	0.985	0.990	0.984	0.979

Notes: Standard errors are clustered at the city level. All regressions include a full set of city and time period dummies. The average retail price in BC during the base period is 108.47. *p<0.1; **p<0.05; ***p<0.01.

Table 7: Difference-in-Difference estimates for retail margin

	Dependent variable:							
	Retail margin (¢/ltr)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	0.135	−0.631	−0.247	−3.114	−3.683*	−3.650**	−1.333	−0.064
	(0.748)	(1.288)	(1.225)	(2.054)	(2.066)	(1.620)	(1.478)	(1.424)
log(building permits)	0.167	0.178*	0.330***	0.460**	0.165	0.361**	−0.004	−0.171
	(0.151)	(0.104)	(0.123)	(0.220)	(0.197)	(0.163)	(0.159)	(0.201)
Retail wage	0.692***	0.391**	0.576***	0.410*	0.254*	−0.049	−0.036	0.287*
	(0.210)	(0.168)	(0.137)	(0.222)	(0.140)	(0.192)	(0.249)	(0.162)
Unemployment rate	−0.050	−0.025	−0.048	−0.175	−0.279	−0.144	−0.299	−0.061
	(0.122)	(0.132)	(0.126)	(0.134)	(0.200)	(0.169)	(0.188)	(0.220)
Constant	−8.398*	−2.653	−5.949**	−2.167	1.184	7.057*	7.557	0.078
	(4.452)	(3.389)	(2.962)	(4.407)	(3.136)	(3.750)	(5.196)	(3.803)
Observations	1,086	1,086	1,086	1,082	1,086	1,084	1,087	1,094
R^2	0.718	0.683	0.675	0.659	0.665	0.664	0.663	0.650

Notes: Standard errors are clustered at the city level. All regressions include a full set of city and time period dummies. The average retail margin in BC during the base period is 8.32. *p<0.1; **p<0.05; ***p<0.01..

Table 8: Difference-in-Difference estimates for number of stations

	Dependent variable:							
	Stations							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	−0.651	−1.118	−1.802*	−1.442	−1.086	−1.498	−2.908**	−3.814***
	(0.837)	(0.929)	(0.978)	(1.161)	(1.542)	(1.322)	(1.267)	(1.472)
Constant	7.606***	8.201***	8.135***	6.838***	5.206***	5.867***	5.713***	5.552***
	(1.053)	(1.092)	(1.034)	(0.925)	(0.974)	(1.104)	(1.087)	(1.130)
NAICS group Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	848	848	848	848	848	848	848	742
R^2	0.998	0.998	0.998	0.998	0.997	0.997	0.997	0.997

Notes: Standard errors are clustered at the census division level. All regressions include a full set of census division and time period dummies. The average number of stations in a BC census division during the base period is 49.76. *p<0.1; **p<0.05; ***p<0.01.

7 Conclusion

In this paper I use a policy change in British Columbia to study the difference between short-run and long-run impacts of a carbon tax on retail gasoline markets. I show that the tax has both a direct effect (in the short-run) and market-structure effect (in the long-run). The direct effect increases the marginal cost of wholesale gasoline, which, in turn, raises the retail price. The market-structure effect reduces the number of stations due to lower short-run profits. This increases market power leading to a secondary price increase, but may also increase average productivity of surviving firms, which dampens the secondary price increase. The short-run impact on price is the direct effect while the long-run impact is the sum of both the direct and the market-structure effects.

In British Columbia's case, incomplete passthrough of the BCCT in the short-run lead to a higher retail price, but a lower margin. However, in the long-run the BCCT lead to a 7.66% decrease in the number of stations and a 8.09¢/ltr increase in the retail price in BC. At a 0.1 significance level, the long-run price increase is significantly larger than the tax of 6.67¢/ltr. These results suggest that the market-structure effect was an important factor for the impact of the BCCT on retail gasoline markets.

This research focuses on tax-induced changes in market power and suggests that carbon taxes on imperfectly competitive industries should be lower than in competitive industries. An optimally chosen carbon tax should be set so that, in long-run equilibrium, the consumer price is equal to the sum of the tax-inclusive cost of production and the social cost of carbon. It follows that, holding other factors fixed, a carbon tax that varies across markets and is decreasing in the level of market power, will be more efficient than a flat tax.

Of course, the goal of carbon pricing is to achieve a sustainable level of atmospheric greenhouse gases, and taxes need to be large enough to achieve this goal. Furthermore, the role of market power is not the only factor to consider. For example, improvements in pollution abatement or production technology are likely to be expedited in the face of more stringent carbon pricing or regulation.

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Appendix

A Differentiated product price competition

This section describes a retail gasoline market with stations setting prices rather than quantities. The model below draws from Weyl and Fabinger (2013) and Miller et al. (2017). Weyl and Fabinger (2013) present a theoretical analysis of tax incidence in a model of imperfect competition, and Miller et al. (2017) provide a detailed examination of passthrough using the Weyl and Fabinger (2013) framework.

Consider a market with n retail stations each with profit

$$\pi_i(\mathbf{p}) = q_i(\mathbf{p})p_i - c_i q_i(\mathbf{p}) - F_i \tag{A1}$$

p_i is the price set by firm i, $\mathbf{p}$ is the vector of prices for all firms c_i is i's marginal cost and F_i is i's fixed cost. Firm i's profit maximizing condition can be written as follows.

$$f_i(\mathbf{p}) \equiv p_i + \left(\frac{\partial q_i(\mathbf{p})}{\partial p_i}\right)^{-1} q_i(\mathbf{p}) - c_i = 0 \tag{A2}$$

If firms are faced with a per unit tax τ then their profit maximizing condition becomes

$$f_i(\mathbf{p}) - \tau = 0 \tag{A3}$$

Note that (A3) implicitly defines firm i's best response price as a function of its marginal cost, the tax, and the prices of other firms. Let $\mathbf{t}$ be a vector of length n with each element equal to τ and $\mathbf{f}(\mathbf{p}) = [f_1(\mathbf{p}), ..., f_n(\mathbf{p})]'$, then the market equilibrium with a tax can be written as

$$\mathbf{f}(\mathbf{p}) - \mathbf{t} = 0 \tag{A4}$$

Implicitly differentiating (A4) gives

$$\rho \equiv \frac{\partial \mathbf{p}}{\partial \mathbf{t}'} = \left(\frac{\partial \mathbf{f}(\mathbf{p})}{\partial \mathbf{p}'}\right)^{-1} = \begin{bmatrix} \rho_{11} & \cdots & \rho_{1n} \\ \vdots & & \vdots \\ \rho_{n1} & \cdots & \rho_{nn} \end{bmatrix} \tag{A5}$$

where ρ_{ij} is the effect on firm i's price of a change in tax to firm j. Note that ρ is a function of all firms prices' and costs. The total effect of a tax on firm i's equilibrium price is $\rho_i = \sum_{j=1}^{n} \rho_{ij}$.

Let $\mathbf{p}^*$ be the solution to (A4). The marginal effect of the tax on firm i's profits in equilibrium is

$$\frac{d\pi_i^*}{d\tau} = -q_i(\mathbf{p}^*)\left(\frac{\partial q_i(\mathbf{p}^*)}{\partial p_i^*}\right)^{-1}\sum_{j\neq i}\frac{\partial q_i(\mathbf{p}^*)}{\partial p_j^*}\rho_j - q_i(\mathbf{p}^*) \tag{A6}$$

Using the first order condition (A4), this can be rewritten as

$$\frac{d\pi_i^*}{d\tau} = -q_i(\mathbf{p}^*)\left(\frac{\partial q_i(\mathbf{p}^*)}{\partial p_i^*}\right)^{-1}\sum_{j\neq i}\frac{\partial q_i(\mathbf{p}^*)}{\partial p_j^*}\rho_j - q_i(\mathbf{p}^*)$$

so firm i's profit is decreasing in τ if

$$\sum_{j\neq i}\frac{\partial q_i(\mathbf{p}^*)}{\partial p_j^*}\rho_j < -\frac{\partial q_i(\mathbf{p}^*)}{\partial p_i^*} \tag{A7}$$

(A7) states that the impact of a tax increase via changes in rival firms' prices must be smaller in magnitude than the responsiveness of a firms demand to a change in its own price only.

