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Abstract

At the end of 2014 a "Green" registration tax on new vehicle sales was introduced in Chile. In this paper we use a vehicle registration dataset to estimate the impact of this policy on average nitrogen oxide (NOx) emission rates of new vehicle purchases. We analyze two impact channels: substitution from diesel to gasoline vehicles and substitution from more to less polluting diesel vehicles. We rely on a difference-in-differences approach and focus our analysis on pickup trucks. Our identification strategy benefits from the fact that for this type of vehicle the policy defined a taxable and exempt group. In addition, the tax was increased on two occasions after its implementation, hence we can estimate its impact as a function of treatment intensity. Our findings suggest that an average tax that reached 7-8% of the sale price resulted in an overall increase of 4 to 8 percentage points in the probability of purchasing a gasoline over a diesel pickup truck for affected purchases, reducing the average emission rate for this class of vehicles. In addition, we find suggestive evidence that within the diesel pickup group the tax may have induced a substitution to a cleaner model once it became available in the market. The policy's aggregate environmental impact is small since a large fraction of the most polluting vehicles are exempt. Finally, we do not find evidence of an increase in CO2 emissions as a result of the tax. Policy recommendations are discussed.

Keywords: emissions, environmental taxation, registration taxes, Chile

1 Introduction

Transport is one of the main contributors to greenhouse gas emissions as well as local pollutants. According to the International Energy Agency (IEA) between 24% and 25% of overall CO2 emissions can be attributed to the transport sector.[1] Transport is also an important source of NOx emissions, particularly from diesel-powered cars, trucks and other vehicles. These emissions can cause ozone pollution and are a precursor to particulate matter.

The conventional approach to tackle transport related emissions in the road sector has been the use of mandatory emission standards and fuel taxes. In the last decades some countries have also introduced vehicle registration taxes as a complementary measure. Whereas standards provide a maximum emission threshold for new vehicles, registration taxes based on environmental criteria may induce individuals and firms to purchase cleaner models within the set of vehicles meeting those standards. Examples of countries that have introduced environmentally based registration taxes include the Netherlands, Norway, Ireland, Czech Republic, Belgium, Denmark, Spain, Switzerland and Italy, among others.

In this paper we use vehicle registration data to estimate the environmental impact of the "Green" registration tax on new vehicle sales implemented in Chile at the end of 2014. The level of the tax is a positive function of the NOx emission rate (g/km) and the value of the vehicle, and a negative function of its fuel efficiency. The tax only applies to new vehicles purchased by private individuals. Purchases by firms are exempt. In the case of pick-up trucks, this last feature generates two distinct groups that can be compared to assess the impact of the policy using a difference-in-differences (DID) approach.

[1] IEA, Energy Statistics Data Browser, CO2 emissions by sector, World, 1990-2021, last accessed April 6th, 2024.

Our results suggest that this tax reduced the average NOx emission rate of new pickup trucks during the sample period considered. First, by inducing substitution from diesel (more polluting in terms of NOx emissions) to gasoline alternatives. Second, we observe a switch from more to less polluting diesel vehicles. However, this last effect is only evident once a new diesel pickup truck model (with a lower NOx emission rate) was introduced in the market at the end of 2016. We cannot disentangle the relative contribution of the corresponding green tax reduction from other attributes of this new model in explaining this last effect. Therefore, we present what must be considered an upper-bound for this second substitution effect of the tax.

Overall, the impact on the average NO_X emission rate of new pick-up trucks is modest owing to the very narrow tax base of the policy. In practice, it only applies to a minor percentage of new diesel vehicle sales. Although we cannot measure actual ex-post emissions from the use of new vehicles, the change in their attributes –in terms of emission rates (g/km)– should have an impact on aggregate pollution. However, due to the small tax base of the policy, the reduction in actual emissions is most probably very small. Simulations using our estimated results suggest that at most it reduced the accumulated emissions of new pickup truck by 1.2% by the end of our sample period.

It is interesting to note that even when the explicit objective of this policy is to reduce NOx emissions, the tax does not appear to have increased average CO2 emission rates as more users purchased gasoline alternatives. This result is consistent with the fact that CO2 emission rates are only slightly higher for gasoline pickups compared to diesel ones.

From a policy perspective, we argue that to have a relevant environmental impact, the tax base must be widened significantly by removing exemptions to commercial vehicle purchases. This would reduce transport-related emissions and provide an interesting economic instrument to complement command and control regulations such as mandatory emission standards. In addition, we argue that the registration tax should be extended to include other pollutants.

This study adds to the literature on several dimensions. First, from a methodological perspective, we use a contemporaneous control group to evaluate the effects of the registration tax. Except for Franckx and Hoornaert (2025) for the case of Belgium, studies on the impact of environmental vehicle registration taxes have not used this approach.

Second, we find that the inter-fuel substitution from diesel to gasoline pickup trucks is the most important behavioral effect of the policy. We also find suggestive evidence for a second channel, substitution to cleaner alternatives within the class of diesel-powered vehicles. However, this intra-fuel substitution only appears once a model with lower emissions became available in the market. This finding suggests that to boost the effects of an environmental tax, complementary policies may have to be implemented to ensure consumers have the option of cleaner alternatives. This issue has not been raised in previous studies and may be relevant for countries where tariff or non-tariff barriers limit the range of model options in the vehicle market.

Third, Chile is one of only a handful of developing countries where a registration tax has been introduced with the specific purpose of curbing negative environmental emissions. Given the more unequal income distribution in these countries, vehicle demand may be influenced by the behavior of wealthier and possibly less price sensitive individuals. In addition, the tax in Chile is relatively low compared to those in developed countries. Therefore, a relevant question in this context is whether there is still a measurable demand response to this policy. We find evidence suggesting that this has been the case. Therefore, the Chilean experience can serve as a catalyst for other developing countries that wish to tackle transport-related environmental externalities using economic instruments.

This paper is organized as follows. In the next section we provide a review of the literature on environmental registration taxes. We then describe the tax introduced in Chile in December 2014 and its evolution until 2019. We then present the data used in this study, the methodological approach and the estimation results. Simulations on the possible environmental impact of the tax are then conducted. The paper concludes with a summary of the main findings and a discussion of their policy implications.

2 Literature review

Many countries have introduced environmental considerations in their vehicle registration taxes (ACEA, 2015).[2] These policy reforms have been introduced as complements to mandatory emission standards, annual road taxes and fuel taxes. In general, empirical research estimating the causal effect of these taxes for developed countries conclude that for the most part they have had a positive environmental impact. Examples includeRyan et al. (2009), Rogan et al. (2011) and Hennessy and Tol (2011) for the case of the registration tax in Ireland, Huse and Lucinda (2014) for the case of a green car rebate in Sweden, D'Haultfœuille et al. (2014) for the feebate (bonus/malus) in France, Kok (2015) for the registration tax and annual road tax in the Netherlands, Klier and Linn (2015) for reforms in France, Germany and Sweden, Yan and Eskeland (2018), Eskeland and Yan (2021) and Ciccone (2018) for the experience in Norway, Alberini and Bareit (2019), Alberini and Horvath (2021), Bergantino et al. (2021) and Franckx and Hoornaert (2025) for the case of Switzerland, Germany, Italy and Belgium, respectively. However, the effects are sometimes found to be small (D'Haultfœuille et al., 2014; Franckx and Hoornaert, 2025) or, in the case of

[2] By a registration tax we denote a one-off payment at the time of purchase of a new or used vehicle. Some authors denote the annual road tax as a registration tax (Cerruti et al., 2019) which is not our use of this term.

Ireland, environmentally counterproductive (Ryan et al., 2019). Generally, these taxes have targeted CO2 emissions.

Researchers have used diverse methodological approaches to study this issue. Some have used reduced form empirical models of vehicle registrations or CO2 emission rates, (Klier and Linn, 2015; Kok, 2015; Yan and Eskeland, 2018; Cerruti et al., 2019; Alberini and Horvath, 2021). In these cases, authors have been careful to control for confounding variables using time and vehicle brand-model fixed effects (Klier and Linn, 2015; Cerruti et al., 2019; Alberini and Horvath, 2021), trends in other European countries (Kok, 2015) or instrumental variable techniques (Yan and Eskeland, 2018). However, strictly speaking, they are not quasi-experimental methodologies best suited to infer causality of taxes on emission rates.

Another strand in the literature is the specification and estimation of an automobile demand model that can then be used to simulate a counterfactual scenario without the registration or road tax. These can be simple, as the optimal choice model based on mileage driven used by Hennessy and Tol (2011) for Ireland, or sophisticated, as the logit or nested logit used by D'Haultfœuille et al. (2014) for France and Alberini and Bareit (2019) for Switzerland, or a BLP (Berry et al., 1995) structural model used by Huse and Lucinda (2014) for Sweden, Stitzing (2016) for Finland and Ji et al. (2022) for China.

More in line with the current paper are studies that use a difference-in-differences (DID) approach and other quasi-experimental empirical techniques. For example, Bergantino et al. (2021) analyze the *Superbollo* tax introduced in Italy in 2011. Since the tax affected newly registered cars over a certain threshold in terms of engine power, they use a regression discontinuity design (RDD) method to determine the effectiveness of this policy. The tax appears to have increased the share of low-emission vehicles and reduced overall CO2 emissions by 5-8%. Klier and Linn (2015) and Alberini and Horvath (2021) also exploit the discontinuity of the tax level around certain emission thresholds in parts of their papers to study the impacts of the tax changes in France and Germany. However, in all these cases results are only valid close to the discontinuity point and do not provide an overall impact of the policy on vehicle registration or emissions.

Closest to our approach are Ciccone (2018), Ryan et al. (2009) and Franckx and Hoornaert (2025). The first estimates the impact of a policy reform introduced in Norway in 2007. This reform changed the vehicle registration tax from one based on vehicle displacement to one based on CO2 emissions. Ciccone (2018) relies on a difference-in-differences (DID) approach, but given that the tax reform affected all new vehicle purchases simultaneously, there was no contemporaneous or staggered control group that could be used in a conventional DID framework (Ciccone, 2018, p.146). To address this problem, the author defines as treatment observations those sales that take place some months before and after the policy announcement. To build the control group, observations from two and three years prior to the policy reform were considered. Time-varying control variables are used to account for factors that may have affected vehicle purchases in those different periods. This methodology has been used previously in the labor economics literature when there is no control group contemporaneous to the introduction of the treatment policy, but its robustness may still be prone to unobservable or unaccounted for confounding effects. All in all, the paper concludes that within the year following the tax implementation, average CO2 emissions of new vehicles fell by 4.3% and the share of diesel vehicles (less polluting in terms of CO2) in total sales increased by 20 percentage points.

Ryan et al. (2019) also use a DID approach to study the effects of the change in the annual road tax and vehicle registration tax in Ireland beginning in 2008. As a control group they use the emission trends in the United Kingdom and find that the policy has reduced average CO2 emission ratings of newly registered passenger cars by 8-11 g/km. However, the policy has also induced an increase in the share of diesel vehicles, increasing emissions of local pollutants such as NOx and SOx. The use of the UK as a control group may be suspect as other policy changes were introduced in that country at the same time. Although the graphical evidence presented by the authors suggests that the parallel trends assumption is met in this case, there is no formal statistical analysis of this proposition.

Franckx and Hoornaert (2025) study the change in the Flemish registration and annual road taxes in 2012 and 2016. In their DID framework they use the other two regions in Belgium as a control group. They find that the policy change accelerated the decrease in CO2 emission rates of new vehicles, but the impact was small relative to the exogenous decreasing trend in emission rates. An interesting methodological innovation in their paper is the estimation of a specific time trend in emission rates in the Flemish region to evaluate the possible bias generated if the parallel trends assumption is not met.

For developing countries, studies are few and, with one exception, not published. Tesemma (2023) uses the same DID approach as Ciccone (2018) to study the impact of a vehicle import tax based on CO2 emissions in Ethiopia. He finds that the policy did not change the average emission intensity of newly registered vehicles. Nkosi et al. (2021) study the 2010 reform that introduced CO2 emission criteria in the vehicle registration tax in South Africa. They find that initially the policy change did not significantly reduce the average CO2 emissions rate of new vehicles. But a subsequent change to the tax in 2013 led to a 21% reduction in the average rate by 2018. However, their methodological approach is based on a time series analysis rather than a DID approach. The only published research on registration taxes in a developing country context is Ji et al. (2022) for the case of China. They study the impact of an increase in the purchase tax rate for internal combustion engine vehicles and the phasing out of subsidies for battery electric vehicles. They estimate a structural random-coefficients logit model for automobile demand as in Berry et al. (1995) and simulate counterfactual scenarios. They find that the increase in the tax reduced CO2 and particulate mater emissions.

