BORRADORES DE ECONOMÍA

Cambio climático

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No. 1292
2024

BANCO DE LA REPUBLICA
COLOMBIA

Carbon tax pass-through: Incidence with vertical integration and price regulation*

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Abstract

The impact of carbon taxes on consumer welfare and emissions in the transportation sector is influenced by both regulatory and market dynamics. As the sources of climate emissions from transportation evolve, how will this impact change in the future? Utilizing extensive data from retail fuel stations and wholesalers in Colombia, we estimate the factors affecting the pass-through of a carbon tax on gasoline prices. Our findings reveal that the pass-through to Colombian consumers is significant, often exceeding one. This phenomenon of "overshifting" vanishes when markets are regulated or when gas stations are vertically integrated with wholesalers. These results indicate that as the global use of carbon taxes to address climate externalities from automobile use increases, the welfare loss for consumers may be greater than what current literature, often focused on the United States, suggests.

Keywords: carbon tax, transportation, tax incidence, overshifting, gasoline.
JEL codes: L91, L98, Q54, H23.

*No financial support was received for this research. Declaration of competing interest: none
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Traspaso del impuesto al carbono: Incidencia con integración vertical y regulación de precios*

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Resumen

El impacto de los impuestos al carbono sobre el bienestar de los consumidores y las emisiones en el sector del transporte está influenciado tanto por la dinámica regulatoria como por la del mercado. A medida que evolucionan las fuentes de emisiones climáticas del transporte, ¿cómo cambiará este impacto en el futuro? Utilizando datos para un amplio número de estaciones de servicio minoristas y mayoristas en Colombia, estimamos los factores que afectan la transferencia de un impuesto al carbono a los precios de la gasolina. Nuestros hallazgos revelan que la transferencia a los consumidores colombianos es significativa, a menudo superior a uno. Este fenómeno de "sobretransferencia" desaparece cuando los mercados están regulados o cuando las estaciones de servicio están integradas verticalmente con los mayoristas. Estos resultados indican que a medida que aumenta el uso global de los impuestos al carbono para abordar las externalidades climáticas del uso del automóvil, la pérdida de bienestar para los consumidores puede ser mayor que lo que sugiere la literatura actual, a menudo centrada en los Estados Unidos.

Palabras clave: Impuesto al carbono, transporte, incidencia de impuestos, sobretransferencia, gasolina
Códigos JEL: L91, L98, Q54, H23

*No se recibió apoyo financiero para esta investigación. Declaración de conflicto de intereses: ninguna
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1 Introduction

According to the United Nations, the transportation sector is responsible for 25% of global greenhouse gas emissions, predominantly from fossil fuels (UN (2021)). To address this, policymakers often use a carbon tax to raise the cost of fossil fuel for transportation. One concern is that most greenhouse gas emissions now come from developing countries, making the impact of carbon taxes felt by those with limited historical emissions (Dissanayake, Mahadevan, and Asafu-Adjaye (2020); Wu et al. (2021)). The burden on consumers in developing countries and the overall emissions impact depend on the pass-through to fuel prices. However, the literature on fuel tax pass-through and incidence is largely limited to developed countries with competitive markets, with only a few studies on developing countries (Nerudová and Dobranschi (2016)). Further, this literature often focuses on alcohol taxes, ignores market structure, and omits the reality that gasoline markets are often regulated (Nelson and Moran (2019); Carranza, Clark, and Houde (2015); Hong and Li (2017)).

Using rich station-level data on monthly average retail price, ethanol mixture, costs, and the effective tax from 2017 to 2022, this paper estimates the pass-through of a carbon tax on retail gasoline prices in Colombia, focusing on local competition, price regulation, and station vertical arrangement. To identify the carbon tax impact on retail gas prices, separate from unobserved costs and demand factors, we use two sources of variation. First, we leverage exogenous variation in the effective carbon tax per gallon due to spatial and temporal variation in ethanol mix across stations, as the tax only applies to the non-ethanol portion of each gallon sold. Second, we combine variation in ethanol mix across stations with the annual carbon tax adjustment every February, with no evidence of anticipation effects, to obtain several notable findings.