B Two stages of production

This model follows the setups in Salinger (1988), Gaudet and Long (1996), and Neumann et al. (2005), but focuses on how changes in the tax, or the number of firms, impact prices. Consider a market with N^I integrated firms, N^R retail-only firms, and N^W wholesale-only firms. Let i denote an integrated firm, j a retail-only firm, and k a wholesale-only firm. Let q_i^I, and q_j^R be quantities in the retail market for the i^{th} integrated firm, and the j^{th} retail-only firm. Define x_i^I, and x_k^W as quantities in the wholesale market for the i^{th} integrated firm, and the k^{th} wholesale-only firm. Note that $x_i^I > 0$ represents sales of wholesale gasoline, and $x_i^I < 0$ represents purchases. Profit for the i^{th} integrated firm is

$$\pi_i^I = (P^R - c - \tau)q_i^I + (P^W - c - \tau)x_i^I - F_i^I \qquad i = 1, ..., N^I, \tag{B1}$$

profit for the k^{th} wholesale-only firm is

$$\pi_k^W = (P^W - c - \tau)x_k^W - F_k^W \qquad k = 1, ..., N^W, \tag{B2}$$

and profit for the j^{th} retail-only firm is

$$\pi_j^R = (P^R - P^W)q_j^R - F_j^R \qquad j = 1, ..., N^R, \tag{B3}$$

where c is the marginal cost of refining crude oil into gasoline and transporting it to the retail market, and τ is the amount of carbon tax. Suppose that fixed costs (F_i^I, F_k^W, F_j^R) are independent draws from type specific distributions. Denote these distributions as $(\mathcal{F}^I, \mathcal{F}^W, \mathcal{F}^R)$, then $F_i^I \sim \mathcal{F}^I, F_k^W \sim \mathcal{F}^W$ and, $F_j^R \sim \mathcal{F}^R$. The demand function in the retail market is

$$P^R = P^R(Q) = A - BQ \tag{B4}$$

with $Q = \left(\sum_i q_i^I + \sum_j q_j^R\right)$. P^W is the market price for wholesale gasoline.

In the first stage, integrated and wholesale-only firms respectively choose x_i^I and x_k^W. Then in the second stage integrated and retail-only firms respectively choose q_i^I, and q_j^R. Given the sequential nature of the game, it must be solved by backward induction. In stage 2, integrated firms and retail-only firms choose quantities q_i^I, and q_j^R conditional on P^W, c, τ, N^I, N^R and the retail market demand. Since the only heterogeneity within a firm type is in their fixed costs, each firm will select the same quantity as others of the same type. The equilibrium quantities are:

$$q_i^{I,*} = \frac{A - (N^R + 1)(c + \tau) + N^R P^W}{(N^I + N^R + 1)B} \tag{B5}$$

$$q_j^{R,*} = \frac{A - (N^I + 1)P^W + N^I(c + \tau)}{(N^I + N^R + 1)B} \tag{B6}$$

This is the standard Cournot outcome when N^I firms have marginal cost $(c + \tau)$, N^R firms have marginal cost P^W, and demand is given by (B4).

A retail-only firm's optimal choice of q_j^R can also be thought of as a demand function for wholesale gasoline given the price P^W. Since all retail-only firms are identical except for their fixed cost, we can aggregate (B6) into an aggregate demand for wholesale gasoline. By letting $X = \sum_{i=1}^{N^I} x_i^I + \sum_{k=1}^{N^W} x_k^W$ denote the net supply of wholesale gasoline available to retail-only firms, and imposing market clearing, the inverse demand function for wholesale gasoline can be written as

$$P^W = \frac{A + N^I(c + \tau)}{N^I + 1} - \frac{N^I + N^R + 1}{N^I + 1}\frac{B}{N^R}X \tag{B7}$$

In stage 1, integrated and wholesale-only firms account for the retail market outcomes when they set their quantities for wholesale gasoline. Plugging, (B5), (B6), and (B7) into the integrated and wholesale-only profit functions gives:

$$\begin{aligned}\pi_i^I &= \left(\frac{1}{N^I+1}\right)^2 B\left(\frac{A-(c+\tau)}{B} - X\right)^2 \\ &\quad + \left(\frac{A-(c+\tau)}{N^I+1} - \frac{N^I+N^R+1}{N^I+1}\frac{B}{N^R}X\right)x_i^I - F_i^I \qquad \text{(B8)}\\ \pi_k^W &= \left(\frac{A-(c+\tau)}{N^I+1} - \frac{N^I+N^R+1}{N^I+1}\frac{B}{N^R}X\right)x_k^W - F_k^W \qquad \text{(B9)}\end{aligned}$$

The integrated and wholesale-only firms choose x_i^I, and x_k^W to respectively maximize (B8), and (B9). Equilibrium quantities solve the first order conditions

$$x_i^I = \frac{N^R(N^I-1)\frac{A-c}{B} - \left[(N^I+1)(N^I+N^R+1) - 2N^R\right]N^W x_k^W}{(N^I+1)^2(N^I+N^R+1) - 2N^R N^I} \qquad \text{(B10)}$$

$$x_k^W = \frac{N^R\frac{A-c}{B} - N^I(N^I+N^R+1)x_i^I}{(N^I+N^R+1)(N^W+1)}. \qquad \text{(B11)}$$

The resulting equilibrium quantities are

$$x_i^{I,*} = \alpha\frac{A-(c+\tau)}{B} \qquad \text{(B12)}$$

$$x_k^{W,*} = \beta\frac{A-(c+\tau)}{B} \qquad \text{(B13)}$$

where

$$\alpha = \left(\frac{N^R}{N^I+N^R+1}\right)\left[\frac{(N^I+N^R+1)(N^I-1) - 2(N^I+1)N^W}{(N^I+N^R+1)(N^I+1)(N^I+N^W+1) - 2N^I N^R}\right]$$

$$\beta = \frac{1}{N^W+1}\left[\frac{N^R}{N^I+N^R+1} - N^I\alpha\right].$$

$[A-(c+\tau)]/B$ is the perfectly competitive output; it is the amount that would be sold on the retail market when both the wholesale and retail markets are perfectly competitive. So, α and β are shares of the competitive output that integrated and wholesale-only firms provide to the wholesale market. For wholesale-only firms, this is always positive. But, integrated firms can either purchase or sell wholesale gasoline. By decreasing x_i^I, integrated firms can increase the wholesale price, which is the marginal cost of their retail-only competitors. In equilibrium, integrated firms' choice of x_i^I balances a trade off between their market share in the retail market on the one hand, and both their wholesale profit and retail marginal cost on the other hand. If the potential gain in market share is large enough, then they may even purchase some gasoline on the wholesale market. The condition for integrated firms to be purchasers of wholesale gasoline is $\alpha < 0$, which can be written as

$$(N^I+N^R+1)(N^I-1) - 2(N^I+1)N^W < 0. \qquad \text{(B14)}$$

When (B14) is satisfied, an integrated firm will produce some gasoline for itself and will purchase the remainder from wholesale only firms. Note from (B14) that for a given number of integrated firms, they are more likely to purchase wholesale gasoline if N^W is large or if N^R is small[14]

The aggregate equilibrium quantities can be written as

$$X = \lambda \frac{A-(c+\tau)}{B} \tag{B15}$$

$$Q = \frac{N^I+\lambda}{N^I+1}\frac{A-(c+\tau)}{B}, \tag{B16}$$

where $\lambda = N^I\alpha + N^W\beta$ is the share of the perfectly competitive downstream output that retail-only firms purchase in the wholesale market.