The green registration tax implemented in Chile represents a good opportunity to expand the literature on this topic. Given that this was a non-universal policy reform, our study is the first implementing a DID approach using a contemporaneous control group in a developing country context. This is warranted as the transport sectors of developing countries represent an increasing share of global emissions. In addition, there may be distinctive issues to research in these cases. For example, Chile has one of the most unequal income distributions among OECD countries, with a post-tax and transfers Gini coefficient of 0.45.[3] Hence, choice behavior may be different to the European case since only relatively wealthier households have access to new vehicles. Furthermore, the green tax in Chile is rather modest by international standards, reaching 4-5% of the sale price in the case of diesel vehicles and below 1.5% in the case of gasoline powered vehicles.[4] Therefore, it is of interest to examine whether a modest registration tax based on vehicle emissions applied in a developing country context had a measurable impact on purchase decisions.

3 The Chilean green tax

Motorized vehicle use is one of the main emission sources in Chile. According to official information from the Ministry of Environment, at the national level this sector accounts for 26% of NOx emissions, while in the Santiago Metropolitan Region this sector represents 56% of total NOx emissions, with more than 26,000 tons emitted into the atmosphere each year (MMA, 2023).

[3] Figure for 2022 (OECD, 2023).

[4] These percentages are higher for pickup trucks and lower for automobiles, as shown in Section 4, but in all cases are among the lowest of OECD countries. Spain has a registration tax that ranges between 4.75% and 14.75% of the sales price. Netherlands and Slovenia have tax rates above 20%, Ireland and Norway above 30%, and other countries reach top rates above 50% (e.g. Israel and Denmark). In some of these countries, there are tax brackets for different levels of CO2 emissions, as well as deductions and/or surcharges.

NOx emissions are of particular concern in Chile. They are a precursor to particulate matter, which is the main local air pollution problem in the capital Santiago, where 40% of the country's population resides, as well as in other medium-sized urban areas (Lapere et al., 2021; Saide et al., 2016). This is more serious during the winter, with frequent PM2.5 daily concentration levels exceeding the average 24-hour mean recommended by the World Health Organization (WHO) (Barraza et al., 2017; Lapere et al., 2020, 2021; Saide et al., 2016; Menares et al., 2021) creating important public health issues.[5]

Vehicle NOx emissions are mostly related to diesel-powered engines, which also emit PM2.5 directly as well as other polluting gases. Despite the health risks, the fuel tax structure in Chile generates strong incentives to purchase diesel vehicles. The tax is four times higher for gasoline than for diesel, causing a significant difference in the pump price between both fuels.[6] For political reasons, increasing the diesel fuel tax has proved unfeasible and the price distortion thus created exacerbates NOx emission problems.

As an alternative, the so-called "green tax on mobile sources" (hereafter green tax) was approved in September 2014 and came into effect on December 29 of that same year. The tax applies to the purchase of new small and medium-sized vehicles with load capacity below 2,000 kg, thus excluding buses and trucks. A feature that is prominent in our empirical analysis is that vehicles purchased by a commercial entity (firm or taxi operator) are exempt. Only those acquired by private individuals are subject to the tax. This creates a natural control group to identify the impact of this policy.

[5]According to recent evidence, Chile has the highest mortality rate attributable to ambient air pollution among all South American countries. The number of premature deaths caused by PM2.5 is estimated to be 230 per million inhabitants (Hartinger et al., 2023). See also Busch et al. (2023) and references therein.

[6]According to information from the National Energy Commission, the average monthly pump price of diesel was 26,3% lower than gasoline between January 2013 and December 2019. See http://www.cne.cl/estadisticas/hidrocarburo. Last accessed April 19, 2024.

The green tax is determined according to the following formula:[7]

$$Tax = [\frac{\alpha}{R} + (\beta \cdot N)] * (\gamma \cdot P) \qquad (1)$$

where *Tax* denotes the tax amount, R the fuel efficiency (kilometers per liter), N the NOx emission rate (grams per kilometer), and P the sales price. Therefore, the tax decreases with fuel efficiency and increases with respect to the NOx emission rate and the sale price. Fuel efficiency and emission rates are measured under laboratory conditions by the CCCV of the Ministry of Transport.[8]

The parameters α and γ take the value of 35 and 0.00000006, respectively. The parameter β was increased over time according to a preset schedule included in the law that introduced this policy. It was 60 until the end of 2015, took a value of 90 starting January 1, 2016, and was again increased to 120 on January 1, 2017. We would expect the increasing importance of NOx emissions in the determination of the green tax amount to have a growing behavioral impact on vehicle choice, something we explore in our empirical analysis.

The tax is based on vehicle characteristics and price. Therefore, buyers' behavioral response would be to choose vehicles with different characteristics. Since emission rates are correlated with fuel efficiency and price (through smaller or more efficient engines), what is observed is the net effect of the tax. An individual could reduce the tax amount by buying a cheaper or more fuel-efficient car which further reduces the tax by lowering the NOx emission rate. We cannot disentangle the impact of each individual component of the tax formula. Therefore, below we estimate the net effect of this tax by observing the effective emission rate of each new vehicle purchase.

[7]The tax is expressed in an indexed monetary unit called UTM (Unidad Tributaria Mensual) that increases each month according to the past inflation rate. In January 2015 it was worth CLP 43,198 or around USD 70.

[8]CCCV is the Spanish acronym for *Centro de Control y Certificación Vehicular*.

Figure 1 presents the total monthly revenue collected from this tax. The red vertical lines show the month when each of the changes in the NOx parameter of the tax formula took place after its introduction at the end of 2014. There was a steady growth, from around US$ 4 million monthly average in 2015 to over US$ 7 million after the last change in the tax formula in January 2017. Revenues are relatively low compared to other transport related taxes. As discussed further below, this is consistent with the small rate and tax base of this policy.

Another thing to note from Figure 1 is that the minimum revenue in each year occurred in January and February, just after the introduction of the tax and the two changes in the formula on January 1st 2016 and 2017. However, this is also the case in 2018 and 2019 which suggests a seasonality effect.[9] Further below we come back to this issue when discussing possible anticipatory effects of purchases induced by the policy.

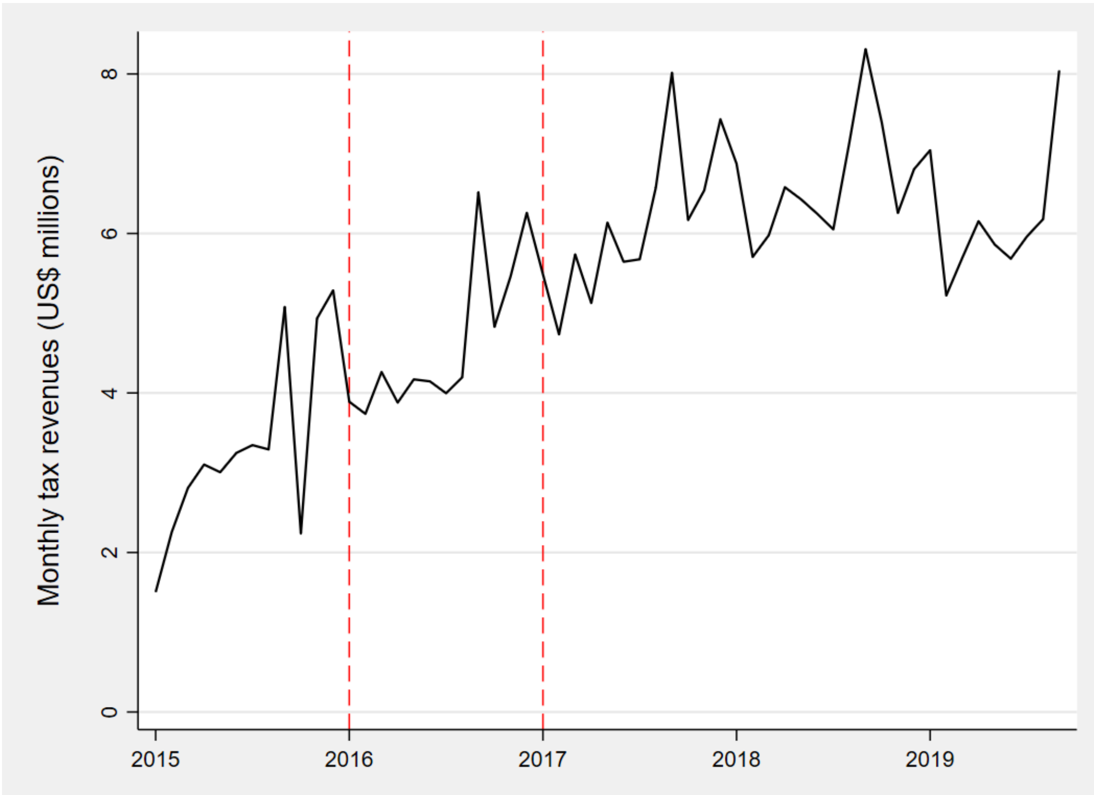
4 Data and descriptive analysis

Our dataset contains the records of daily new light-duty vehicles (LDV) sales, from April 2012 to September 2019.[10] The information comes from several sources, including the Ministry of Transportation, the Treasury, the General Register Office, and the National Tax Agency. Appendix A presents details of the construction of the dataset and the corresponding information sources.

[9] January and February are the summer months in the southern hemisphere.

[10] The original dataset contains data from January 2012 to December 2019. However, during the first three months many vehicle models complied with the EURO 3 emission standard (and its equivalent EPA94), and for a large fraction of those models we lack data on emission rates. On the other hand, in October 2019 there was a major social crisis in Chile that affected the whole economy, including the vehicle market. Later, in March 2020 the COVID-19 pandemic began which also resulted in an alteration to normal economic activities. To avoid these unusual events from affecting our results, we only consider data from April 2012 to September 2019. For reasons detailed below, our empirical estimations are based on data from March 2013 to September 2019.

Figure 1: Monthly tax revenues, January 2015 to September 2019 (US$ millions)



Source: Tesorería General de la República and Banco Central de Chile. We first expressed the revenues in CLP of December 2023 and then used the average 2023 exchange rate for that month (CLP$839/USD) to convert tax revenues from domestic currency to dollars.

The dataset presents for each vehicle its brand, model, transmission, fuel type, fuel efficiency, weight, footprint, displacement, category, pollution emission rates, sale date and, for vehicles purchased after December 28, 2014, the sale price and the amount of the green tax paid. We also know whether the vehicle was purchased by a private individual or a commercial entity.

Vehicles are classified into three broad categories: cars, pickup trucks and cargo vans.[11] Automobiles and pickup trucks are the most numerous categories. The former includes sedans, station-wagons, hatchbacks, jeeps and other automobile models. Under the "cargo vans" we consider closed cargo vans and

[11]We exclude minibuses from the analysis, for they represent around 1% of total vehicle sales.

box-like cargo vans. Table 1 presents, for each of these three categories, the number of new vehicles sold as well as the breakdown by fuel type and tax status. Automobiles are all taxable (purchased by private individuals) since commercial entities cannot claim these vehicles as part of their assets.[12] On the contrary, cargo vans are all exempt (commercial vehicles). Figure 2 shows the monthly sales of each type of vehicle.[13]

[12]There are some minor exceptions, such as taxi owners.