First, we find that pass-through of the carbon tax in Colombia is greater than one, indicating that Colombian consumers shoulder most of the welfare loss. This over-shifting in prices is not uncommon in the literature (Pless and Van Benthem (2019); Nelson and Moran (2019); Fabra and Reguant (2014); Sijm, Neuhoff, and Chen (2006)) and indicates imperfect competition (Fullerton and Metcalf (2002)). We corroborate this with evidence that pass-through is lower among stations with many nearby competitors. Second, we provide evidence that stations subject to price regulation, have a lower pass-through level. Finally, contrary to most previous literature (Bajo-Buenestado and Borrella-Mas (2022); Chang (2024)), we document that pass-through of the carbon tax on prices is lower for vertically integrated stations, resulting in incomplete pass-through for this group.

We contribute to several literature strands at the intersection of industrial, public, and environmental economics. First, previous evidence for overshifting in cost pass-through has largely been with respect to alcohol taxes or energy subsidies; we confirm competition's role in driving these results for retail gasoline (Pless and Van Benthem (2019); Nelson and Moran (2019)). Second, we contrast the evidence that vertical integration raises pass-through by finding a negative effect (Bajo-Buenestado and Borrella-Mas (2022); Chang (2024)). Models with vertical integration can justify either an increase or a decrease in pass-through (see Bourreau et al. (2011)). Third, we provide evidence that price regulations modestly alleviate price increases caused by a carbon tax. Although our findings do not address the long-term impacts of these regulations, they highlight the importance of future work on their interaction with carbon taxes. Finally, our estimates from the application of a carbon tax in

Colombia are relevant to future climate policy discussions, as the share of global carbon emissions from developing countries grows (Wu et al. (2021)). If the carbon tax aims to curb carbon-emitting fuels, an accurate measure of pass-through is crucial for assessing its effectiveness in reducing emissions. Our findings indicate that these carbon taxes will be effective but likely more regressive than previously thought.

2 Policy Background & Data

The carbon tax on fuel in Colombia was introduced in 2017. The tax consists of an amount of pesos per ton of carbon emitted, starting at $5.08 USD ($15,000 COP) and increasing annually with inflation.[1] For gasoline, the predominant fuel source in Colombia, the tax is assessed based on the carbon produced by burning one gallon. However, gasoline in Colombia is sold mixed with ethanol, which is not taxed. Consumers only pay taxes on the gasoline portion of their fuel. The ethanol mix in retail gasoline ranges from 4% to 10%.

We primarily use monthly data on prices for all gas stations in Colombia between January 2018 and May 2022.[2] Using supplementary information on transactions between these stations and wholesalers, we identify vertically integrated stations by matching tax identification codes. We also identify which stations are subject to price regulation, and observe the Terminal Gate Price (TGP), the primary determinant of fuel costs for retailers. Due to the richness of our data, we observe the ethanol mix in the fuel sold by every retailer. In the following section, we provide evidence that the ethanol mix and carbon tax vary exogenously over time and across stations.

The summary statistics of our main variables and the characteristics of all gas stations in our sample are provided in Table 1.[3] We distinguish by station type: vertically integrated or price regulated. In accordance with the basic intuition of models studying double marginalization (Spengler (1950)), both cost and prices are on average lower for integrated stations. Important for our analysis, the difference in the average tax between regulated and non-regulated stations is only significant at the 5% level and is economically insignificant, representing less than 1% of the sample mean. Similarly, we see no large differences in the average ethanol content between station types, although the difference between regulation types is statistically significant. Lastly, we find that vertically integrated stations face more competitors on average, which poses a challenge that we address in our heterogeneity analysis.[4]

[1] More details about the tax can be found here.

[2] We exclude stations in border cities—defined by the regulator—because they face different regulations.

[3] We drop extreme outliers in terms of price, those in the bottom half of the 1st percentile or top half of the 99th percentile.

[4] Since there is little entry and exit during our sample period, we define the number of competitors as those within a half kilometer of the station in the middle of our sample period.