The equilibrium prices are

$$P^W = \left(\frac{1-\frac{N^I+N^R+1}{N^R}\lambda}{N^I+1}\right)A + \left(\frac{N^I+\frac{N^I+N^R+1}{N^R}\lambda}{N^I+1}\right)(c+\tau) \tag{B17}$$

$$P^R = \left(\frac{1-\lambda}{N^I+1}\right)A + \left(\frac{N^I+\lambda}{N^I+1}\right)(c+\tau). \tag{B18}$$

It is easy to verify that when $N^I = 0$, the wholesale price is $P^W = \frac{1}{N^W+1}A + \frac{N^W}{N^W+1}c$, which is independent of N^R. In other words, without the presence of integrated firms, changes in retail market power would not affect the wholesale price.

The margin for a retail-only firm is

$$M^R = P^R - P^W, \tag{B19}$$

and the retail margin for an integrated firm is

$$M_I^R = P^R - (c+\tau). \tag{B20}$$

The outcomes in (B17)-(B20) are the key outcomes of interest. In the remainder of this section I describe how these outcomes change in the short- and long-run following a tax increase.

B.1 Impact of a tax on market outcomes

The direct effect of the tax is to increase the marginal cost of producing gasoline, so the short-run impact of the tax is determined by the derivatives of prices and margins with

[14]The left hand side of (B14) is decreasing in N^W and increasing in N^R.

respect to τ. The change in the wholesale price is

$$\frac{\partial P^W}{\partial \tau} = \left(\frac{N^I + \frac{N^I + N^R + 1}{N^R} \lambda}{N^I + 1} \right). \tag{B21}$$

The change in the retail price is

$$\frac{\partial P^R}{\partial \tau} = \left(\frac{N^I + \lambda}{N^I + 1} \right). \tag{B22}$$

The change in the retail-only firms' margin is

$$\frac{\partial M^R}{\partial \tau} = -\frac{\lambda}{N^R}. \tag{B23}$$

The change in the integrated firms' retail margin is

$$\frac{\partial M_I^R}{\partial \tau} = -\left(\frac{1 - \lambda}{N^I + 1} \right). \tag{B24}$$

$\lambda \in (0, 1)$ implies that the wholesale price, P^W, and the retail price, P^R, are increasing in τ, while the retail-only firms' margin, M^R, and the retail margin for integrated firms, M_I^R, are decreasing in τ.

The market structure effect depends of the decision to exit when the tax is increased. Let $\bar{F}^R$ denote the break-even fixed cost for a retail-only firm.

$$\bar{F}^R = F_j^R : \pi_j^R = (P^R - P^W) q_j^R - F_j^R = 0. \tag{B25}$$

A retail-only firm makes a positive profit if its fixed cost is less than $\bar{F}^R$, and it makes a negative profit if its fixed cost is greater than $\bar{F}^R$. If $F_j^R > \bar{F}^R$, then firm j would exit in the long-run.[15] Also, suppose that an integrated firm's fixed cost is $F^I = F^R + F^W$ and let $\bar{F}_I^R$ denote the break-even fixed cost for an integrated firm's retail outlet.

$$\bar{F}_I^R = F_i^R : \pi_i^R = (P^R - c - \tau) q_i^R - F_i^R = 0. \tag{B26}$$

If a firm's fixed cost in the retail market is greater than $\bar{F}_I^R$, then the station would exit in the long-run. Since profits are decreasing in τ, $\bar{F}$ decreases when τ increases. Therefore, a higher tax will mean that the break-even fixed cost will decrease. In turn, stations with high fixed cost may exit the market. To see the changes in market outcomes associated with retail outlets closing, I define the following functions.

$$\Delta^R(\theta) \equiv \theta(N^I, N^R + 1, N^W) - \theta(N^I, N^R, N^W) \tag{B27}$$

$$\Delta_I^R(\theta) \equiv \theta(N^I, N^R + 1, N^W - 1) - \theta(N^I, N^R, N^W). \tag{B28}$$

[15] The firm will continue producing in the short-run as long as $(P^R - P^W) q_j^R > 0$.

$\Delta^R(\theta)$ gives the impact on the variable θ when a retail-only station enters, and $\Delta_I^R(\theta)$ is the impact when a wholesale-only firm opens a retail station (becomes integrated). Alternatively, $-\Delta^R(\theta)$ is the effect of a retail-only station exiting, and $-\Delta_I^R(\theta)$ is the effect of an integrated firm closing their retail site only.

Analytic solutions for the signs of $\Delta^R(\cdot)$, and $\Delta_I^R(\cdot)$ are difficult to interpret so I present numerical results in section B.2 of the appendix. I evaluate the model for each point in the parameter space $\chi = \{(N^R, N^W, N^I) : N^R \in \{1, ..., 20\}, N^W \in \{0, ..., 20\}, N^I \in \{0, ..., 20\}\}$ with $c = 0$.[16] The numerical results shows that: (i) The wholesale price increases when retail sites close, $\Delta^R(P^W) < 0$ and $\Delta_I^R(P^W) < 0$ (see figures B5 and B6)[17]; (ii) The retail price increases when retail sites close, $\Delta^R(P^R) < 0$ and $\Delta_I^R(P^R) < 0$ (see figures B7 and B8); (iii) The retail margin increases when retail sites close, $\Delta^R(M^R) < 0$, $\Delta_I^R(M^R) < 0$, $\Delta^R(M_I^R) < 0$ and $\Delta_I^R(M_I^R) < 0$ (see figures B9, B10, B11 and B12). This is the market structure effect.

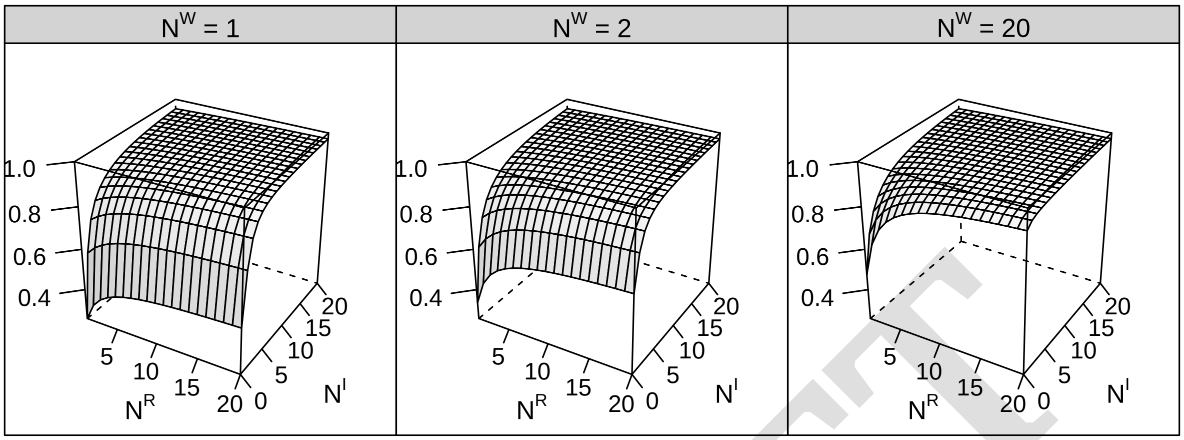
To summarize, the model predicts that in the short-run the impact of the tax is to raise prices in both wholesale and retail markets, and decrease retail margins; this is the direct effect of the tax change. However, in the long-run, the market structure effect will arise if the decrease in margins results in exit of stations from the retail market.

[16] I set $c = 0$ for simplicity, but the results are robust to $c > 0$.

[17] There are two exceptions to this result. The first is when $N^I = 0$. In this case, P^W does not change with N^R because the wholesale firms provide a quantity such that P^W is equal to the Cournot equilibrium with N^W firms in the downstream market. This allows their profit to approach the Cournot profit as the downstream market becomes more competitive; so $\Delta^R(P^W) = 0$ in this case. The second exception occurs when $(N^I, N^W) = (0, 1)$. In this case, when the wholesale firm integrates it will stop selling to retail-only firms and P^W becomes undefined, so $\Delta_I^R(P^W)$ is not defined here.

