CLEF Canadian Labour Economics Forum

WORKING PAPER SERIES

The Effectiveness of Consumption Tax on the Reduction of Car Pollution in China

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Fall 2018, WP #15

The Effectiveness of Consumption Tax on the Reduction of Car Pollution in China

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September 21, 2018

Abstract

Exposure to airborne pollution has substantial adverse health consequences (Cohen et al, 2004). Governments around the world have paid attention to this problem and started to take actions to mitigate it harmful effects. In this paper, we investigate how a change in the consumption tax structure affects car emissions by exploiting exogenous variation from a natural experiment that took place in China. Our results show that this tax policy, which doubled the imposition paid on cars with large engines, reduced the emissions of all the pollutants studied, with the most significant decrease of 11% noted in Particulate Matter and Carbon Monoxide.

1 Introduction

Air pollution has ominous consequences on health. A study by the World Health Organization estimated that urban air pollution accounts for 6.4 million years of life lost worldwide annually Cohen, Anderson, Ostro, Pandey, Krzyzanowski, Künzli, Gutschmidt, Pope III, Romieu, Samet et al. (2004). Cars emit most of the pollutants associated with deterioration of health. For example, Currie and Walker (2011) estimated that the prenatal exposure to traffic congestion reduced welfare in the United Stated by $557 million per year and Ngo (2017) found evidence that maternal exposure to old buses in New York City is associated with reductions in birth weight and gestational ages at birth. Governments around the world have begun to respond to this problem through a variety of actions designed to mitigate the consequences of pollution. In this paper we study

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how a significant increase in a consumption tax paid on automobiles having a cylinder capacity larger than 3 liters affects emissions by exploiting exogenous variation from a natural experiment that took place in China.

It is well known that China has experienced steady and fast economic growth in the last several years. Average income has been increasing consistently since then, leading to growth in the consumption of durable goods by the middle class, especially cars. Car purchases are steadily increasing according to the China Association of Automobile Manufacturers. Production levels reached roughly 29 million cars in 2017, representing an increase of 3.16% from 2016 and effectively placing the country in first place for car production worldwide for the ninth consecutive year.

The increase in car consumption raised many concerns within the Chinese government, most notably the environmental consequences brought about through this massive circulation of new vehicles. In the first decade of the 2000s, the Chinese government implemented a series of policies that were both aimed to battle pollution emitted by cars and to tackle their consumption patterns by imposing a higher tax on bigger, more polluting automobiles.

This paper analyzes the impact of this policy on the total emissions of different pollutants using a difference in difference (DD) methodology. We construct a data set on emissions using the COPERT 4 model, which was developed by the European Environmental Agency and is now widely used in environmental engineering to estimate emissions. The new tax impacted high cylinder vehicles with engine sizes larger than 3 liters while taxes on small cylinder cars remained unchanged. Since the change in tax did not affect all cars, we have the ideal conditions in which to estimate the change in total emissions by high cylinder cars in comparison to smaller ones.

The COPERT model uses general information about infrastructure and certain driving conditions to calculate total emissions by engine size. One of the main concerns about the effectiveness of the DD results is the possibility of an anticipation effect by consumers in light of the upcoming policy change. We argue that the anticipation effect is unlikely to have a significant impact on our results because policies in China are not shared with the public and therefore consumers are unable to anticipate upcoming policy changes.

Our results, therefore, should be considered in light of our depart from the assumption that people use their car at an average pace including policies that restrict circulation as described in Viard and Fu (2015). Even though these rules might affect total emissions, we believe that they are not substantial enough to significantly impact the emissions of large cars compared to small ones. There is extensive evidence that circulation restrictions induce substitution patterns among consumers who bypass the policy by purchasing new cheaper cars or used ones, thereby increasing pollution compared to its levels before policy implementation (see for example, (Davis, 2008; Carrillo, Malik, and Yoo, 2016)). In our study, we show that restriction policies are not driving our results, as they are robust to the inclusion of provinces that have implemented such policies.