3 Empirical Analysis

3.1 Preliminary Assessment of Annual Carbon Tax Adjustment

Following Bajo-Buenestado and Borrella-Mas (2022), we start by providing preliminary evidence on the validity of the exogenous variation in the annual adjustment of Colombia's carbon tax with respect to gasoline prices and station-level ethanol mixture. However, since we observe multiple adjustments to the carbon tax in our data, we differ from previous literature by plotting the results from an event study analysis rather than raw data. This allows us to compare the trend in retail gasoline prices in the months before and after the February adjustment across multiple years, while formally testing for differential pre-trends or anticipation effects that could compromise our primary analysis. Our preliminary econometric specification for the stacked event study analysis is:

$$ln(Y_{i,t}) = \alpha_0 + \sum_{\tau \epsilon [-3,1]} \beta_\tau \cdot 1\{t = \tau\} + \gamma_i + \rho_{i,Year(t)} + \theta \cdot Ethanol_{i,t} + \varepsilon_{i,t} \quad (1)$$

Where we start by defining $Y_{i,t}$ as $Price_{i,t}$ or the average price of a gallon of gasoline sold at station i in month t. The key coefficients β_τ represent changes in retail gasoline price in the months surrounding the annual carbon tax adjustment on February 1st. The identified event study window is three months prior to and two months following. We normalize with respect to prices in January ($\beta_{-1} = 0$). This specification includes station fixed effects and station-year time trends, as well as a control for ethanol mix to account for changes in local station competition and costs over time, relative to the tax adjustment. Figure 1 (a) plots the estimated coefficients (also reported in Table A1 of the online appendix) for these sample months, indicating no differential trend in retail gasoline prices in the months prior to the tax increase and a large, statistically significant increase in prices following it. Next, we redefine $Y_{i,t}$ as $Ethanol_{i,t}$ or the average ethanol mixture at station i in month t and re-estimate equation (1), omitting the ethanol mixture control on the right-hand side. Figure 1 (b) presents results from this second event study analysis, indicating that the ethanol mixture is exogenous to changes in the carbon tax. There is no statistically significant change in ethanol mixture in the months prior to or following a carbon tax increase. This result is consistent with the understanding that the ethanol mixture is likely determined by international sugar or corn prices, depending on the ingredient source. Overall, these preliminary results support the use of this variation, combined with spatial and temporal variation in station use of ethanol not subject to the carbon tax, as a means of identifying carbon tax pass-through in the following section.

3.2 Primary Specification

We follow the literature on pass-through (Bajo-Buenestado and Borrella-Mas (2022); Hong and Li (2017)) and consider a log price outcome in the following two-way fixed effects (TWFE) model:

$$ln(Price_{i,t}) = \beta_0 + \beta_1 ln(Tax_{i,t}) + \beta_2 Regulation_i \cdot ln(Tax_{i,t}) + \beta_3 VI_i \cdot ln(Tax_{i,t}) + \beta_4 Regulation_i \cdot VI_i \cdot ln(Tax_{i,t}) + \gamma_{i,Month(t)} + \rho_{i,Year(t)} + \delta_t + \varepsilon_{i,t} \quad (2)$$

Where $Price_{i,t}$ is the average price of a gallon of gasoline sold and $Tax_{i,t}$ is the effective carbon tax at station i in month t. VI_i is a dummy variable taking a value of one if gas station i is vertically integrated with a wholesaler and zero otherwise. Similarly, $Regulation_i$ is another dummy variable that takes a value of one if the station is subject to price ceiling regulation. $\gamma_{i,Month(t)}$ is a station-month fixed effect to account for both time-invariant and seasonal station-level factors, while $\rho_{i,Year(t)}$ is a station-year trend to account for time-variant heterogeneity. δ_t is a month fixed effect to account for general time effects, such as ethanol or crude prices, and $\varepsilon_{i,t}$ is an idiosyncratic station-month level shock. $\varepsilon_{i,t}$ is clustered at the station level to reflect the variation in treatment, the effective carbon tax. We interpret β_1, our primary parameter of interest, as the impact of a change in the carbon tax on the retail gasoline price. We are also interested in the heterogeneity of this effect according to whether the station is subject to price regulation, β_2, or is vertically integrated with a refiner, β_3. Finally, β_4 captures the interaction of the vertical integration and regulation effects on pass-through.

Unlike a standard difference-in-differences approach where treatment is absorbing, in our baseline TWFE specification the effective carbon tax at an individual gas station varies monthly according to the ethanol mix used and the annual inflation adjustment from the Colombian government. We argue this provides plausibly exogenous variation in the carbon tax, allowing us to causally identify our β parameters. Conditional on station-calendar month fixed effects, station-year trends, and month fixed effects, variation in station ethanol content and therefore the effective tax per gallon is random. Further, the interaction of this mix with the annual inflation adjustment for the overall carbon tax every February creates useful heterogeneity in the tax change across stations, allowing for identification. This is supported by our previous event study analysis, which shows no differential price trend in the preceding months. The random variation in the effective tax at the station level also allows us to identify the β interaction terms, as the time-invariant price impact of a station being regulated or vertically integrated is absorbed by the station-month fixed effects.