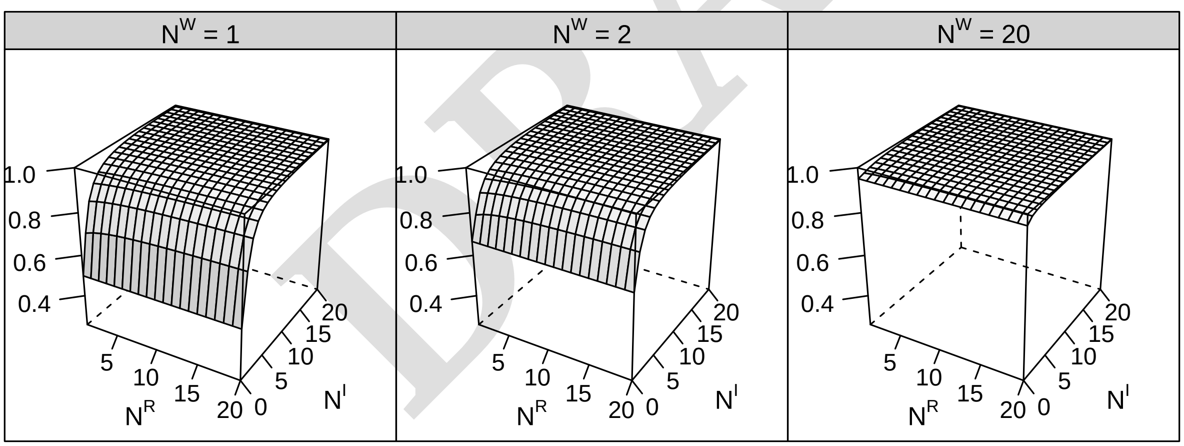
B.2 Numerical solutions to theoretical model

Figure B1: $\partial P^R/\partial\tau$



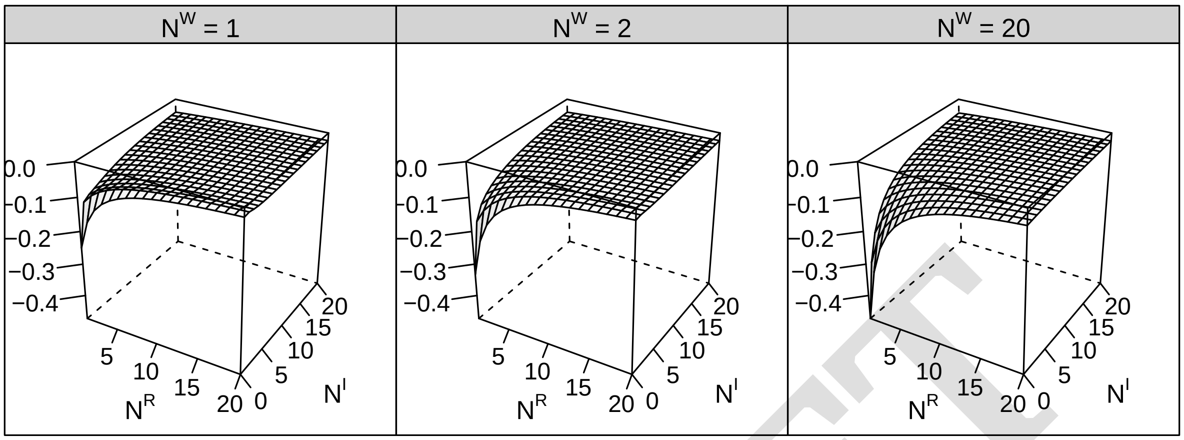
Notes: Showing the derivative of the retail price with respect to the tax.

Figure B2: $\partial P^W/\partial\tau$



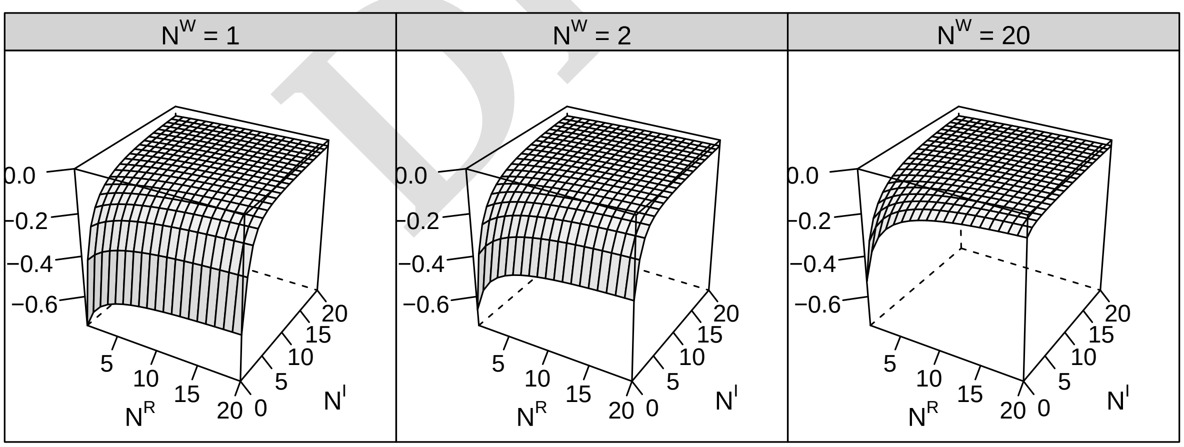
Notes: Showing the derivative of the wholesale price with respect to the tax.

Figure B3: $\partial M^R/\partial \tau$



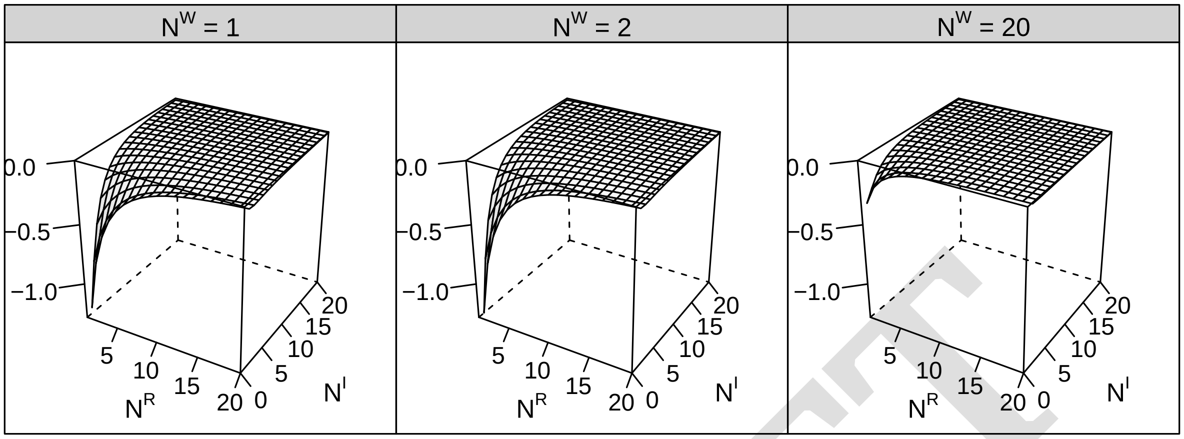
Notes: Showing the derivative of a retail-only firm's margin with respect to the tax.