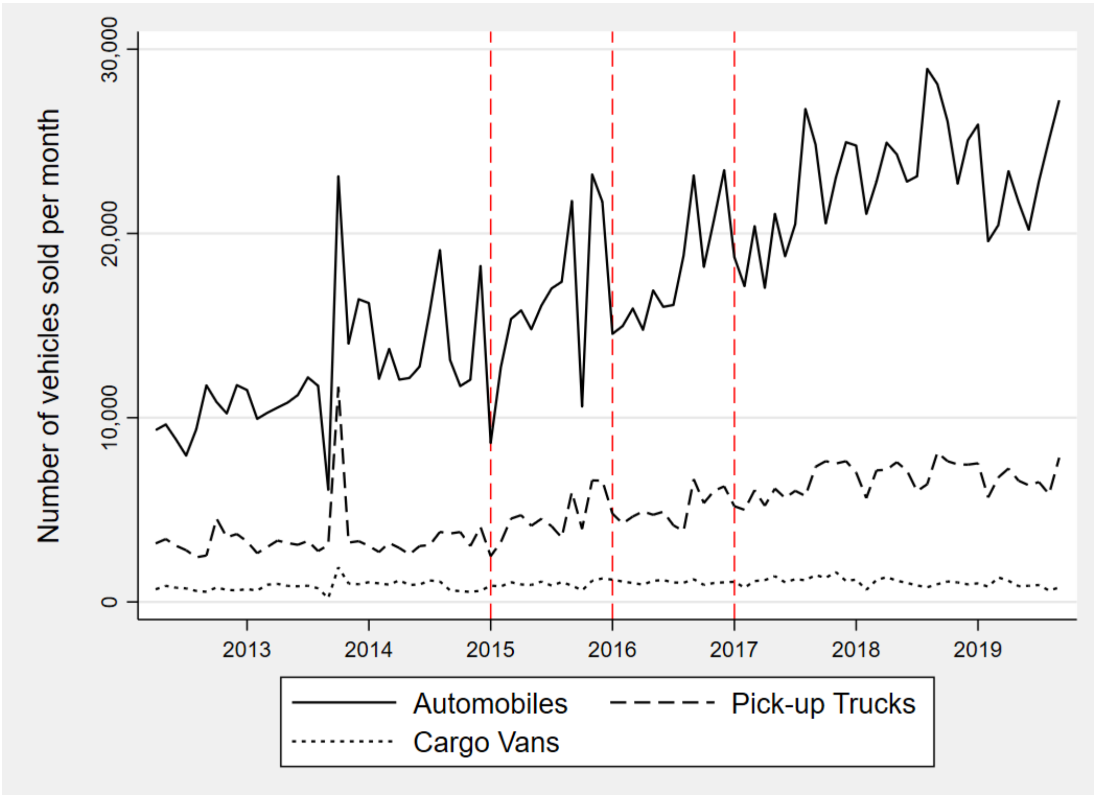
[13]The spike in 2013 for all types of vehicles is related to a strike by government workers in the civil registration office in September of that year. All vehicle sales during that period were subsequently registered in October, explaining the drop and then the spike in those months.

Table 1: New vehicle sales by fuel type and tax status, April 2012 to September 2019.

	Gasoline			Diesel			Total		
	Exempt	Taxable	Total	Exempt	Taxable	Total	Exempt	Taxable	Total
Automobiles									
Frequency		1,402,525	1,402,525		167,625	167,625		1,570,150	1,570,150
Percent		(66.8)	(66.8)		(8.0)	(8.0)		(74.8)	(74.8)
Pick-up Trucks									
Frequency	59,803	24,583	84,386	324,792	32,735	357,527	384,595	57,318	441,913
Percent	(2.8)	(1.2)	(4.0)	(15.5)	(1.6)	(17.0)	(18.3)	(2.7)	(21.0)
Cargo Vans									
Frequency	29,675		29,675	57,893		57,893	87,568		87,568
Percent	(1.4)		(1.4)	(2.8)		(2.8)	(4.2)		(4.2)
Total									
Frequency	89,478	1,427,108	1,516,586	382,685	200,360	583,045	472,163	1,627,468	2,099,631
Percent	(4.3)	(68.0)	(72.2)	(18.2)	(9.5)	(27.8)	(22.5)	(77.5)	(100.0)

Source: see Appendix A. Percentages are calculated with respect to total vehicle sales

Figure 2: Monthly vehicle sales by type, April 2012 to September 2019 (US$)



Source: See Appendix A. The red vertical lines display the first month when the tax was applicable (January 2015) and then the first month after the increase in the NOx parameter in the tax formula (January 2016 and January 2017).

In the case of pickup trucks, we have taxable and tax-exempt sales for vehicles with both types of fuel, so there is a contemporaneous control group that can potentially be used to assess the causal effect of this policy. Therefore, in our empirical work below we focus our analysis on this group of vehicles.

When analyzing the environmental impact of the tax, the distinction between diesel and gasoline powered vehicles is relevant, given the significantly different NOx emission levels. This is shown in Table 2. A diesel automobile is on average eight times more polluting per kilometer than its gasoline counterpart. In the case of pickup trucks, the diesel type is ten times more polluting per kilometer than a gasoline one. Thus, although diesel vehicles represented only 27.8% of total sales during our sample period, they are the major contributor to overall NOx emissions.

Table 2: NOx emission rates (g/km) by fuel, tax status and vehicle type, April 2012 to September 2019.

	Gasoline		Diesel	
	Exempt	Taxable	Exempt	Taxable
Automobiles				
Mean		0.017		0.131
Standard deviation		0.012		0.073
Pick-up Trucks				
Mean	0.023	0.023	0.242	0.232
Standard deviation	0.020	0.015	0.060	0.066
Cargo Vans				
Mean	0.031		0.191	
Standard deviation	0.017		0.043	

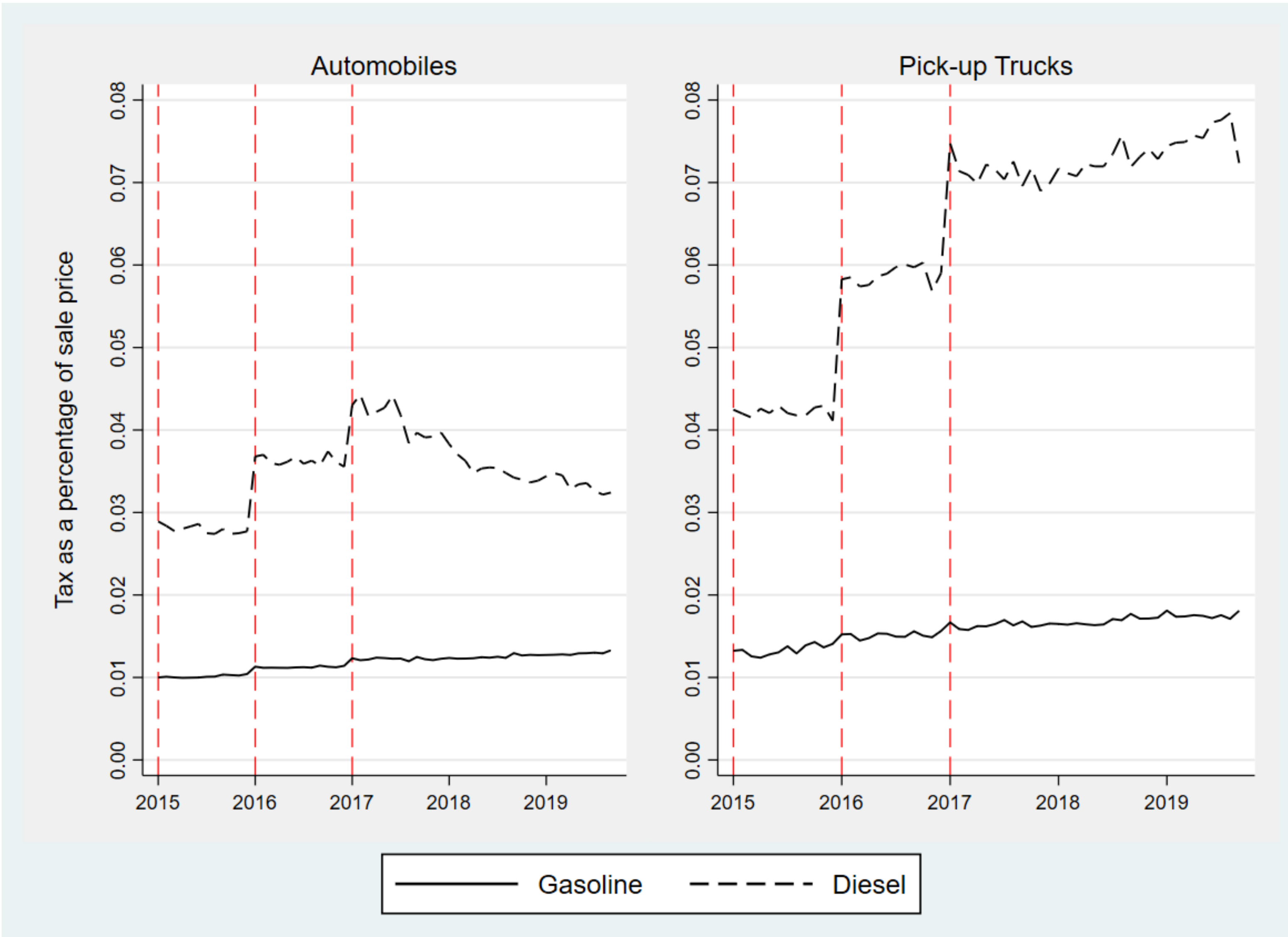
Source: see Appendix A.

Figure 3 shows the evolution of the average tax as a percentage of the sale price for taxable vehicles. The graph begins in January 2015 right after the tax was introduced and the two vertical lines represent the months when the NOx parameter in the tax formula was increased. The first panel shows the percentage for automobiles while the second is for pickup trucks.[14] In each case, the information is presented separately for gasoline and diesel vehicles. We see an important difference between gasoline automobiles, for which on average the tax represented 1%-1.5% of the sale price, and diesel automobiles for which on average the tax represented 3%-4.5% of the sale price when the policy was first introduced. These percentages are higher for diesel pickup trucks, ranging from 4.2% when the policy was introduced, to around 7.8% by the end of the sample period. The effect of the increase in the NOx parameter in the tax formula (January 2016 and January 2017) is clear for diesel vehicles. In the case of gasoline vehicles, these jumps are smaller owing to their much lower

[14]Cargo vans are not considered in this analysis because, as mentioned above, they are all exempt.

NOx emission rates. Finally, the negative trend observed in the left panel as of 2017 reflects the significant reduction in the average emission rate of diesel automobiles.

Figure 3: Tax as percentage of sale price by fuel type, January 2015 to September 2019



Source: see Appendix A.

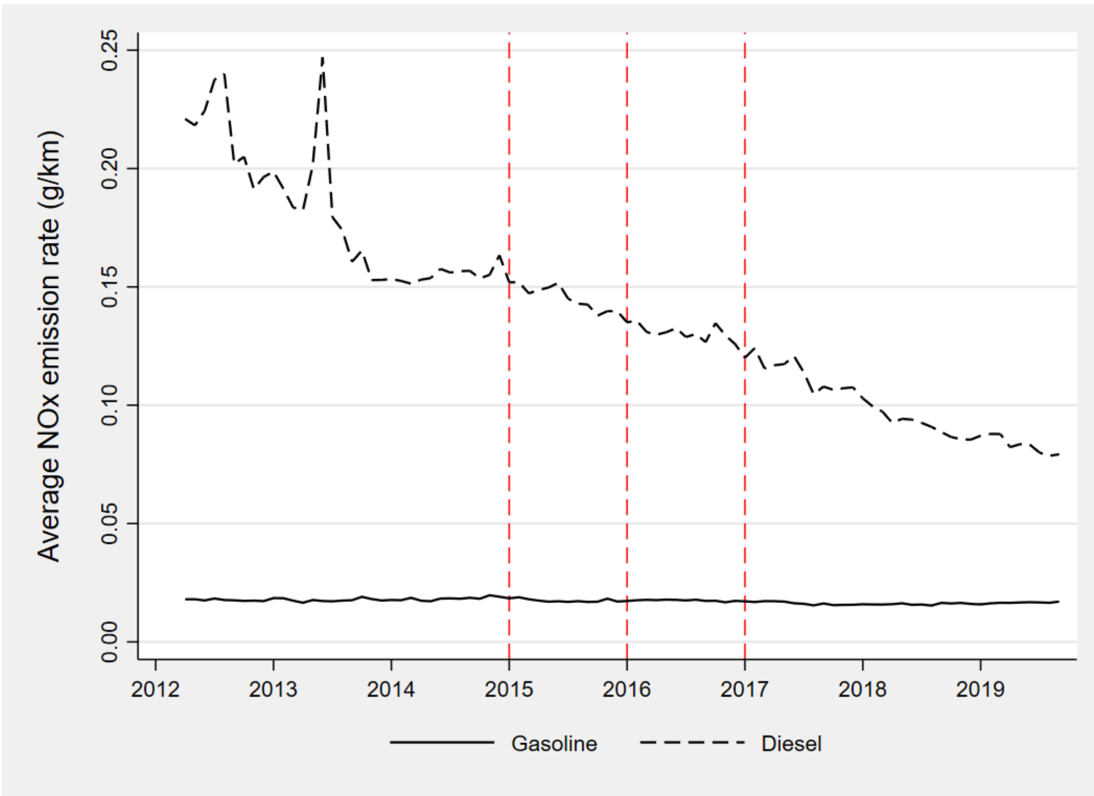
Figure 4 shows the average NOx emission rate of new automobile sales, which are all taxable. For gasoline-powered automobiles there does not seem to be a major change in average NOx emission rates. However, for diesel automobiles there is a steady decline starting just about the time the green tax was introduced.[15] This last observation may suggest a positive impact of the green tax on average emissions for this type of vehicle. Although we cannot rule this out, there may be other confounding effects. By 2015 all diesel automobiles sold in Chile complied with the Euro 6 standard even before it became mandatory (March 2023), simply because they were the only diesel models imported.[16] With our DID methodology we cannot disentangle the relative contribution of the tax versus these other confounding effects. Therefore, we leave the analysis of the effect of this policy on automobiles (for which there is no contemporaneous control group) for future research. In the remainder of this paper we will focus on pickups.