The contributions of this paper are threefold. Firstly, we construct a novel data set on emissions that is calculated with a model that is widely used among environmental engineers and that can therefore be replicated in other setups and research questions. This is the first paper to take a more technical approach when estimating emissions by using information from road conditions in COPERT 4. This methodology allows us to effectively estimate emissions by cars, an advantage over the environment measures that can be contaminated by other sources of pollution. Our database can be used for this purpose as well as for other scenarios that require aggregate information from micro data.

Secondly, this research adds to the literature on taxation to reduce pollution. We show evidence to strengthen the work by Fullerton and West (2002), Adda and Cooper (2000), Li, Timmins, and Von Haefen (2009) and Engers, Hartmann, and Stern (2009), which all argue that automobile consumption taxes are policy tools that stimulate the consumption of low polluting commodities as they are more easily implemented than fuel taxes. We also found that this type of policy was highly effective in reducing pollution from larger vehicles. Furthermore, we extend the work by Zhao (2013) and Jiang (2009) who analyze the effect of this tax on the consumption of cars and its effect on overall pollution levels. Moreover, this document shows how policy makers can avoid the adverse consequences of pollution on health as found in Currie and Walker (2011), Ngo (2017), Ngo, Bao, and Zhong (2018) and Chen and Whalley (2012) through the effective use of policy instruments.

Finally, to the best of our knowledge, we are the first to assess the effectiveness of this policy in terms of environmental outputs and policy implications. Our results show that there was indeed a significant change in environmental outputs in all the emissions factors that we consider. This leads us to conclude that the policy was highly effective in reducing pollution by large cars in the country compared to small ones. The results are also robust in their inclusion of several control variables like province fixed effects and economic activity in the country.

The rest of the paper is organized as follows. Section 2 includes a literature review on environmental policy. Section 3 explains the policy change, its background and the data. Section 4 presents the econometric framework and the core of our results and section 6 concludes with some final comments.

2 Background, Policy Change and Data

China first imposed a sales tax on cars in 1989 in order to exercise some control over ever increasing car sales. On 1 January 1994, the automobile consumption tax was officially implemented. Due to the small number of car sales, product specialization lag and other factors, it was based solely on car displacement and only divided passenger cars into three groups. In addition to increasing the national financial revenue, the primary purpose of this imposition was to set limits on over consumption of non-necessities.

After twelve years of socio-economic development, the increasing popularity of household automobiles led to increasing problems of resource consumption and environmental pollution. The original passenger vehicle consumption tax was low for large displacement vehicles and lacked regulation on the consumption of passenger cars with large displacement and high-energy consumption. In response to these policy shortcomings, on April 1st of 2006, the Ministry of Finance and the state administration of taxation reformed the passenger vehicle consumption tax. The policy adjustment, which mainly refined the grade of automobile displacement from the original three groups, was the most significant adjustment of the consumption tax since the previous tax reform in 1994. At the same time, it widened the tax rate gap between different emission levels, lowered the car consumption tax rate of 1.0-1.5 liters displacement, and increased the consumption tax rate of all vehicles of 2.0 liters displacement or more. The purpose of this consumption tax reform was to limit the production and sales of passenger cars with high displacement and high fuel consumption while simultaneously encouraging the purchase of small cars.

The adjusted automobile consumption tax had an impact on the purchase behavior of automobile consumers in the two years following its implementation. However, passenger car ownership in China continued to rise sharply along with the demand for gasoline and diesel, resulting in more serious air pollution. As a result, on September 1st, 2008, the Ministry of Finance and the State Administration of Taxation jointly implemented a car consumption tax adjustment. The adjustment of automobile consumption tax aimed to increase the sales tax rate of large displacement passenger cars, control their sales volume and strengthen the guiding role of consumption tax on automobile consumption by adjusting the tax structure of cars. These changes can be seen in Table 1