Figure B4: $\partial M_I^R/\partial \tau$



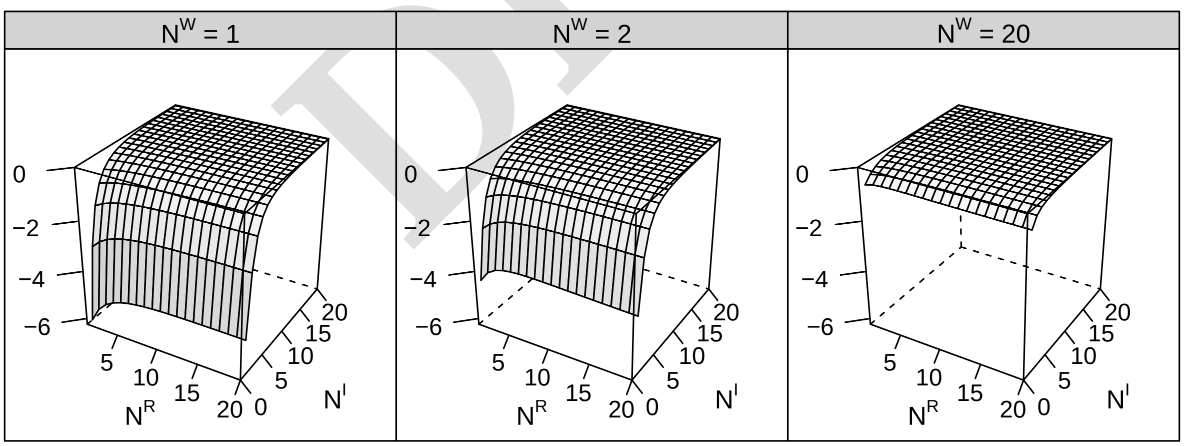
Notes: Showing the derivative of an integrated firm's margin in the retail market with respect to the tax.

Figure B5: $\Delta^R(P^W)$



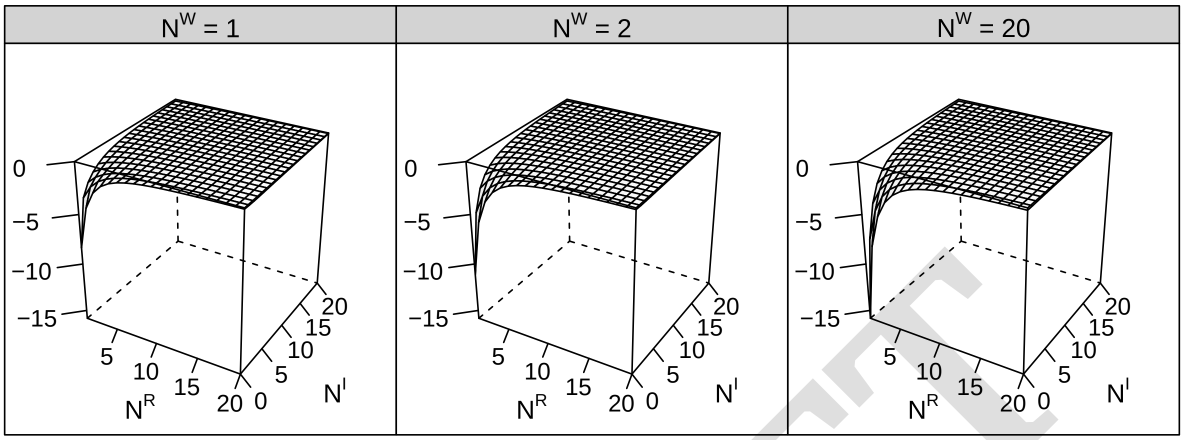
Notes: Showing the change in the wholesale price when a retail-only firm enters.

Figure B6: $\Delta_I^R(P^W)$



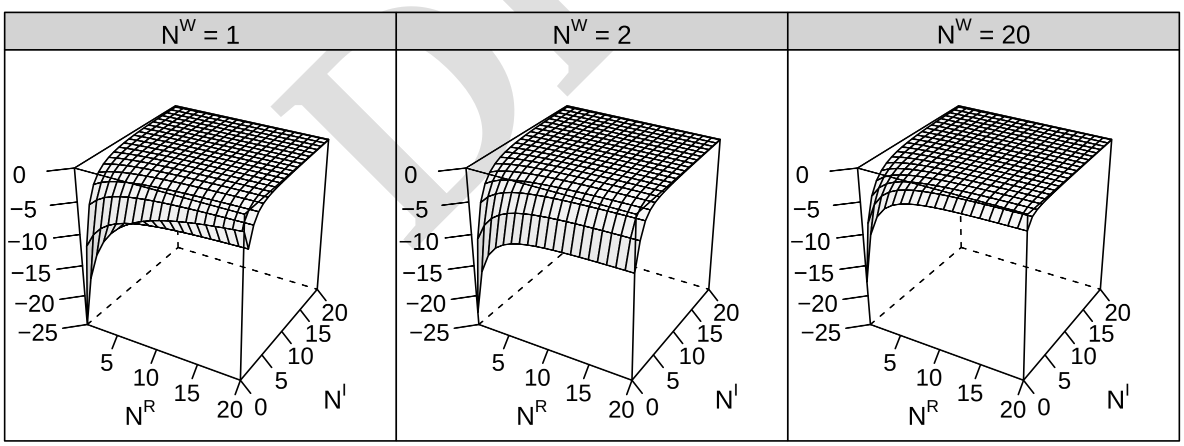
Notes: Showing the change in the wholesale price when a wholesale-only firm opens a retail site (becomes integrated).

Figure B7: $\Delta^R(P^R)$



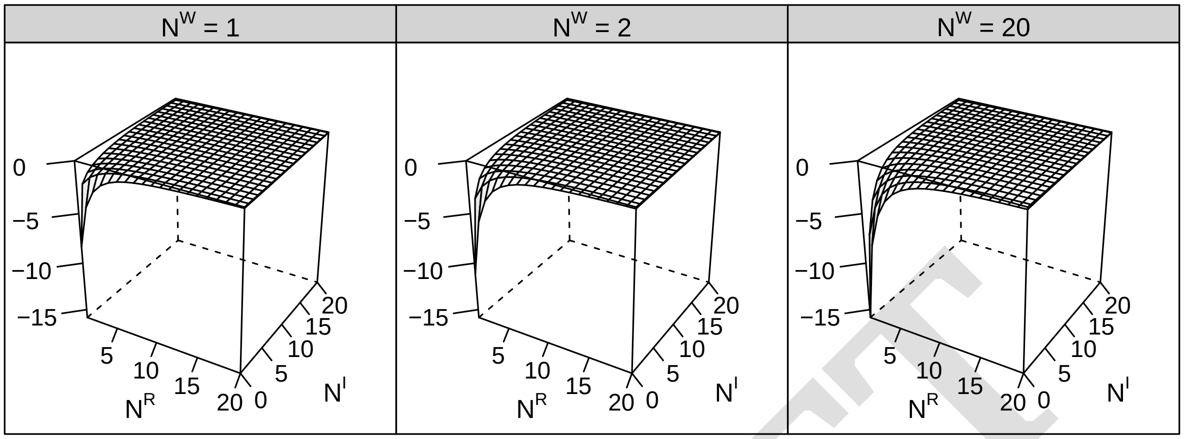
Notes: Showing the change in the retail price when a retail-only firm enters.

Figure B8: $\Delta_I^R(P^R)$



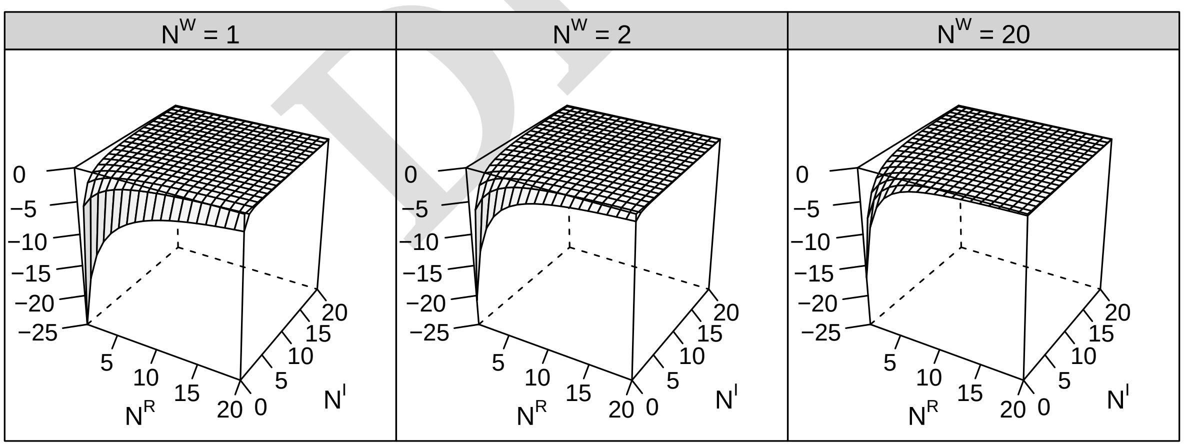
Notes: Showing the change in the retail price when a wholesale-only firm opens a retail site (becomes integrated).