Between 2012 and 2014 there were various changes to these mandatory emission standards for new vehicles. They were not introduced homogeneously across the country nor by fuel type. Figure 5 shows their evolution across time, region, type of vehicle and fuel. In the case of diesel, the Euro 5 norm (or the EPA equivalent) was introduced earlier for vehicles sold in the Santiago Metropolitan region; in 2011 for light passenger vehicles and commercial vehicles with a net weighing of less than 1,305 kilos and September 2012 for the rest of light and medium sized vehicles. But for diesel vehicles sold in the rest of the country it was not mandatory until September 2013. Prior to that, the Euro 4 norm applied for six months that year and the Euro 3 norm earlier. For gasoline vehicles there was also a difference between the Santiago Metropolitan region and the rest of

[15]The spike observed in the average emission rate in 2013 is related to the sale of the remaining Euro 3 models before a new mandatory emission standard came into effect (see further below).

[16]All vehicles in Chile are imported. Owing to 33 free trade agreements (covering almost 80% of world GDP) almost all vehicles are imported free of custom duties. There is a wide array of brands and models available in the market, imported from Asia, Europe, and the United States.

Figure 4: Average NOx emissions of new gasoline and diesel automobiles (g/km)

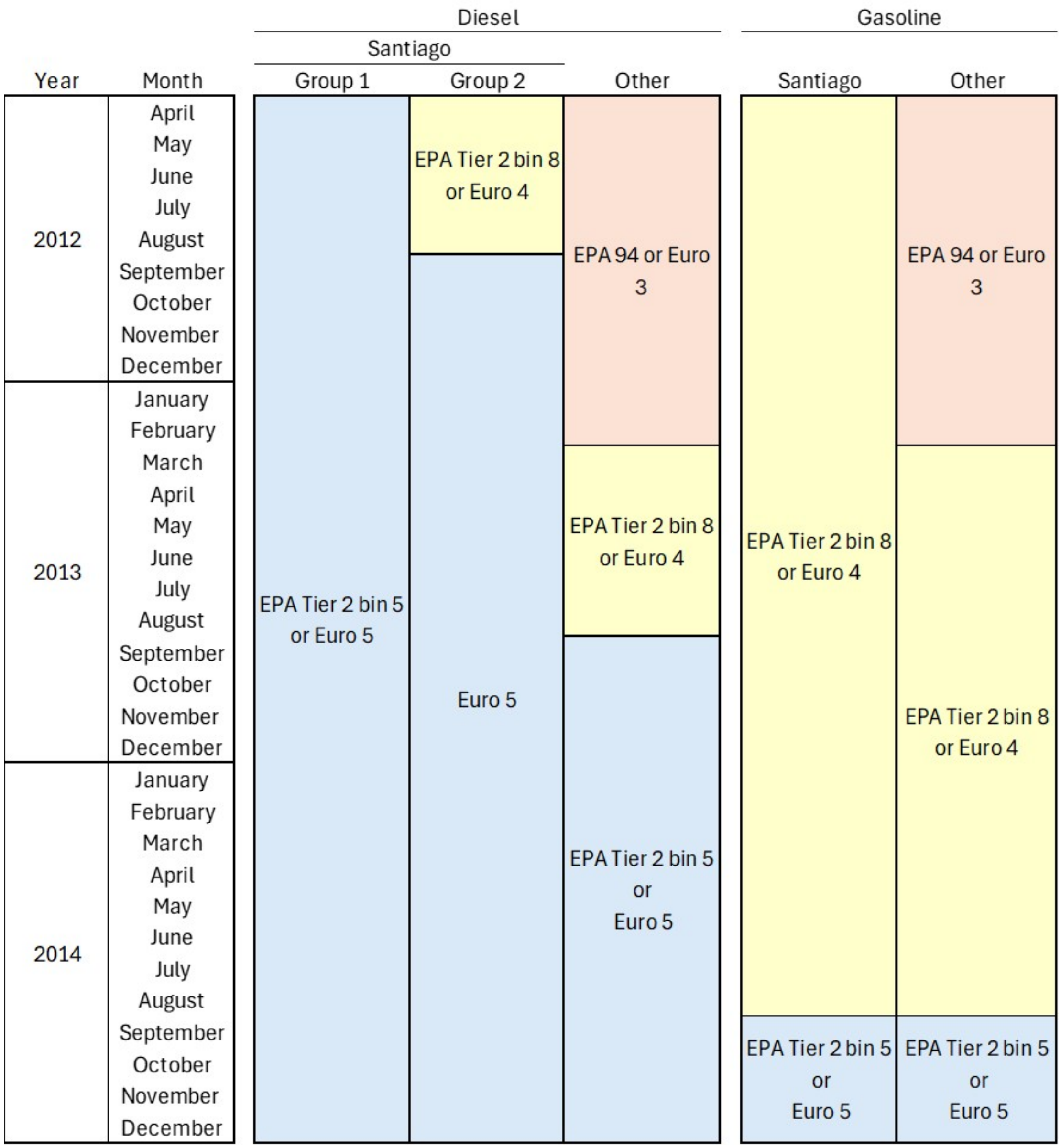


Source: see Appendix A.

the country, but only in relation to the timing of the introduction of the Euro 4 standard.

To minimize noise in the data from the staggered introduction of these norms, in our econometric estimations we use data from March 2013 onwards. In addition, we include different monthly time effects for Santiago and the rest of the country to control for the remaining difference in the introduction of these standards. The Euro 6 became mandatory for all vehicles and geographic areas in March 2023, beyond the horizon of our dataset. Although, as will be discussed below, vehicles with this norm were sold prior to this standard being mandatory.

Figure 5: Evolution of mandatory emission standards for new vehicles, April 2012 to December 2014



Source: Subsecretaría de transportes (2023). Group 1 includes all passenger vehicles and commercial vehicles with a net weight less than 1,305 kilos. Group 2 includes commercial vehicles with a net weight between 1,305 and 2,700 kilos plus medium sized vehicles (weight between 2,700 and 3,860 kilos).

5 Possible transmission channels for the tax

As mentioned above, for pickup trucks we have both a taxable and non-taxable group. We will exploit this feature to estimate the possible casual effects of the tax. Therefore, in what follows, we limit the discussion to this type of vehicle only.[17]

There are several behavioral changes that the tax could induce in the pickup vehicle market. These are:

1. Lower vehicle sales (extensive margin). Individuals who have to pay the tax and would otherwise have bought a pickup truck, desist from purchasing a vehicle.

2. Substitution to an automobile. Individuals who have to pay the tax and would otherwise have bought a pickup truck, purchase an automobile instead.

3. Since the tax only applies to pickups with load capacity below 2,000 kilos, there is a discontinuity in the tax that may induce some individuals to purchase a heavy-duty vehicle with a load capacity above this threshold.

4. Substitution to a gasoline pickup truck. Individuals who have to pay the tax and would otherwise have purchased a diesel pickup truck, purchase a gasoline one instead.

5. Substitution for a cleaner pickup model. Individuals who have to pay the tax and would otherwise have purchased a particular model of pickup truck (either gasoline or diesel), opt for a cleaner pickup model within the same fuel type.

[17] Summary statistics for pickup trucks are presented in Appendix B

In this section, we will briefly discuss each of these points in turn. Table 3 shows the number of taxable and exempt pickup truck sales and the share in the total for the full years of our sample (2013-2018).[18] If the tax reduced overall pickup sales, we should expect a fall in the proportion of taxable purchases over the total since exempt vehicles are not affected. However, from the table we see that, except for 2014, the proportion of taxable pickup sales remained relatively stable, and it even increased in the last two years of the sample.

Table 3: Pickup truck sales by tax status, 2013-2018

	Diesel + Gasoline				
Year	Taxable	Share	Exempt	Share	Total
2013	5,039	12.0%	36,936	88.0%	41,975
2014	5,226	14.1%	31,745	85.8%	36,971
2015	6,638	12.2%	47,678	87.8%	54,316
2016	7,349	12.1%	53,211	87.9%	60,560
2017	9,531	12.7%	65,661	87.3%	75,192
2018	11,805	13.9%	72,959	86.1%	84,764

Source: see Appendix A.

Therefore, we do not find much evidence for a significant impact of the tax on the extensive margin of the demand for pickup trucks. For the same reason, it is unlikely that there was substitution from pickup trucks to automobiles. This last effect would also have been evidenced by a fall in the share of taxable pickup truck sales over total sales.

The figures shown in Table 3 also suggest that there is no evidence of an increase in the use of a commercial entity to purchase a pickup truck without paying the tax. The tax authorities are very strict on the type of firm that can incorporate a pickup as part of their assets. More importantly, prior to the green tax there

[18]We thank Leonel Borja for suggesting this table.

were large tax benefits of purchasing a vehicle through a firm.[19] Therefore, it would be expected that all those who could purchase a pickup through a firm would do so irrespective of the green tax.

As for channel 3, there are very few pickup models with a load capacity over 2,000 kilos.[20] In our sample period, the sale of these heavier pickups was small and unlikely to affect our results. Furthermore, number of sales of these models –as well as all pickups with an engine size above 6 liters– declined starting in 2015. Therefore, we can also discount this possible transmission avenue of the tax.

This leaves channels 4 and 5 as possible substitution effects. Figure 6 shows the proportion of new diesel vehicle sales during the sample period.[21] Among exempt sales, this proportion fell slightly but remained close to 85% before and after the introduction of the tax. However, for taxable sales, the decline was greater, from around 60% before the tax to as low as 50% at the end of the sample period. A visual inspection of the graph may suggest an anticipatory effect of the tax for the taxable group, as the share of diesel vehicles increased significantly in the last quarter of 2014 just before the tax was introduced.

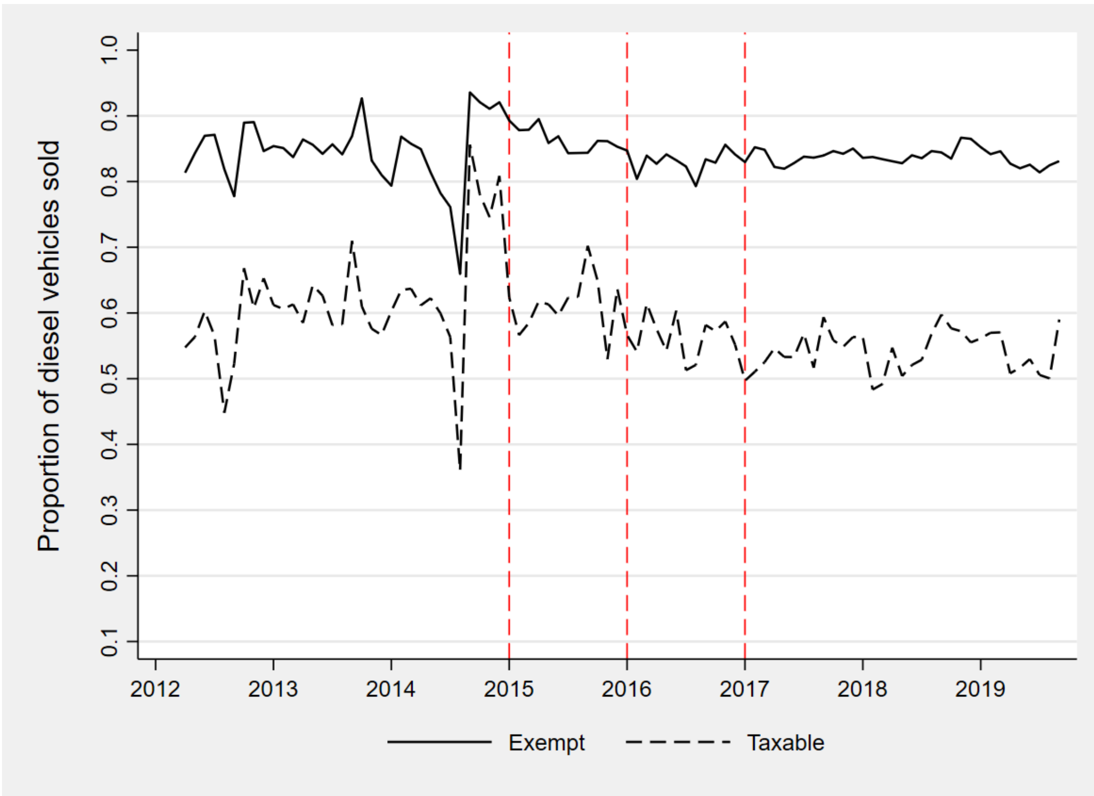
The tax could also have an impact on NOx emissions through substitution inside the diesel-powered pickup category (intra-fuel substitution) in favor of cleaner models. To inspect this visually, we plot the average emission rate of new diesel pickup trucks separated between exempt and taxable vehicles (Figure 7). We see

[19]These purchases do not pay the 19% value added tax. When the vehicle is later sold, they would have to pay this tax. However, given the lower price of a used vehicle and the financial benefit of deferring the tax payment, the economic benefits of purchasing a pickup truck through a commercial entity are large. Furthermore, if the vehicle is sold after three years by or to a small business, then this sale is not even subject to VAT tax.