We will analyze the change in total emissions by cars with high displacement engines (bigger than 3 liters) compared to the change in total emissions by cars with low displacement engines (less than or equal to 3 liters) before and after the policy implementation in 2008. As a pre-policy period we use emissions from 31 provinces in China between 2006 and 2008. This is because in these periods cars with high displacement engines had a significant increase in the consumption tax while the small cars remain the same. We do not exclude cars that have an engine displacement less than 1 liter, as they are very small in our sample (around 3-4 % of the total sample of new car registrations in China during the period analyzed). We calculated emissions during the period of 2003 to 2013 and compared this longer sample to the estimation and found no significant changes for some pollutants[1]. Nevertheless, we prefer the estimation using as pre-policy period the years after the first tax change as is easier to motive that the

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[1] These estimations are available upon request

Table 1: Evolution of Tax Rate on Passenger Cars in China (%)

Displacement	Tax rate -1994	Tax rate (April.1.2006)	Tax rate (Sept.1.2008)
$\leq 1.0L$	3	3	1
$(1.0L \quad 1.5L]$	5	3	3
$(1.5L \quad 2.0L]$	5	5	5
$(2.0L \quad 2.2L]$	5	9	9
$(2.2L \quad 2.5L]$	8	9	9
$(2.5L \quad 3.0L]$	8	12	12
$(3.0L \quad 4.0L]$	8	15	25
$\geq 4.0L$	8	20	40
MLCPC	0	5	5

Source: The Authors and Minster of Finance, State Administration and Taxation

assumption of parallel trends holds.

Table 2: Emission Formulas for Selected Pollutants

Pollutant	**Cylinder capacity**	**Emission Factor (g/km)**
CO	CC < 1,4 l	$9,846 - 0,2867V + 0,0022V^2$
	1,4 l < CC < 2,0 l	$9,617 - 0,245V + 0,0017285V^2$
	CC > 2,0 l	$12,826 - 0,2955V + 0,00177V^2$
NMVOC	CC < 1,4 l	$0,628 - 0,01377V + 8,52E - 05V^2$
	1,4 l < CC < 2,0 l	$0,4494 - 0,00888V + 5,21E - 05V^2$
	CC > 2,0 l	$0,5086 - 0,00723V + 3,3E - 05V^2$
NOX	CC < 1,4 l	$0,5595 - 0,01047V + 10,8E - 05V^2$
	1,4 l < CC < 2,0 l	$0,526 - 0,0085V + 8,54E - 05V^2$
	CC > 2,0 l	$0,666 - 0,009V + 7,55E - 05V^2$

Source: The Authors and COPERT 4 Model

2.1 Data

This section gives a detailed explanation on how the emissions from cars with different engine displacements are calculated and the assumptions on which these are based. We use administrative records of all new car registrations in China which include car characteristics such as the cylinder capacity and number of doors, year and month of registration, as well as city and province as an input in the COPERT model to estimate the total emissions.

2.1.1 The COPERT 4 Model

The COPERT model Gkatzoflias, Kouridis, Ntziachristos, and Samaras (2007), funded by the European Environment Agency (EEA), can be used to calculate annual emissions of pollutants and vehicle emission factors. The model, which is widely employed in European countries, uses a large number of reliable experimental data and can be compatible with different national standards and parameter variables. From the COPERT III in 1985 to the current COPERT 4, the information in the model such as standards and vehicle classification are continuously updated which enable the simulation values to be closer to the real world.

2.1.2 Principle of emission factor calculation in COPERT 4 model

The COPERT 4 model considers the pollutants emitted by motor vehicles from three sources: the thermal stabilized engine operation, the cold starting process and fuel evaporation and then calculates the emission factors respectively. (1) In the thermal steady state, the emission factors of different types of engines are only related to the traveling speed of the vehicle; (2) The emissions during the cold starting process is obtained by adding an additional value to the emission at the thermal steady state; (3) The NMVOC of fuel evaporate emissions consists of three components, diurnal emissions, hot soak emissions and running losses, whose emission factors are expressed as a function of the vapor pressure of the fuel and the environment temperature.