3.3 Primary Results

Table 2 reports our estimates for the price effect of a carbon tax. Column (1) presents the baseline estimate of equation (2), without interaction terms, indicating a 1% increase in the carbon tax corresponds with a 0.12% increase in the retail price. Using the sample average carbon tax and gas prices of 138.73 and 9,101.96 pesos from Table 1, this implies a one peso increase in the carbon tax raises retail fuel prices by 7.87 pesos. Further, the 90% confidence interval for this estimate is above 0.0152, the coefficient value for complete pass-through. A finding of pass-through greater than one, or "overshifting," is not uncommon in the literature, particularly in the context of alcohol taxation, and is attributable to imperfect competition, significant market power, or convex demand (Nelson and Moran (2019);

Pless and Van Benthem (2019); Fabra and Reguant (2014); Lise, Sijm, and Hobbs (2010)). Column (2) of Table 2 includes the first interaction for whether the station is subject to price regulation. For this specification, the coefficient estimate for the gas price increase rises to 0.14 and is statistically distinguishable from complete pass-through at the 5% level, but this price effect declines by 0.033 for stations subject to price regulation. To our knowledge, the finding that regulatory approval requirements for price increases lowers the extent of pass-through is a novel contribution to the literature. However, these are short-term estimates that ignore the long-run impacts of price regulations on market conduct (Carranza, Clark, and Houde (2015)). Column (3) introduces an interaction between the carbon tax and whether a station is vertically integrated, with the estimated price impact for non-vertically integrated stations similar to previous specifications. Interestingly, the combined effect of the carbon tax and the negative interaction effect indicates the overall price impact is negative but statistically indistinguishable from zero for vertically integrated stations. There are two reasons why our finding differs from prior literature that has found that vertical integration increases the rate of pass-through. First because the price effect implications of models with vertical integration are very sensitive to the many aspects describing the vertical structure, like whether the integrated firm can foreclose its rivals or how efficient downstream competitors are (Bourreau et al. (2011)). Second, because it is well known that the incidence of a tax depends fundamentally on the shape of the demand curve (Weyl and Fabinger (2013)). Finally, Column (4) of Table 2 combines the two previous interaction terms with a triple interaction between whether a station is vertically integrated, subject to price regulation, and the effective carbon tax. Similar to previous specifications, both price regulation and vertical integration lower carbon tax pass-through, but at a decreasing rate as the triple interaction term is positive but does not entirely offset the vertical integration effect.

To demonstrate the relevance of these results for determining the emissions impact of a 10% increase in the carbon tax, Figure 2 projects the avoided annual CO_2 emissions according to whether stations are subject to price regulation or vertically integrated. Using the 2019 sample year, with a total of 1.66 billion gallons sold, we see that at various gas price elasticities, emissions abatement is highest for stations not integrated with wholesalers and not subject to price regulation, while the lowest level of emissions abatement is found among stations subject to both factors. Further, the gap in emissions abatement is larger the more elastic consumers are in terms of gasoline consumption.

To evaluate the role of competition or market power for our finding of overshifting and the differential pass-through rate with respect to vertically integrated gas stations, we re-estimate our baseline specification (1), without interaction terms, for different competition sub-samples. Specifically, we split our sample by the median number of competitors within half a kilometer (three), for the full sample, price-regulated subsample, and vertically integrated subsample. The results of this empirical exercise are presented in Figure 3, where we plot the baseline coefficient β_1 and the corresponding standard errors for each subsample. Consistent with the previous conjecture about the role of market competition, pass-through for stations with more competitors is substantially lower, implying these stations have less market power. Interestingly, when we examine the subset of vertically integrated stations, we see that pass-through for the subsample with three or fewer competitors is substantially higher than the other samples with the same level of competition, consistent with prior literature that vertical integration raises the pass-through rate (Bajo-Buenestado and

Borrella-Mas (2022)). Intuitively, it is among the vertically integrated stations with greater competition that we find evidence of a pass-through rate equal to zero; these vertically integrated stations likely face a higher drop in demand for high pass-through.

In the online appendix, we demonstrate the robustness of our primary results in several ways. First, we present results with a level-level specification. Second, we estimate our baseline specification with reported costs and ethanol mixture as control variables. Finally, we provide evidence that our result is not sensitive to the choice of standard errors.