[20]An online search identified only the Ford F-350 and F-450, the RAM 3500, the Chevrolet Silverado Super Duty 3500 HD and the GMC Sierra 3500 HD.

[21]The sharp drop in diesel sales in September 2014 is explained by the liquidation of gasoline Euro 4 stocks before the Euro 5 norm became mandatory in September of that year for gasoline vehicles.

Figure 6: Proportion of diesel pickup trucks sold by taxable status, April 2012 to September 2019

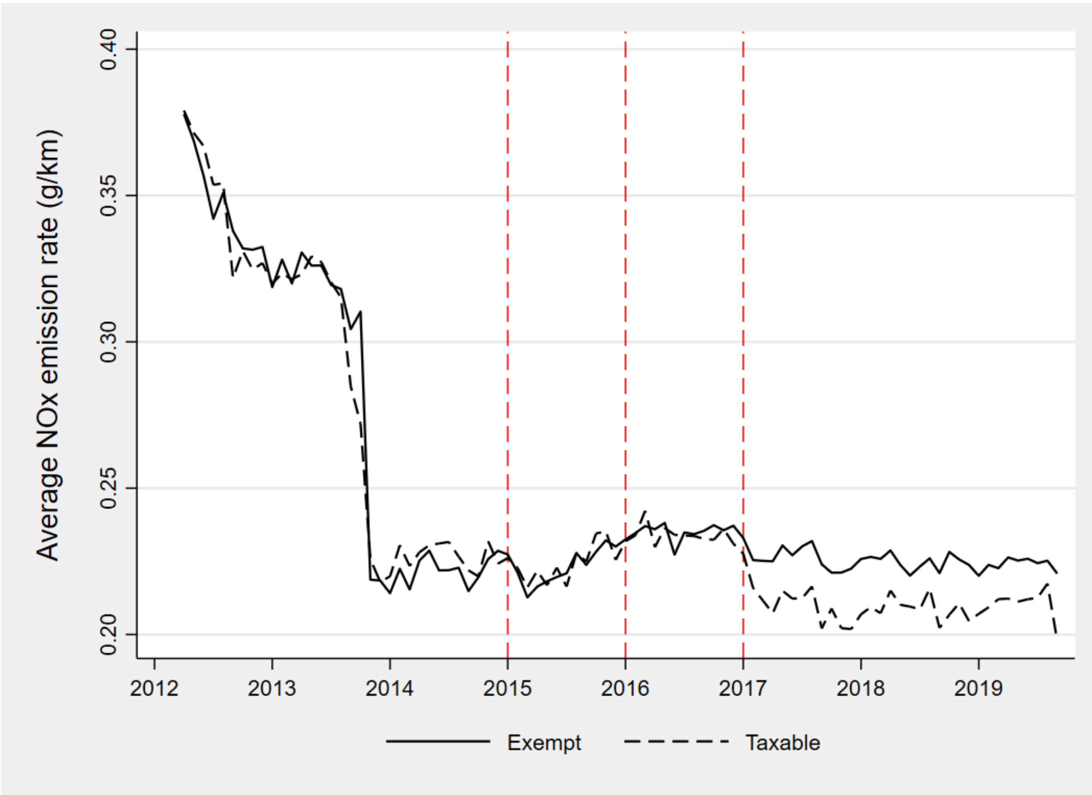


Source: see Appendix A.

a large drop in the average emission rate in 2013, related to the Euro 5 standard becoming mandatory for new diesel vehicles in September 2013. The impact of this standard seems to be the same for both groups, albeit slightly earlier in the taxable group. We also observe a divergence in the average NOx emission rate of each group at the end of 2016. Below we analyze this change empirically and provide some possible explanations.

An analogous decrease is not present in the case of gasoline pickups (Figure 8). In this case, it seems that post-tax the average NOx emission rate of new vehicles increased. This may be related to the substitution from diesel to gasoline powered pickup trucks. For example, if individuals who substituted from a diesel to a gasoline alternative have a preference for a relatively larger

Figure 7: Average NOx emission rate (g/km) of new diesel pickup trucks by taxable status, April 2012 to September 2019

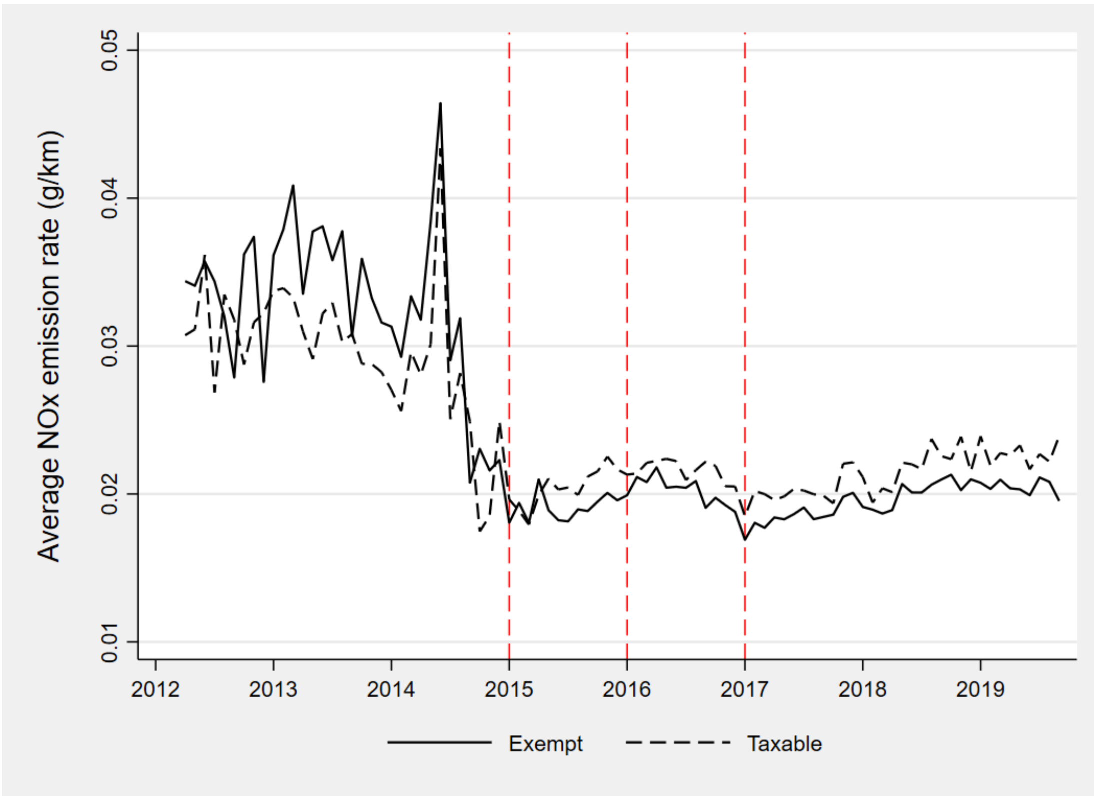


Source: see Appendix A.

than average gasoline model (or another characteristic correlated with the NOx emission rate).

In summary, we find suggestive evidence for an impact of the new tax through channels 4 and 5 discussed above. We now proceed to analyze these two issues using a more rigorous empirical approach.

Figure 8: Average NOx emission rate (g/km) of new gasoline pickup trucks by taxable status, April 2012 to September 2019



Source: see Appendix A.

6 Methodology

To estimate the effect of the green tax we use a DID approach. As mentioned above, in the case of new pickup truck sales, one group paid the tax (private purchase) while another group were exempt (commercial purchase). We consider the former group as the treatment group and the latter as the control group.[22]

[22]The exogeneity assumption may be suspect if after the tax was implemented more individuals chose a commercial entity to purchase a new vehicle. However, this is unlikely. As discussed in footnote 19 there were (and still are) tax incentives to purchase a new vehicle through such an entity, so we would expect all those who could, to have done so independently of the green tax. As shown in Table 3, close to 90% of all pickup trucks are purchased through a commercial entity and this proportion did not change in the sample period.

Equation (2) presents our model:

$$y_{it} = \alpha + \beta \cdot T_i + \sum_{d=1}^{3} \delta_d \cdot D_{it}^d + \gamma_{tr} + \epsilon_{it} \tag{2}$$

where:

- y_{it}: dependent variable.
- T_i: treatment variable, which takes the value 1 if observation i is a private purchased vehicle subject to the tax and 0 otherwise.
- D_{it}^d: are the interactive (DID) terms. These are our main variables of interest and are discussed in more detail below.
- γ_{tr}: month-region time effects that control for variables affecting sales of both taxable and exempt vehicles in each month and region (Santiago and the rest of the country).
- α, β and δ_d: model parameters.
- ϵ_{it}: the error term.

As dependent variable, we first use the probability of choosing a diesel (instead of gasoline) powered pickup truck. We then estimate the model on the NOx emission rates, separately for diesel and gasoline-powered pickup trucks. These variables account for the potential effect of the tax through the two transmission channels discussed in the previous section: an inter-fuel channel (substitution from diesel to gasoline vehicles) and an intra-fuel channel (substitution from more to less polluting models inside each fuel category). As a complementary analysis, we also discuss results for the CO2 emission rates.

The treatment dummy, T_i controls for the difference in the average level of the outcome variable between the taxable and exempt group not influenced by the policy.

The D_{it}^{d} interactive variables are the three treatment periods, corresponding to the original introduction of the tax, and the increase in the NOx parameter in the tax formula in early 2016 and early 2017, multiplied by the treatment status. The coefficients associated with these three variables measure the casual effect of the initial impact of the tax and the incremental effect of each change in the NOx parameter with respect to the previous treatment and are therefore the parameters of interest in our research.[23] Specifically, these terms are defined as:

$$D_{it}^{1} = T_i \cdot I(t > Dec.2014)$$
$$D_{it}^{2} = T_i \cdot I(t > Dec.2015)$$
$$D_{it}^{3} = T_i \cdot I(t > Dec.2016)$$

where T_i is the discrete variable described above defining whether a vehicle is in the treated group (private purchase) or not, and $I(c)$ is an indicator function equal to one if condition c is met and zero otherwise.

The regional monthly dummies are important to control for macroeconomic shocks (inflation, exchange rate movements, unemployment, etc.) and other unobservables that affected all vehicle sales in a given month. We estimate a separate time effect for Santiago and the rest of the country since the mandatory emission standards came into effect at different times in each of these zones.

[23]Note that our data is not a panel so we are not faced with the problems of two-way fixed effects staggered difference-in-differences estimations as in de Chaisemartin and D'Haultfoeuille (2020), Goodman-Bacon (2020) and Callaway and Sant'Anna (2021).

7 Results

As described above, we restricted the sample to March 2013 through September 2019 to reduce noise from the introduction of emission standards.[24] We examine first the substitution effect from diesel to gasoline vehicles and then the substitution to cleaner models within each fuel type.