Figure B9: $\Delta^R(M^R)$



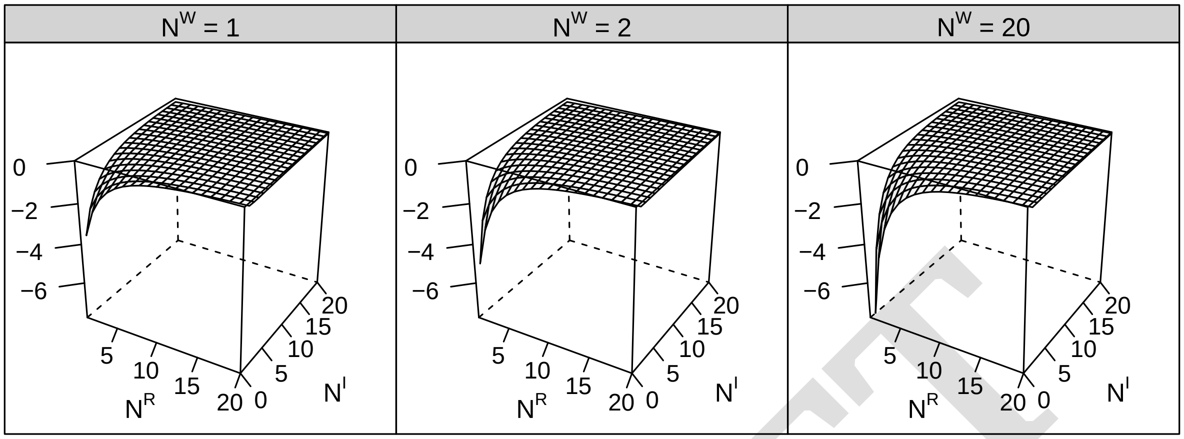
Notes: Showing the change in a retail-only firm's margin when another retail-only firm enters.

Figure B10: $\Delta^R_I(M^R)$



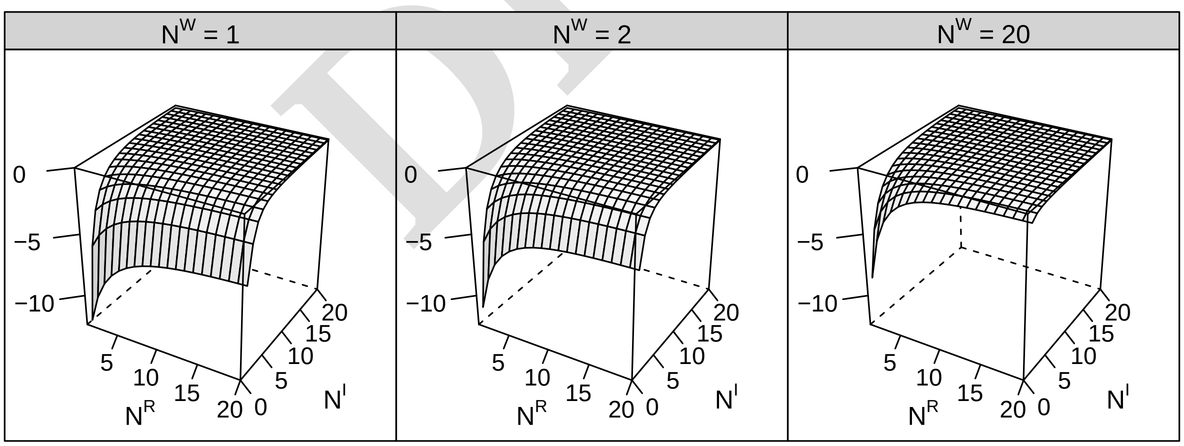
Notes: Showing the change in a retail-only firm's margin when a wholesale-only firm opens a retail site (becomes integrated).

Figure B11: $\Delta^R(M_I^R)$



Notes: Showing the change in an integrated firm's retail margin when a retail-only firm enters.

Figure B12: $\Delta_I^R(M_I^R)$



Notes: Showing the change in an integrated firm's retail margin when a wholesale-only firm opens a retail site (becomes integrated).

C Results without Alberta

Table C1: Difference-in-Difference estimates for number of stations

	Dependent variable:							
	Stations							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	−0.651	−1.118	−1.802*	−1.442	−1.086	−1.498	−2.442**	−3.557**
	(0.837)	(0.929)	(0.978)	(1.161)	(1.542)	(1.322)	(1.243)	(1.509)
Constant	7.606***	8.201***	8.135***	6.838***	5.206***	5.867***	5.451***	5.283***
	(1.053)	(1.092)	(1.034)	(0.925)	(0.974)	(1.104)	(1.056)	(1.284)
NAICS group Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	848	848	848	848	848	848	832	726
R^2	0.998	0.998	0.998	0.998	0.997	0.997	0.997	0.997

Notes: Standard errors are clustered at the census division level. All regressions include a full set of census division and time period dummies. The average number of stations in a BC census division during the base period is 49.76. *p<0.1; **p<0.05; ***p<0.01.

Table C2: Difference-in-Difference estimates for retail margin

	Dependent variable:							
	Retail margin (¢/ltr)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	0.135	−0.631	−0.247	−3.114	−3.683*	−3.650**	−1.367	0.277
	(0.748)	(1.288)	(1.225)	(2.054)	(2.066)	(1.620)	(1.486)	(1.455)
log(building permits)	0.167	0.178*	0.330***	0.460**	0.165	0.361**	0.002	−0.127
	(0.151)	(0.104)	(0.123)	(0.220)	(0.197)	(0.163)	(0.161)	(0.192)
Retail wage	0.692***	0.391**	0.576***	0.410*	0.254*	−0.049	0.103	0.237*
	(0.210)	(0.168)	(0.137)	(0.222)	(0.140)	(0.192)	(0.274)	(0.141)
Unemployment rate	−0.050	−0.025	−0.048	−0.175	−0.279	−0.144	−0.236	−0.240
	(0.122)	(0.132)	(0.126)	(0.134)	(0.200)	(0.169)	(0.192)	(0.245)
Constant	−8.398*	−2.653	−5.949**	−2.167	1.184	7.057*	4.459	1.201
	(4.452)	(3.389)	(2.962)	(4.407)	(3.136)	(3.750)	(5.735)	(3.336)
Observations	1,086	1,086	1,086	1,082	1,086	1,084	1,071	1,046
R^2	0.718	0.683	0.675	0.659	0.665	0.664	0.672	0.655

Notes: Standard errors are clustered at the city level. All regressions include a full set of city and time period dummies. The average retail margin in BC during the base period is 8.32. *p<0.1; **p<0.05; ***p<0.01..