4 Conclusion

There is a rich literature that has examined pass-through of taxes on retail gasoline prices and informed the likely effectiveness of using carbon taxes to reduce fossil fuel use in transportation. However, evidence from this literature is largely based on estimates from developed countries with relatively competitive markets, contrasting with where the majority of climate externalities from transportation now originate—the developing world (UN (2021); Nerudová and Dobranschi (2016)). We fill this gap by estimating tax pass-through for retail gasoline in Colombia. Our results point to overshifting, with pass-through rates greater than one, a result associated with imperfect competition or market power issues. This is supported by supplementary analysis indicating substantially lower pass-through rates for stations with more local competitors. If our findings generalize, the practical implication is that consumers in the developing world are likely to shoulder a significantly higher portion of the burden from carbon taxes than prior literature indicates.

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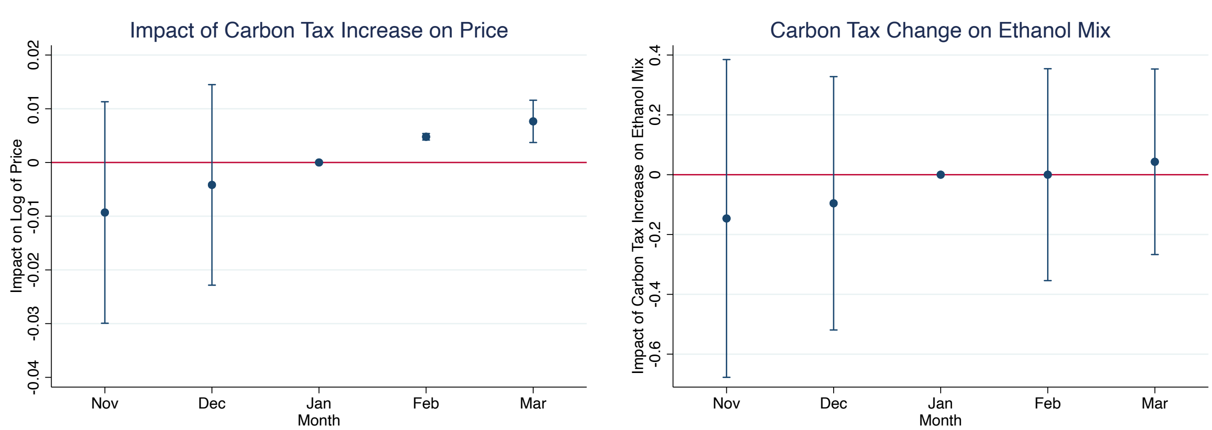
Tables and Figures



(a) Gas Price Impact-All Stations

(b) Ethanol Mix Impact-All Stations

Figure 1: Event study results of equation (1). Plots show estimated $\hat{\beta}_\tau$ from equation (1) along with 99% confidence interval error bars for various sample groups.

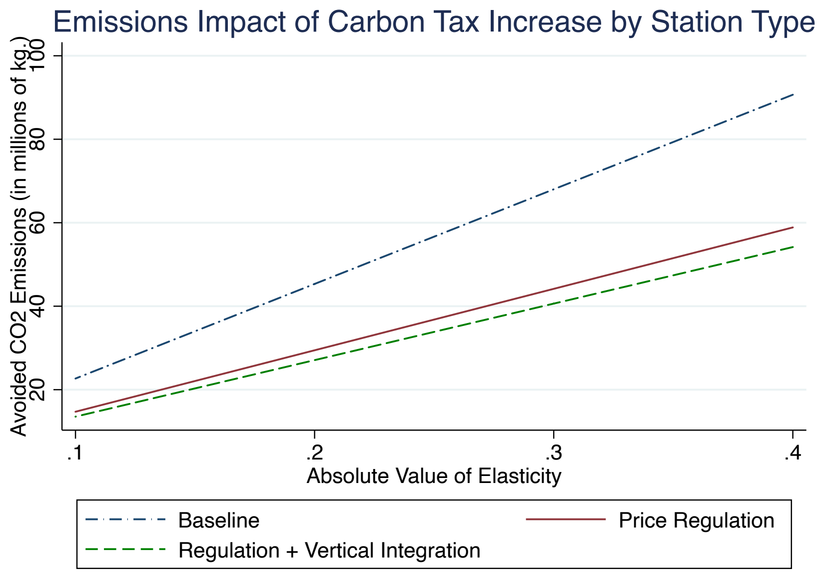


Figure 2: Impact of a 10% increase in the carbon tax on annual emissions by station type based on Table 2 estimates.