7.1 Substitution from diesel to gasoline pickups

Table 4 presents the estimated results for the probability of particular sale being a diesel versus a gasoline pickup truck. We estimated both a linear probability model and a logit model.[25] The second column in the case of each model corresponds to the elimination of observations of the last three months of 2014, 2015 and 2016, in case there was an anticipatory effect before the introduction of the tax and each subsequent change to the tax formula. For the logit model the reported results are the marginal effects at the sample average.

Qualitatively, the results are similar for both models, although the impacts are smaller in the case of the logit. In both cases, there is a reduction in the probability of choosing a diesel pickup for treated observations when the tax was introduced in December 2014. This effect varies between 2.1 to 3.6 percentage points according to the linear model and between 2.5 to 2.7 in the case of the logit model.

The change in the NOx parameter of the tax formula in January 2016 reveals a further decrease in the probability of choosing a diesel vehicle among taxable

[24] The qualitative results are unchanged if the full sample is used. These are available upon request.
[25] Some authors recommend the LPM over a binary response model because of the strong distributional assumptions required on the error term in these last models. See the discussion in Angrist and Pischke (2009), Chapter 3.

Table 4: Linear probability model and logit estimates of the probability that a new pickup truck was diesel-powered

Variables	(1) LPM	(2) LPM	(3) Logit	(4) logit
Treated	-0.211***	-0.222***	-0.174***	-0.179***
	(0.005)	(0.006)	(0.004)	(0.004)
D^1	-0.036***	-0.021**	-0.027***	-0.025***
	(0.008)	(0.009)	(0.006)	(0.007)
D^2	-0.021**	-0.022**	0.002	0.004
	(0.009)	(0.010)	(0.006)	(0.007)
D^3	-0.029***	-0.032***	-0.019***	-0.023***
	(0.007)	(0.008)	(0.004)	(0.005)
Observations	408,386	363,012	408,386	363,012
Adj. or pseudo R^2	0.065	0.065	0.058	0.058
Observations from Oct-Dec 2014, 2015 and 2016 omitted	No	Yes	No	Yes

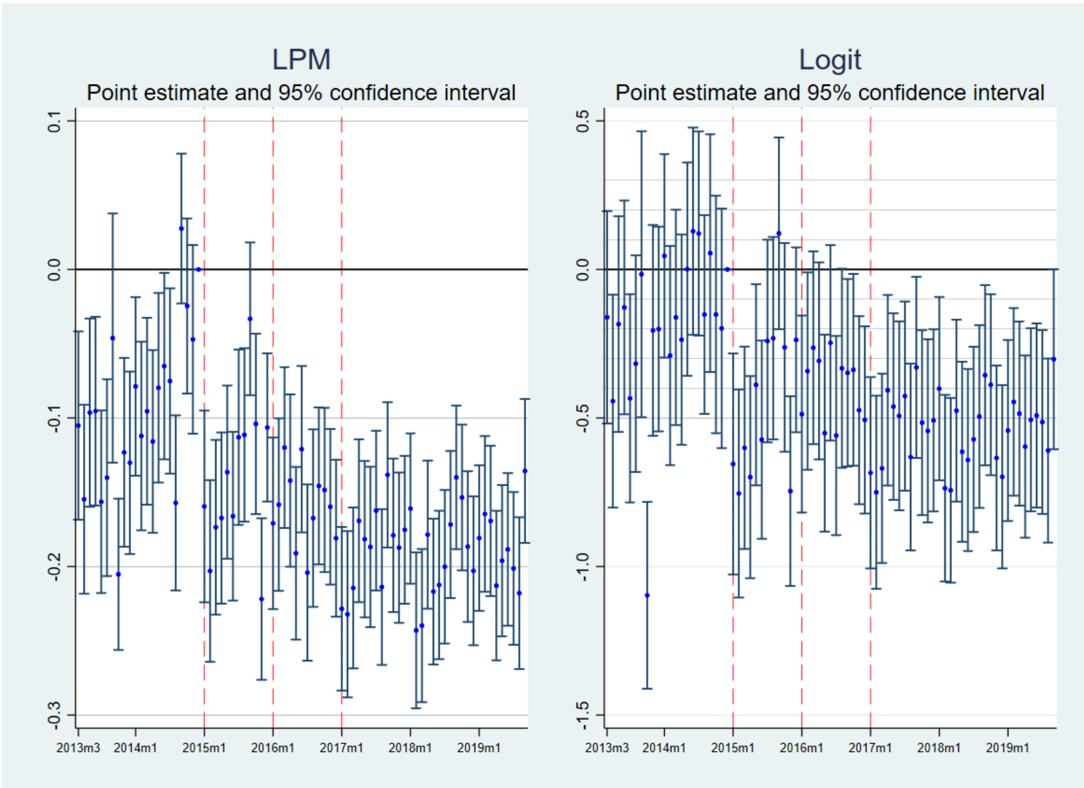
Source: see Appendix A. LPM stands for Linear Probability Model. The reported coefficients in the case of the Logit model correspond to the marginal effects at the sample mean. All models include separate monthly time effects for Santiago and for the rest of the country.

sales, but this is only apparent in the results for the linear model. When the NOx parameter was further increased in January 2017 there is an additional negative effect on this probability of between 1.9 to 3.2 percentage points, depending on the model.

Therefore, we do find evidence for an impact of the tax on the probability of a given sale being a gasoline rather than a diesel pickup truck. Overall, the introduction of the tax and the subsequent changes to the tax formula increased this probability by 4 to 8 percentage points. This reduced the average NOx emission rate as gasoline vehicles emit less of this pollutant compared to diesel vehicles.

Figure 9 presents the event study results for both of the above models. These figures show that after the tax was introduced the probability of purchasing a diesel-powered vehicle fell among treated observations. However, in the case

Figure 9: Event study of impact of green tax on the probability of a diesel sale



Source: see Appendix A.

of the linear model, the assumption of parallel trends prior to the introduction of the tax would have to be rejected, although this seems to be caused by the last few months of 2014 and may be related to an anticipatory effect. In both models there seems to be a trend towards a higher probability of purchasing a diesel vehicle among non-commercial buyers prior to the tax. However, this would tend to generate a downward bias in the estimated impacts of the tax so our regression results would be conservative.

7.2 NOx emissions rates within each fuel type

Table 5 presents the regression results on the NOx emission rate by fuel type. The first two columns are the results for diesel pickup trucks while the last two for gasoline ones. The models in the even-numbered columns were estimated excluding the three months prior to the introduction of the tax and before each of the subsequent changes in the tax formula.

Table 5: Regression results of NOx emission rates by fuel type

Variables	(1) Diesel	(2) Diesel	(3) Gasoline	(4) Gasoline
Treated	-0.008**	-0.008**	-0.079***	-0.089***
	(0.003)	(0.003)	(0.014)	(0.014)
D^1	0.009**	0.010*	0.149***	0.139***
	(0.004)	(0.005)	(0.021)	(0.024)
D^2	-0.008	-0.002	0.007	0.021
	(0.005)	(0.006)	(0.021)	(0.025)
D^3	-0.098***	-0.104***	0.023	0.029*
	(0.005)	(0.006)	(0.014)	(0.017)
Observations	330,061	292,052	78,325	70,960
Adjusted R^2	0.135	0.144	0.073	0.077
Observations from Oct-Dec 2014, 2015 and 2016 omitted	No	Yes	No	Yes

Source: see Appendix A.

For the case of diesel vehicles, the introduction of the tax did not lower the NOx emission rate. On the contrary, there is a very small increase in this parameter during 2015, close to 1% although not very significant statistically when the last three months of 2014 are omitted. Only in January 2017, after the second increase in the NOx parameter, is there a significant change in the average emission rate by -9.3% compared to the exempt group.[26] Eliminating the three months prior to each tax changes this percentage slightly (to -9.9%). Also noteworthy is that in Table 5 the coefficient of the *Treated* variable is very small. This implies that on average the emission rates of diesel pickup trucks

[26]Since the dependent variable is in logarithm, the percentage change in average emissions is calculates as $(e^{\beta} - 1)$ where β is the estimated coefficient.

purchased by commercial entities were not much different to those purchased by private individuals, except for the impact of the tax.

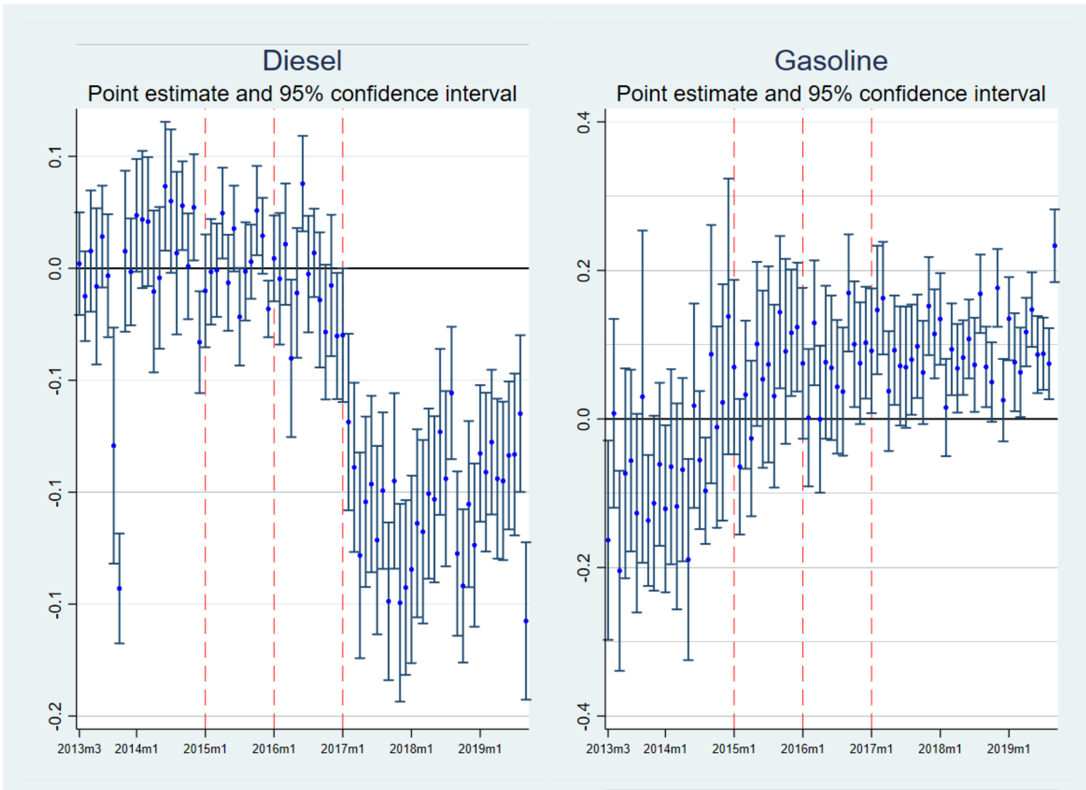
The case of gasoline pickups is different. In this case, there is an increase in the average NOx emission rate when the tax was introduced, between 14.9% to 16.0%, depending on the estimation sample. However, subsequent tax changes do not seem to have increased this parameter further.

These last results can be rationalized as follows. When the tax was introduced, there was substitution from diesel-powered pickups to gasoline pickups among treated observations. The D^1 coefficient in column (1) and (2) of Table 5 would suggest that the substituted vehicles had a NOx emission rate similar to the group average. That is, the substituted pickups were not the least polluting ones among diesel trucks. However, they may have substituted to an above average sized (or weight) model among the gasoline options, implying a higher NOx emission rate compared to the average for that group. On average, diesel pickup trucks are larger and heavier (and thus more polluting) than gasoline models.[27] Some individuals that would have purchased a diesel-powered pickup truck in the absence of the tax may have chosen a more polluting than average gasoline powered model. The same conjecture, however, would not apply for the case of the D^3 coefficient, although it is marginally positive in the model shown in column (4).

Although reasonable, this last conjecture must be tempered by the evidence from the event study results (Figure 10) that indicate that in the case of gasoline sales the parallel trend assumptions is suspect. There seems to be a rising trend of the NOx emission rate among gasoline powered pickups prior to the tax that could bias the results of Table 5 for this fuel type.

[27] Before the tax was introduced there were few diesel-powered pickup trucks purchased with a displacement under 2.0 liters and the mode was 2.5 liters. While for gasoline there were many sold with a displacement between 1.0 and 1.3 liters and the mode was 2.2 liters.