Table C3: Difference-in-Difference estimates for wholesale price

	Dependent variable:							
	Wholesale price (¢/ltr)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	1.344***	−1.120***	0.079	−0.081	−1.586***	−1.201**	0.539	3.951***
	(0.372)	(0.376)	(0.407)	(1.273)	(0.436)	(0.550)	(0.582)	(0.463)
log(building permits)	0.671**	0.730***	0.721***	0.500**	0.412	−0.146	0.385	1.343***
	(0.243)	(0.257)	(0.272)	(0.245)	(0.260)	(0.378)	(0.271)	(0.406)
Retail wage	0.571***	0.242	0.305	0.017	0.422	0.018	−0.110	0.166
	(0.272)	(0.319)	(0.196)	(0.462)	(0.467)	(0.216)	(0.424)	(0.275)
Unemployment rate	−0.135	−0.037	−0.079	−0.009	0.343	0.141	0.056	−0.303
	(0.140)	(0.238)	(0.207)	(0.342)	(0.313)	(0.311)	(0.228)	(0.280)
Constant	48.695***	54.417***	53.567***	58.467***	48.747***	57.172***	60.874***	57.870***
	(5.655)	(6.961)	(4.432)	(9.976)	(9.970)	(4.018)	(9.020)	(6.238)
Observations	742	742	742	741	742	741	734	717
R^2	0.985	0.969	0.974	0.973	0.965	0.977	0.975	0.966

Notes: Standard errors are clustered at the city level. All regressions include a full set of city and time period dummies. The average wholesle price in BC during the base period is 66.35. *p<0.1; **p<0.05; ***p<0.01.

Table C4: Difference-in-Difference estimates for retail price

	Dependent variable:							
	Retail price (¢/ltr)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	2.081***	2.213*	4.881***	3.335*	3.752*	4.244***	5.949***	8.239***
	(0.786)	(1.218)	(1.155)	(2.009)	(1.956)	(1.395)	(1.322)	(1.132)
log(building permits)	0.172	0.144	0.332***	0.496**	0.177	0.383***	0.017	−0.169
	(0.138)	(0.091)	(0.121)	(0.246)	(0.212)	(0.130)	(0.135)	(0.177)
Retail wage	0.560***	0.341*	0.453***	0.307	0.255*	0.144	0.063	0.452***
	(0.165)	(0.176)	(0.121)	(0.225)	(0.151)	(0.181)	(0.254)	(0.144)
Unemployment rate	−0.052	−0.078	−0.052	−0.212	−0.333*	−0.181	−0.211	−0.102
	(0.114)	(0.125)	(0.117)	(0.153)	(0.173)	(0.136)	(0.146)	(0.202)
Other taxes	1.772***	1.929***	1.223***	1.177***	1.213***	1.323***	1.230***	1.429***
	(0.184)	(0.285)	(0.096)	(0.102)	(0.107)	(0.084)	(0.103)	(0.144)
Wholesale price	1.003	0.985***	0.964***	0.947***	0.929***	0.947***	0.949***	0.948***
	(0.031)	(0.032)	(0.034)	(0.040)	(0.039)	(0.041)	(0.028)	(0.032)
Constant	−25.009***	−23.519***	−6.612**	−0.915	0.551	−1.194	2.660	−11.272**
	(4.433)	(7.417)	(3.359)	(5.298)	(4.227)	(4.534)	(5.771)	(4.533)
Observations	1,134	1,134	1,134	1,130	1,134	1,132	1,114	1,076
R^2	0.991	0.982	0.985	0.985	0.985	0.990	0.985	0.979

Notes: Standard errors are clustered at the city level. All regressions include a full set of city and time period dummies. The average retail price in BC during the base period is 108.47. *p<0.1; **p<0.05; ***p<0.01.

D Results without Vancouver and Victoria

Table D1: Difference-in-Difference estimates for number of stations

	Dependent variable:							
	Stations							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	−0.390	−0.822	−1.558*	−1.084	−0.409	−0.942	−2.264*	−3.001**
	(0.768)	(0.886)	(0.932)	(1.100)	(1.465)	(1.287)	(1.264)	(1.381)
Constant	8.725***	9.164***	9.125***	7.763***	6.700***	7.643***	7.641***	8.465***
	(1.084)	(1.191)	(1.078)	(1.036)	(1.123)	(1.208)	(1.245)	(1.221)
NAICS group Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	832	832	832	832	832	832	832	728
R^2	0.997	0.997	0.997	0.997	0.996	0.996	0.996	0.997

Notes: Standard errors are clustered at the census division level. All regressions include a full set of census division and time period dummies. The average number of stations in a BC census division during the base period is 49.76. *p<0.1; **p<0.05; ***p<0.01.

Table D2: Difference-in-Difference estimates for retail margin

	Dependent variable:							
	Retail margin (¢/ltr)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	−0.758	−0.651	−1.183	−2.264***	−3.399**	−3.931***	−1.456***	−0.570
	(0.693)	(1.195)	(0.755)	(0.645)	(1.562)	(0.540)	(0.395)	(0.865)
log(building permits)	0.180	0.203**	0.277**	0.461***	0.096	0.296*	−0.091	−0.211
	(0.149)	(0.080)	(0.115)	(0.173)	(0.155)	(0.154)	(0.138)	(0.192)
Retail wage	0.682***	0.355**	0.594***	0.437**	0.140	−0.065	0.094	0.230
	(0.219)	(0.143)	(0.134)	(0.185)	(0.111)	(0.195)	(0.257)	(0.153)
Unemployment rate	−0.028	−0.025	−0.064	−0.195	−0.302	−0.138	−0.278	−0.021
	(0.116)	(0.135)	(0.128)	(0.135)	(0.202)	(0.173)	(0.194)	(0.221)
Constant	−8.096*	−1.704	−6.103**	−2.467	3.736	7.513**	4.960	1.209
	(4.630)	(2.917)	(2.950)	(3.777)	(2.612)	(3.778)	(5.313)	(3.676)
Observations	990	990	990	986	990	988	991	998
R^2	0.717	0.695	0.686	0.713	0.697	0.691	0.690	0.659

Notes: Standard errors are clustered at the city level. All regressions include a full set of city and time period dummies. The average retail margin in BC during the base period is 8.32. *p<0.1; **p<0.05; ***p<0.01..

Table D3: Difference-in-Difference estimates for wholesale price

	Dependent variable:							
	Wholesale price (¢/ltr)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	1.516***	−1.129***	0.017	−0.765	−1.512***	−1.246**	0.664	4.569***
	(0.373)	(0.392)	(0.447)	(1.601)	(0.499)	(0.605)	(0.789)	(0.601)
log(building permits)	0.556**	0.616***	0.579***	0.356**	0.337	−0.228	0.262	1.062**
	(0.211)	(0.223)	(0.196)	(0.167)	(0.287)	(0.372)	(0.237)	(0.464)
Retail wage	0.732***	0.393	0.351*	0.211	0.560	0.116	−0.089	0.632**
	(0.259)	(0.304)	(0.204)	(0.486)	(0.502)	(0.231)	(0.437)	(0.295)
Unemployment rate	−0.157	−0.045	−0.056	0.0002	0.370	0.171	−0.126	−0.394**
	(0.152)	(0.249)	(0.213)	(0.349)	(0.324)	(0.326)	(0.312)	(0.183)
Constant	45.259***	51.126***	52.233***	54.223***	45.638***	54.888***	60.838***	48.584***
	(5.242)	(6.546)	(4.518)	(10.248)	(10.602)	(4.038)	(9.306)	(6.101)
Observations	694	694	694	693	694	693	694	693
R^2	0.987	0.972	0.977	0.976	0.967	0.979	0.977	0.966

Notes: Standard errors are clustered at the city level. All regressions include a full set of city and time period dummies. The average wholesle price in BC during the base period is 66.35. *p<0.1; **p<0.05; ***p<0.01.