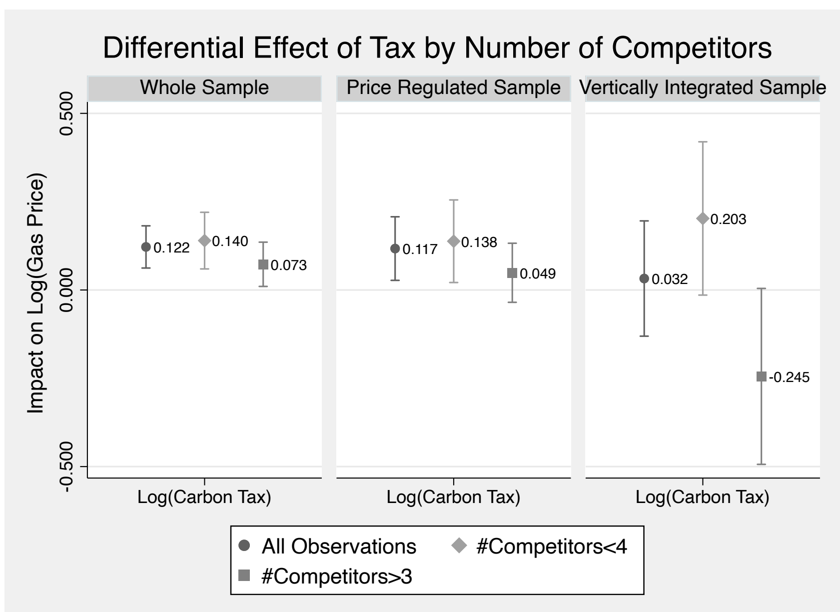


Figure 3: Regression results for our baseline equation (2) without interaction terms for different subsamples. We separate out gas stations by whether they are above or below the median number of competitors (3), whether they are subject to price regulations, and whether they are vertically integrated. Plot shows estimated coefficients and standard errors.

Table 1: Summary Statistics

	(1) Full Sample mean/sd	(2) Price Regulation No mean/sd	(3) Price Regulation Yes mean/sd	(4) b/t	(5) Vertical Integration No mean/sd	(6) Vertical Integration Yes mean/sd	(7) b/t
Avg. Price	9101.96	8945.66	9252.21	-306.55***	9122.90	8808.43	314.48***
	605.91	552.98	616.47	-116.73	605.08	537.51	58.27
Avg. Tax	138.73	138.68	138.78	-0.10**	138.73	138.79	-0.06
	9.74	9.75	9.73	-2.31	9.74	9.80	-0.72
Avg. Cost	2428.38	4954.61	-	-	2261.86	4762.44	-2500.59***
	3768.74	4057.42	-	-	3689.07	4086.13	-74.90
Avg. Ethanol	0.09	0.09	0.09	0.00***	0.09	0.09	-0.00
	0.02	0.02	0.02	3.62	0.02	0.02	-0.34
#Competitors	3.61	3.63	3.59	0.04**	3.60	3.81	-0.21***
	4.13	4.05	4.21	2.07	4.11	4.41	-5.63
N	199,392	97,727	101,665	199,392	186,114	13,278	199,392

Notes: This table reports station-month level summary statistics for the 4,252 sample stations between 2018 and 2022. Column (1) reports the full sample, while Columns (2) and (3) separates by whether the station is not or is subject to price regulation. Column (4) reports the difference in means between columns (2) and (3), along with test statistics for a null hypothesis that the difference in the corresponding variable between them is zero. Columns (5) and (6) separate the sample by vertical integration status and Column (7) reports results regarding the difference in means between them. Standard errors used in the calculations behind columns (4) and (7) are derived by assuming equal variances of the variables between comparison groups. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table 2: Primary Estimates of Carbon Tax Pass-Through on Gas Prices