Figure 10: Event study of NOx emission rates by fuel type



Source: See Appendix A

One final point to make is that comparing column (1) to (2) and (3) to (4) of Table 5 we see that the coefficient estimates are very similar, so there does not seem to be much evidence for an anticipatory effect of the tax.

8 Discussion

We find evidence that the tax induced a substitution from diesel to gasoline vehicles. We did not find much evidence for an intra-fuel substitution to cleaner models within the diesel alternatives, except after January 2017. We will discuss this last finding below given that it raises some interesting issues.

In the case of gasoline-powered pickups, we find evidence for an increase in NOx emission rates. This may be related to individuals that without a tax would have purchased a diesel alternative, vehicles that tend to be larger than the average gasoline model. So, there is a composition effect on the average NOx emission rate.

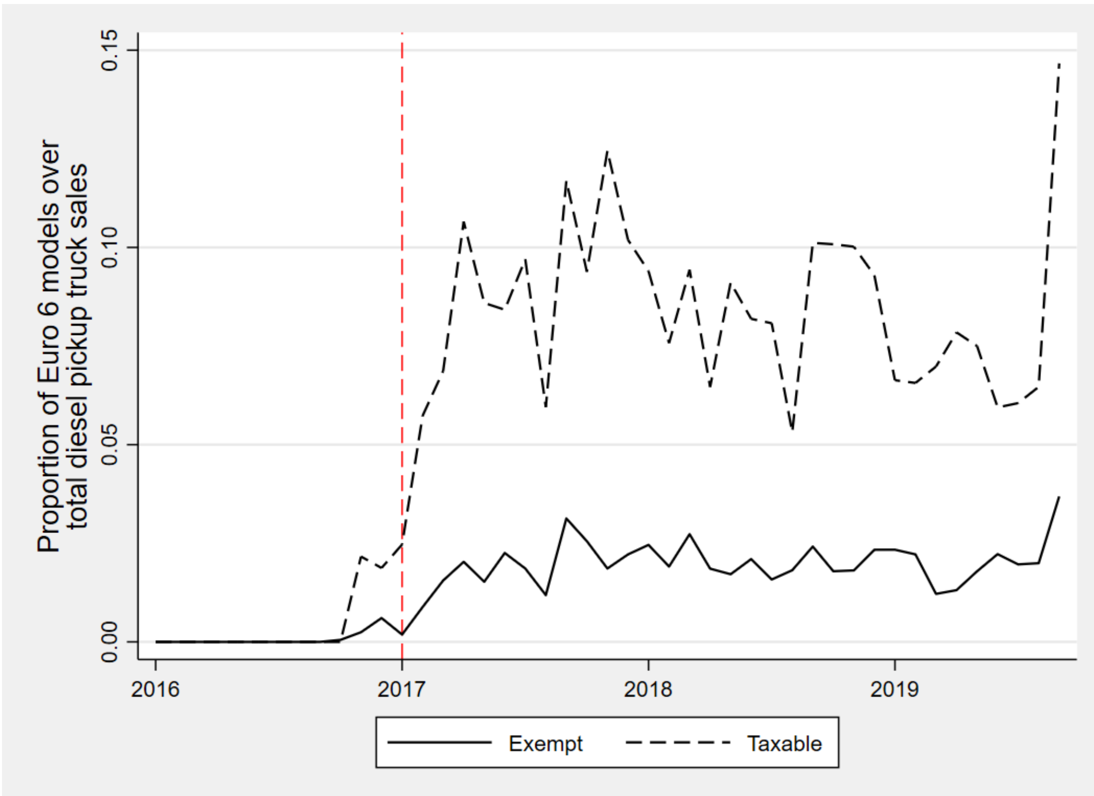
Despite the increase in the average NOx emission rate for gasoline pickups, the next section shows that there was an overall reduction in this parameter. The substitution from diesel to gasoline had a much larger effect in reducing the emission rates than the increase in this parameter for gasoline vehicles.

For diesel pickups there is a drop in the average emission rate starting in January 2017. This last result must however be interpreted with caution. Around the same time that the tax parameter changed, the available choice set among diesel pickup trucks increased.

Until September 2016 there were no diesel pickup trucks available in the Chilean market meeting the Euro 6 standard. In October of that year the Euro 6 SsangYong Actyon Sports pickup truck was introduced. The Euro 6 standard sets an upper limit for NOx emissions that is much lower than that of the Euro 5 standard (0.08 grs/km vs. 0.18 grs/km, respectively), and this translates into a much lower tax.

Figure 11 shows the participation of the new SsangYong pickup truck models in both the treatment and control groups. Soon after the introduction of these models and after the increase in the NOx parameter in the tax formula in January 2017, the share of Euro 6 pickup trucks in total sales within the taxable group increased to over 10%. In the exempt group, the sales of these models remained well below 5%.[28]

Figure 11: Market share of Euro 6 diesel pickup trucks (taxable vs exempt)



Source: see Appendix A.

Unfortunately, we cannot determine what portion of the estimated effect is due to tax and what portion is due to the particular characteristics of these new pickup models. The new alternative may have attributes that made them

[28]A buyer switching from a diesel pickup truck to an otherwise similar gasoline alternative results in a more significant reduction of NOx emissions than a buyer switching from a more to a less polluting diesel model. Therefore, the environmental impact of the introduction of the new models is ambiguous. On the one hand, for those who would not switch to a gasoline alternative, the cleaner Euro 6 models may be an attractive alternative, reducing the NOx emission rate of their purchase. On the other hand, if these cleaner models reduced the substitution towards gasoline alternatives, then the average emission rate would be higher compared to a counterfactual without these new models.

relatively more attractive to non-commercial customers irrespective of the tax.[29] However, it is interesting to note that the marketing strategy used by the manufacturer and dealers of the new models emphasized the tax reduction benefits of these lower emission vehicles. An example is the Facebook post from SaangYong Chile in April 2017 (Figure 12) which reads:[30] "With the Actyon Sports 2.2 the adventure is more convenient, thanks to the low cost of the Green Tax". There were many other ads, posts, press and specialized media reports making explicit reference to the associated green tax reduction for this new model.[31]

In summary, we cannot be certain that the reduction on average NOx emissions of diesel pickup trucks during the last period of our data can be entirely attributed to the green tax. We therefore treat the estimated coefficient for D^3 in columns (1) and (2) of Table 5 as an upper bound of the effect of this policy.[32]

[29]As note by an anonymous reviewer, a zero effect of the tax cannot be ruled out. A structural demand model would need to be estimated to explore this issue further. This goes beyond the scope of the current paper.

[30]Own translation.

[31]See for example:
https://www.racing5.cl/euro-6-la-norma-de-emisiones-que-te-hara-pagar-menos-impuesto-verde/
https://www.ssangyong.cl/noticias/ssangyong-primera-en-chile-con-norma-euro-6/
https://noticias.autocosmos.cl/2017/04/15/ssangyong-actualiza-a-euro-vi-toda-su-gama-de-modelos
https://www.rutamotor.com/ssanyong-presenta-su-nueva-version-de-la-actyon-sports-en-chile/
https://noticias.autocosmos.cl/2017/10/02/test-drive-ssangyong-actyon-sports-2017
https://www.emol.com/noticias/Autos/2017/03/22/850637/Nuevo-motor-diesel-Euro-VI-para-la-Ssangyong-Actyon-Sports.html
https://www.df.cl/noticias/site/docs/20230428/20230428200505/suplemento_20230430.pdf.

[32]One seminar participant noted that we may be underestimating the beneficial impact of the tax if it accelerated the arrival of the Euro 6 model given the price advantage that it would have. As mentioned earlier, the Euro 6 standard was not mandatory at the time. If this was the case, the early reduction in emissions from taxable and non-taxable sales of Euro 6 vehicles –compared to a counterfactual scenario without the tax– could possibly be attributed to the green tax.

Figure 12: Example of publicity for the SaangYong Actyon pickup truck, April 2017

Source: https://web.facebook.com/ssangyongchile/posts/sabías-que-con-los-modelos-ssangyong-euro-6-terminas-pagando-menos-impuesto-verd/10155722154869423/?_rdc=1&_rdr.

It is interesting to note that if the introduction of Euro 6 models coupled with the tax did in fact reduce average emissions, then the Chilean experience provides an interesting policy lesson: to maximize the environmental impact of a registration tax, other complementary policies may be required to widen the choice set available to consumers. Relevant to our study, Chile and Korea signed a free trade agreement in 2003 that allowed the Euro 6 SsangYong to arrive free of import duties. Other free trade agreements signed by Chile guarantee that advances in vehicles technology can be quickly introduced in this market, giving consumers more choices to react to a price signal.

9 Expected environmental impact

How significant was the reduction in NOx emissions attributed to the green tax? To obtain an order of magnitude, in this section we simulate total emissions with and without the tax.

To do this we estimate the model for all pick-up trucks, irrespective of their fuel type. This will incorporate both substitution channels noted above: the switch between diesel and gasoline models and the substitution within each fuel type.[33]

The results are presented in Table 6. There is a significant fall in average emissions starting in January 2015. This is most probably due to substitution

[33]To see this more clearly note that the expected value of emissions for a new pickup truck will be:

$$E[NO_x] = P[Diesel] \cdot E[NO_x|Diesel] + P[Gasoline] \cdot E[NO_x|Gasoline]$$

where $P[i]$ is the probability that individuals purchase a pickup truck powered by $i \in (diesel, gasoline)$ and $E[NO_x|i]$ is the average NOx emissions conditional on the vehicle being of fuel type i. Therefore, changes in average emissions will be a combination of changes in the probability of purchasing each fuel type $P[i]$ and changes in the average emissions of each fuel type due to a substitution effect.

towards gasoline vehicles. There is a smaller decrease starting in January 2016. Finally, there is an additional drop in average emissions starting in January 2017. This last effect is an upper-bound to the true effect as noted above. Nonetheless, we use it to see whether in this best-case scenario the green tax had a relevant impact on overall NOx emissions.

Table 6: Regression results of NOx emission rates by fuel type

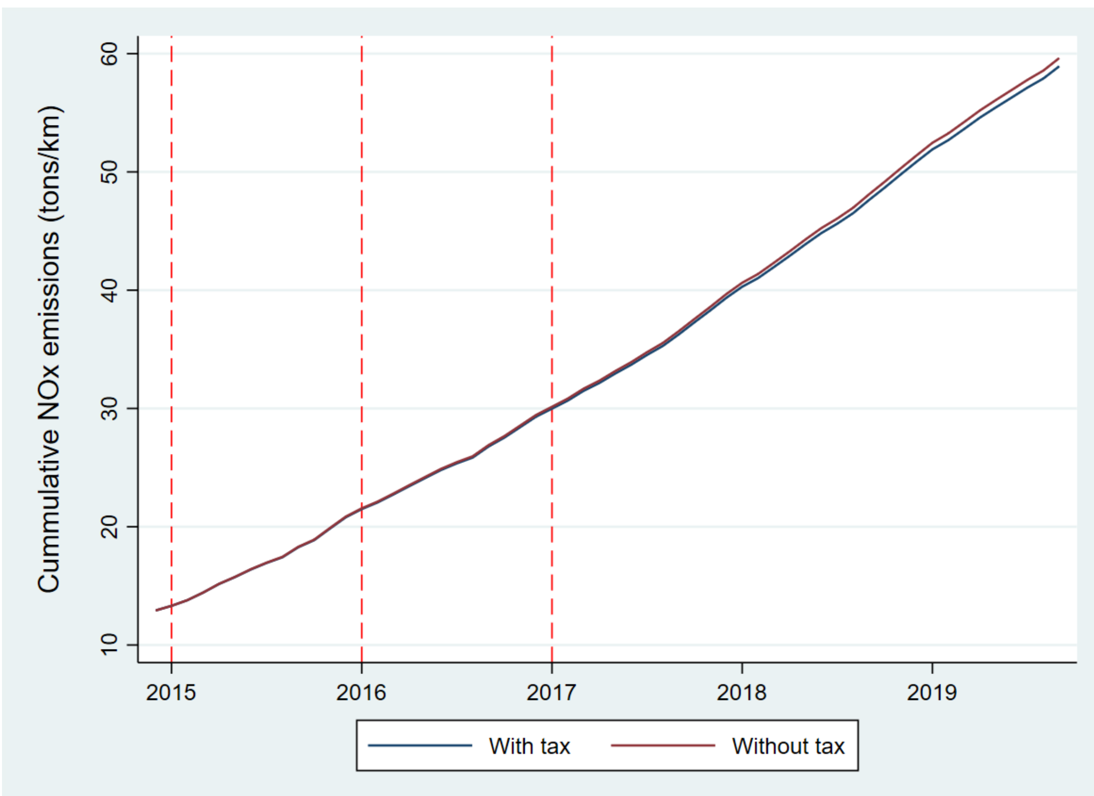
	(1)
Variables	ln_nox
Treated	-0.525***
	(0.013)
D^1	-0.098***
	(0.022)
D^2	-0.046**
	(0.023)
D^3	-0.095***
	(0.018)
Observations	408,386
Adjusted R-squared	0.070
Observations from Oct-Dec 2014, 2015 and 2016 omitted	No

Source: see Appendix A. Includes separate monthly time effects for Santiago and for the rest of the country.