Table D4: Difference-in-Difference estimates for retail price

	Dependent variable:							
	Retail price (¢/ltr)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	1.348**	2.783**	4.075***	4.161***	4.043**	4.233***	5.997***	7.979***
	(0.656)	(1.133)	(0.853)	(0.879)	(1.588)	(0.601)	(0.383)	(0.879)
log(building permits)	0.204	0.184**	0.297**	0.507***	0.131	0.332***	−0.055	−0.219
	(0.134)	(0.077)	(0.119)	(0.196)	(0.177)	(0.128)	(0.132)	(0.199)
Retail wage	0.488***	0.290*	0.477***	0.342*	0.134	0.121	0.013	0.394***
	(0.165)	(0.163)	(0.118)	(0.192)	(0.133)	(0.178)	(0.233)	(0.128)
Unemployment rate	−0.027	−0.071	−0.072	−0.222	−0.327*	−0.164	−0.272*	0.012
	(0.107)	(0.125)	(0.118)	(0.153)	(0.186)	(0.144)	(0.152)	(0.194)
Other taxes	1.780***	1.995***	1.189***	1.123***	1.152***	1.282***	1.178***	1.393***
	(0.187)	(0.385)	(0.095)	(0.096)	(0.102)	(0.082)	(0.099)	(0.152)
Wholesale price	1.029	1.004***	0.972***	0.989***	0.937***	0.933***	0.961***	0.989***
	(0.034)	(0.036)	(0.040)	(0.029)	(0.045)	(0.051)	(0.035)	(0.036)
Constant	−25.165***	−24.993**	−6.494*	−2.599	4.054	1.143	4.612	−11.330***
	(4.571)	(9.838)	(3.485)	(3.314)	(3.433)	(4.229)	(5.604)	(3.995)
Observations	1,038	1,038	1,038	1,034	1,038	1,036	1,038	1,040
R^2	0.991	0.982	0.985	0.988	0.987	0.991	0.984	0.978

Notes: Standard errors are clustered at the city level. All regressions include a full set of city and time period dummies. The average retail price in BC during the base period is 108.47. *p<0.1; **p<0.05; ***p<0.01.

E Results with reduced pre-treatment period

Table E1: Difference-in-Difference estimates for number of stations

	Dependent variable:							
	Stations							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	−0.755	−1.261	−1.844*	−1.666	−1.147	−1.390	−2.806**	−3.901***
	(0.855)	(0.957)	(0.966)	(1.166)	(1.593)	(1.308)	(1.265)	(1.453)
Constant	6.281***	7.302***	7.697***	6.093***	4.784***	5.715***	5.621***	5.141***
	(1.161)	(1.339)	(1.065)	(0.951)	(1.015)	(1.032)	(1.110)	(1.244)
NAICS group Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	742	742	742	742	742	742	742	636
R^2	0.998	0.998	0.998	0.998	0.997	0.997	0.997	0.997

Notes: Standard errors are clustered at the census division level. All regressions include a full set of census division and time period dummies. The average number of stations in a BC census division during the base period is 49.76. *p<0.1; **p<0.05; ***p<0.01.

Table E2: Difference-in-Difference estimates for retail margin

	Dependent variable:							
	Retail margin (¢/ltr)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	0.140	−0.600	−0.174	−3.071	−3.629*	−3.570**	−1.298	−0.038
	(0.773)	(1.332)	(1.267)	(2.116)	(2.120)	(1.671)	(1.523)	(1.449)
log(building permits)	0.143	0.205*	0.364**	0.491*	0.160	0.401**	0.016	−0.173
	(0.174)	(0.116)	(0.155)	(0.260)	(0.226)	(0.194)	(0.187)	(0.236)
Retail wage	0.752***	0.418**	0.608***	0.499**	0.278*	−0.097	−0.063	0.253
	(0.226)	(0.168)	(0.134)	(0.220)	(0.147)	(0.197)	(0.250)	(0.169)
Unemployment rate	−0.096	−0.039	−0.084	−0.223	−0.336	−0.197	−0.388*	−0.130
	(0.147)	(0.139)	(0.137)	(0.152)	(0.226)	(0.200)	(0.211)	(0.250)
Constant	−9.423*	−3.117	−6.364**	−3.743	0.946	8.306**	8.596*	1.180
	(4.841)	(3.426)	(2.998)	(4.374)	(3.328)	(3.810)	(5.210)	(4.053)
Observations	942	942	942	938	942	940	943	950
R^2	0.709	0.674	0.668	0.653	0.664	0.661	0.661	0.647

Notes: Standard errors are clustered at the city level. All regressions include a full set of city and time period dummies. The average retail margin in BC during the base period is 8.32. *p<0.1; **p<0.05; ***p<0.01..

Table E3: Difference-in-Difference estimates for wholesale price

	Dependent variable:							
	Wholesale price (¢/ltr)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	1.120**	−1.354***	−0.132	−0.326	−1.781***	−1.459***	0.475	4.213***
	(0.444)	(0.396)	(0.416)	(1.174)	(0.438)	(0.518)	(0.563)	(0.484)
log(building permits)	0.684***	0.786***	0.746***	0.501*	0.442	−0.208	0.375	1.325**
	(0.243)	(0.267)	(0.272)	(0.265)	(0.320)	(0.398)	(0.304)	(0.529)
Retail wage	0.719***	0.316	0.371*	0.046	0.504	0.044	−0.305	0.610**
	(0.224)	(0.286)	(0.199)	(0.444)	(0.462)	(0.195)	(0.393)	(0.291)
Unemployment rate	−0.119	−0.004	−0.047	0.010	0.377	0.162	−0.110	−0.343*
	(0.150)	(0.241)	(0.223)	(0.356)	(0.339)	(0.340)	(0.321)	(0.204)
Constant	45.532***	52.594***	51.931***	57.567***	46.728***	56.268***	65.198***	49.058***
	(4.632)	(6.255)	(4.378)	(9.504)	(9.911)	(3.216)	(8.671)	(6.097)
Observations	646	646	646	645	646	645	646	645
R^2	0.981	0.934	0.964	0.968	0.958	0.974	0.964	0.931

Notes: Standard errors are clustered at the city level. All regressions include a full set of city and time period dummies. The average wholesle price in BC during the base period is 66.35. *p<0.1; **p<0.05; ***p<0.01.

Table E4: Difference-in-Difference estimates for retail price

	Dependent variable:							
	Retail price (¢/ltr)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	2.036**	2.053	5.042***	3.490*	3.942**	4.422***	6.126***	8.268***
	(0.835)	(1.291)	(1.192)	(2.069)	(1.984)	(1.430)	(1.343)	(1.055)
log(building permits)	0.155	0.156	0.373**	0.542*	0.186	0.449***	0.057	−0.205
	(0.154)	(0.102)	(0.159)	(0.291)	(0.246)	(0.153)	(0.145)	(0.211)
Retail wage	0.528***	0.241	0.481***	0.397*	0.303*	0.123	−0.120	0.463***
	(0.165)	(0.165)	(0.119)	(0.232)	(0.161)	(0.176)	(0.230)	(0.153)
Unemployment rate	−0.081	−0.082	−0.087	−0.263	−0.404**	−0.245	−0.382**	−0.069
	(0.134)	(0.128)	(0.131)	(0.177)	(0.193)	(0.169)	(0.157)	(0.208)
Other taxes	1.945***	2.206***	1.248***	1.203***	1.247***	1.350***	1.258***	1.502***
	(0.239)	(0.437)	(0.098)	(0.103)	(0.105)	(0.081)	(0.101)	(0.139)
Wholesale price	1.007	0.978***	0.959***	0.939***	0.923***	0.940***	0.978***	0.967***
	(0.032)	(0.037)	(0.036)	(0.039)	(0.037)	(0.040)	(0.030)	(0.032)
Constant	−28.764***	−27.920***	−7.234**	−2.627	−0.513	−0.607	4.920	−13.816***
	(5.594)	(10.015)	(3.473)	(5.151)	(4.394)	(4.528)	(5.245)	(4.691)
Observations	984	984	984	980	984	982	984	986
R^2	0.989	0.971	0.982	0.984	0.984	0.990	0.981	0.971

Notes: Standard errors are clustered at the city level. All regressions include a full set of city and time period dummies. The average retail price in BC during the base period is 108.47. *p<0.1; **p<0.05; ***p<0.01.