	(1) b/se	(2) b/se	(3) b/se	(4) b/se
Ln(Tax)	0.122**	0.140**	0.125**	0.154**
	(0.060)	(0.060)	(0.060)	(0.060)
Ln(Tax)·Regulation		-0.033**		-0.054***
		(0.015)		(0.015)
Ln(Tax)·VI			-0.139***	-0.187***
			(0.025)	(0.028)
Ln(Tax)·Regulation·VI				0.179***
				(0.062)
N	199,392	199,392	199,392	199,392
adj. R^2	0.818	0.818	0.819	0.819
Station-Calendar Month FEs	Y	Y	Y	Y
Month of Sample FEs	Y	Y	Y	Y
Station-Year Trends	Y	Y	Y	Y

Notes: This table reports our baseline equation (2) estimates of carbon tax pass-through to retail gasoline price. Columns (2)-(4) add interaction terms for a stations price regulation and vertical integration status. All columns include station-year time trends, month of sample fixed effects, and station-calendar month fixed effects. Standard errors are clustered at the station-level. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. **Sample:** Gas station-month level data from the beginning in 2017 and ending in 2022 for 4,252 gas stations.

Online Appendix

Table A1: Impact of Annual Carbon Tax Adjustment on Prices and Ethanol

	Ln(Price)	Ln(Ethanol)
-3 (November)	-0.009	-0.146
	(0.004)	(0.191)
-2 (December)	-0.004	-0.096
	(0.004)	(0.152)
-1 (January)	-	-
0 (February)	0.005***	0.000
	(0.000)	(0.127)
1 (March)	0.008***	0.043
	(0.001)	(0.111)
N	89,652	89,530
adj. R^2	0.314	0.305

Notes: This table reports robustness analysis with our event study equation (1) for the outcomes of log price and log ethanol mix. Column (1) considers the outcome of the log of gasoline price. Column (2) considers the outcome of log ethanol mix, excluding that control from the right hand side. All columns include station-year time trends and station fixed effects. Standard errors are clustered at the station month level. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.
Sample: Gas station-month level data from the beginning in 2017 and ending in 2022 for 4,252 gas stations.

Table A2: Level-Level Estimates of Carbon Tax Pass-Through on Gas Prices

	(1) b/se	(2) b/se	(3) b/se	(4) b/se
Tax	6.955**	7.165**	7.186**	8.051**
	(3.455)	(3.463)	(3.461)	(3.469)
Tax·Regulation		-0.394		-1.658*
		(0.825)		(0.857)
Tax·VI			-9.579***	-11.664***
			(1.382)	(1.576)
Tax·Regulation·VI				9.213***
				(3.265)
N	199,392	199,392	199,392	199,392
adj. R^2	0.828	0.828	0.828	0.828
Station-Calendar Month FEs	Y	Y	Y	Y
Month of Sample FEs	Y	Y	Y	Y
Station-Year Trends	Y	Y	Y	Y

Notes: This table reports robustness analysis with our baseline equation (2) and level measures of the carbon tax and retail fuel price. Columns (2)-(4) add interaction terms for a stations price regulation and vertical integration status. All columns include station-year time trends, month of sample fixed effects, and station-calendar month fixed effects. Standard errors are clustered at the station-level. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. **Sample:** Gas station-month level data from the beginning in 2017 and ending in 2022 for 4,252 gas stations.

Table A3: Robustness Checks for Primary Specification

	(1) b/se	(2) b/se	(3) b/se	(4) b/se
Ln(Tax)	0.122**	0.122***	0.119**	0.079
	(0.060)	(0.035)	(0.055)	(0.083)
N	199,392	199,392	97,727	199,392
adj. R^2	0.818	0.818	0.769	0.818
Cost Controls	-	-	Y	-
Ethanol Mix Controls	-	-	-	Y
Station-Year Trends	Y	Y	Y	Y
Station-Calendar Month FEs	Y	Y	Y	Y
Month of Sample FEs	Y	Y	Y	Y
Station-Year Trends	Y	Y	Y	Y

Notes: This table reports our baseline equation (2) estimates of carbon tax pass-through to retail gasoline price. Column (1) is the original primary specification with standard errors clustered at the station-level. Columns (2) presents the same estimates with standard errors clustered at the station-month level. Column (3) re-estimates equation (2) with the unregulated market subsample and with reported costs added as a right hand side variable. Finally, Column (4) re-estimates equation (2) with average station ethanol mixture as a control. All columns include station-year time trends, month of sample fixed effects, and station-calendar month fixed effects. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. **Sample:** Gas station-month level data from the beginning in 2017 and ending in 2022 for 4,252 gas stations.