We use this estimated equation to predict average NOx emissions, first with the estimated DID coefficients and then with these three coefficients equal to zero. These two series are multiplied by the number of pick-up trucks sold each month to simulate emissions with and without the tax. We also accumulate the effects to get a more dynamic picture. That is, the lower emissions from the new vehicles purchased in 2015, for example, are accumulated to the end of the period.

Strong assumptions lie behind our approach, the most important being that all new vehicles are assumed to travel the same number of kilometers or that the distribution of kilometers traveled does not significantly vary by model. In addition, we only consider emissions from new pickup trucks, ignoring emissions from other types of new and used vehicles. Therefore, our simulation should be interpreted with care and only to get a general sense of the aggregate impact of the tax, not as an estimate of actual emissions. With this caveat in mind, the results are presented in Figure 13.

Figure 13: Cumulative NOx emissions of the new pickup truck fleet, December 2014 to September 2019



Source: own calculations based on information described in Appendix A.

Despite the positive impact of the green tax on average NOx emissions and even in our best-case scenario, the aggregate effect is very small. By the end of the period, the cumulative emissions of the new pickup truck fleet are only 1.2% below the trajectory without the tax.

The most important explanation for our simulated result is that the tax base is very narrow. In fact, 80% of pickup trucks are diesel-powered, and of this group 90% are commercial and therefore exempt from the tax. This leaves a small group of highly polluting vehicles for the tax to operate. Below we discuss the policy options to increase the effectiveness of the green tax as an environmental policy.

Furthermore, our results probably overestimate the environmental impact of the policy. If the reasonable assumption is made that commercial vehicles travel more kilometers per year than privately own vehicles, then the share of overall emissions attributed to this last group is lower than in our simulation. Therefore, a policy that reduces the emissions from the taxable group would have an even lower impact than those reported here. Likewise, an optimal fuel choice model –as in Hennessy and Tol (2011)– would indicate that, given the pump price difference, those that substitute from a diesel to a gasoline model are probably individuals at the lower end of the distribution of kilometers traveled per year. Both effects imply that our results overstate the emissions reduction attributed to the tax.

Another environmental concern is that due to the substitution towards gasoline pickup trucks the green tax may have increased CO2 emissions. In Appendix C we present the results of a model analogous to those of Table 6 but for CO2 emissions (Table C.1). The results indicate that there is scant evidence for an increase in these emissions, except a small rise of 1.6% post January 2016. Unlike NOx, the emission rates for CO2 are similar between diesel and gasoline pickup trucks (see Table B.1 in Appendix B). Therefore, the substitution from diesel to gasoline vehicles should not have had a large impact on this pollutant.

10 Conclusions

In this paper we estimated the behavioral changes of an environmental registration tax introduced in Chile at the end of 2014. This tax targets NOx emissions of new light and medium duty vehicle sales. Based on a novel dataset and taking advantage of the fact that the policy design defined the taxable and exempt groups in the case of pickup trucks, we estimate a difference in differences model for this group of vehicles.

Our results suggest that the tax, that represented at most 7% to 8% of the purchase price of a new diesel pickup truck, may have induced consumers to switch to a gasoline alternative with much lower NOx emission rates. The probability that affected individuals chose a diesel pickup truck fell by 2 to 4 percentage points (depending on the estimated model) when the tax was introduced and a further 2 to 4 percentage points when the NOx parameter in the tax calculation formula was increased in January 2017.

Our findings also suggest that some consumers might have switched to cleaner diesel models. By the end of our sample period the average NOx emission rate of new diesel pickup trucks affected by the tax decreased by around 9% to 10%. However, this second substitution channel is only noticeable after a new "cleaner" diesel pickup model was introduced in the market in October 2016. Although the marketing strategy used to sell this new model emphasized the savings in the registration tax, we cannot be certain that the tax was responsible for its early arrival or for the higher sales of this model observed among taxable compared to exempted purchases. Thus, the 9%-10% reduction in the average NOx emission rate would represent an upper bound of the impact of the tax on the substitution to cleaner models within diesel sales.

If part or all of this last effect could be attributed to the policy, it would suggest that to maximize the environmental impact of a tax or other economic price instrument, complementary measures should be adopted to broaden the set of available substitutes. For example, by reducing trade barriers to vehicle imports.

As for the aggregate environmental impact of the registration tax, we estimate that it was quite low. The cumulative NOx emissions of new pickup trucks was at most 1.2% lower by the end of the period. The reason is that the tax base of this policy is very narrow, with most diesel pickup trucks (90%) purchased by commercial entities and therefore exempt. We do not find evidence for a significant associated increase in CO2 emissions because of the tax induced substitution to gasoline vehicles.

There are several policy recommendations to increase the environmental impact of the policy. First, the tax base should be broadened to include all light-duty vehicles. This would substantially increase the effectiveness of the tax by including 90% of diesel pickup truck sales that are currently exempt. It would also affect diesel cargo van sales that currently do not pay the tax. Second, the tax rate should be increased. It is currently low according to international standards. Finally, we suggest considering other gases in the tax calculation formula, in order to tackle not just local air pollution problems related to NOx but also global climate change emissions. Good examples in this line are the experiences of Ireland (Leinert et al., 2013) and Israel (OECD, 2016).

Our analysis only uses data on pickup trucks. By not considering the impact of the green tax on automobiles we are possibly underestimating the effect of this policy. However, this bias is most likely small. First, the tax for gasoline vehicles is low, reducing the expected impact on consumer behavior. Second, there is no evidence of a decrease in the share of new diesel cars purchased during the sample period (hovering around 10% throughout) suggesting that there is no substitution from diesel to gasoline cars. The only significant bias may come from not considering the substitution towards cleaner diesel cars induced by the tax. But this group represents only 10% of new automobiles sold, so any environmental effect of the policy would be small.

Future research could tackle the above omission by estimating a structural demand model. This could also be used to calculate the optimal tax level and structure to minimize environmental impacts.

One of the main takeaways from this paper is that a small environmental tax in a developing country can induce positive behavioral changes. Although mandatory standards are by far the most effective way to reduce emissions, registration taxes could be used as a complementary policy even in a developing country context.

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Appendices

A Data sources and dataset construction

The dataset was constructed from a variety of sources. The easiest part was for the period after the tax was introduced (December 29, 2014). From that date onward we use the information provided by the National Treasury (Tesorería General de la República or TGR). This agency is in charge of collecting the green tax payments and records each vehicle sale, together with a set of variables including the sales price, model, manufacturer and other vehicle characteristics. Two variables from this dataset are of prime importance: the amount of the green tax paid and the CIT. The first variable allows us to determine whether a new vehicle was tax-exempt (no green tax paid) or taxable (positive amount of tax paid). The second variable, a code developed by the Ministry of Transport and Telecommunications (MTT), is explained in what follows.

All new light weight and medium weight vehicles and motorcycles that distributors wish to import and sell in Chile must first be certified by the Center for Vehicle Control and Certification (3CV for its Spanish acronym) of the MTT.[34] 3CV undertakes a technical analysis of a model prototype in its laboratories and determines the emission coefficients for several pollutants (including for NOx), fuel efficiency and compliance with national safety, size and components vehicle regulations. Once approved, a model is given an Individual Homologation Certificate (CHI by its Spanish acronym). To keep track of the models and their CHI, 3CV assigns a code to each model (Technical Report Code or CIT by its Spanish acronym).

[34]All new vehicles sold in Chile are imported.

Using the CIT, we were able to pair each vehicle sale recorded by the TGR dataset with the corresponding NOx emissions coefficients as determined by 3CV.

More difficult was the construction of the dataset for the period prior to the introduction of the tax.

For this first period, we obtained data from the General Register Office (SNRC by its Spanish acronym). This agency keeps the Motor Vehicle Registry, which contains all vehicle transactions (both new and used) and for the period after the tax was introduced coincides with the TGR dataset for new vehicle sales. The challenge was to assign a NOx emissions coefficient to all sales prior to December 29th, 2014, given that the SNRC data does not contain the CIT code and cannot therefore be matched directly with the data from the 3CV, referred to above. However, it does contain the license plate number (PPU).

Using the PPU of each vehicle we were able to merge the SNRC data with the data coming from the authorized testing centers that (generally once a year) certify vehicles' technical conditions, including pollutant emissions (new vehicles only have to undertake a bi-annual inspection the first four years). This dataset was provided by the MTT and contains not only the PPU but also the Vehicle Identification Number (VIN), which allows us to merge the resulting data with a Car Dealers dataset, also provided by MTT, that contains the CIT code for each VIN. We therefore ended up with a pre-tax dataset presenting for each new vehicle sold its corresponding CIT code, which we then used to merge with the 3CV emissions information.

One final step was required for the pre-tax data to be completed: identifying the type of ownership, i.e. the vehicles purchased by a commercial entity (which are tax-exempt under the terms of the yet to be implemented green tax) and those purchased by private individuals. To this end we were provided with information from the National Tax Agency (SII for its Spanish acronym) for the 2012 to 2015 period. Since we have one year of overlap with the TGR data (2015) we could verify that the SII data matches that of the TGR.

The SII calculates the tax amount for each model, applying the formula presented in section 3. For this, it receives the sale price from the seller and the information on polluting potential and fuel efficiency from the 3CV.

B Descriptive statistics

Table B.1 presents summary statistics for pickup trucks by fuel type and tax status. NOx is measured in milligrams per kilometer; CO2 in grams per kilometer; displacement in liters; efficiency in kilometers per liter; weight in metric tons; and footprint in square meters.

Table B.1: Summary statistics for pickup trucks by fuel type and tax status, April 2012 to September 2019

	Mean	Std. Dev.	Min	Max
NOx				
Gasoline				
Exempt	22.82	19.65	3.76	550.00
Taxable	23.25	15.25	3.76	389.90
Diesel				
Exempt	241.68	60.14	6.80	670.00
Taxable	231.70	66.23	10.90	650.00
CO2				
Gasoline				
Exempt	216.21	80.36	0.00	399.00
Taxable	216.84	64.53	0.00	399.00
Diesel				
Exempt	208.60	57.56	0.00	298.00
Taxable	210.14	51.47	0.00	344.00
Displacement				
Gasoline				
Exempt	2.54	1.48	1.00	6.20
Taxable	2.21	1.25	1.00	6.20
Diesel				
Exempt	2.42	0.29	1.00	5.30
Taxable	2.38	0.31	1.00	5.70
Efficiency				
Gasoline				
Exempt	8.43	2.19	4.30	11.90
Taxable	8.67	2.02	4.30	11.70
Diesel				
Exempt	10.06	1.64	6.30	14.50
Taxable	10.02	1.45	5.20	14.50
Weight				
Gasoline				
Exempt	2.45	0.59	1.10	3.72
Taxable	2.40	0.51	1.10	3.72
Diesel				
Exempt	2.96	0.25	1.58	3.55
Taxable	2.94	0.22	1.10	3.50
Footprint				
Gasoline				
Exempt	5.83	1.22	4.29	8.13
Taxable	5.57	1.00	4.29	8.13
Diesel				
Exempt	5.62	0.50	4.24	8.61
Taxable	5.64	0.44	4.24	8.27

Source: see Appendix A. The units of each variable are described in the text above.

C Results for CO_2

Table C.1: Regression results for CO_2 emission rates aggregated across all pickup trucks, March 2013 to September 2019

Variables	(1) All
Treated	-0.015***
	(0.002)
D^1	-0.001
	(0.003)
D^2	0.016***
	(0.003)
D^3	0.001
	(0.002)
Observations	397,094
Adjusted R-squared	0.052
Anticipation	No

Source: see Appendix A. Includes separate monthly time effects for Santiago and for the rest of the country.