Table 2 shows the calculation formulas of various emission factors of CO, NMVOC and NOx with 3 different cylinder capacity in the thermal stability state. In the cold-start process and the fuel-evaporative emission state, vehicle emission factors of various types of pollutants formula can be found in the literature Gkatzoflias et al. (2007)

2.1.3 The calculation principle

Vehicle emissions are determined by the vehicle's integrated emission factor, average annual mileage and number of vehicles. Vehicles emit carbon monoxide (CO), nitrogen oxides (NOx) including nitric oxide (NO), non-methane volatile organic compounds (NMVOC), volatile organic compounds (VOC), particulate matters including PM2.5, PM10, and total PM, etc. The common expressions of vehicle emissions of various types of vehicles in COPERT 4 are as follows 1

$$Q_m = \sum (P_{m,i,j,k} \times M_i \times EF_{m,i,j,k}) \tag{1}$$

Where m is a certain area, i is one of the types of different vehicles, j is the driving conditions;$P_{m,i,j,k}$ is the vehicle emission in the area m for the type i under driving condition j and emission standard k, measured in 10 million vehicles; M_i is average annual mileage for vehicles category i, measured in kilometers; $EF_{m,i,j,k}$ is an integrated emission factor for vehicles category i under traveling conditions j with emission standard k , measured in gram/kilometer.

We divide the passenger cars into three categories: mini gasoline passenger cars, small gasoline passenger cars and small diesel passenger cars. The passenger cars are then continuously sub-classified according to emission standards and displacement sizes, and can be subdivided into a maximum of 20 sub-categories. Condition j is divided into three categories: urban areas, suburbs and highways. Emission standards are divided into national 1, national 2, national 3 and national 4 standards for diesel vehicles and gasoline vehicles.

The data of the newly registered passenger cars used in this study comes from the passenger cars database of China Transportation Administration from 2003 to 2013. The data of passenger car ownership in 2002 comes from China Statistics Website. Other relevant data comes from China Automotive Industrial Yearbook, China Meteorological Statistical Yearbook and China Automotive Market Yearbook, etc. Among these, the newly registered passenger cars database of China Transportation Administration from 2003 to 2013 is a large-scale original database, and the numbers of newly registered passenger cars of all types are calculated and collated from this database. In addition, a very small amount of data is consulted from other publications and then used cautiously. In the process of calculation and collation, in order to ensure the reliability and effectiveness of the results, the data and document used here are consistent with the original intend as far as possible.

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2.2 Descriptive Statistics

Table 3 shows some descriptive statistics of the total emissions for eight pollutants we consider. All panels show averages, standard deviations as well as minimum and maximum emissions. The first two do so for low and high engine sizes respectively, the third panel is the sum of low and high engine size, while the final panel corresponds to the collapsed information by province and fuel type. The scale of each pollutant is 10 thousand of tons so that, for example, the average emissions of PM2.5 by a low engine sized car is around 1.29 tons or 240 tones for big engine cars. It is also worth noting that some of these emissions are highly variable. For instance, the variation coefficient (standard deviation divided by the mean), which is a measure of relative variability, is very high for the PM2.5 emissions in the high engine size, a value of 1.18 approximately.

Figure 1 shows a heat map of pollutant PM2.5, VOC, NOX and NMVOC by province in different years. It is evident that total emissions have been increasing in most provinces, especially in coastal areas such as Shandong, Zhenjiang and Shanghai. Figure 2 illustrates the evolution by quarters of the shares of low engine size cars in panel a and of high engine size cars in panel b. The vertical lines represent the moment where the policy tax change happened and the blue dotted line is the mean for the inter periods. Clearly the mean of the share of the low displacement cars was bigger after the two changes, inducing a decrease in the same indicator for high displacement cars. We argue that, by graphical inspection, the response in the consumption was in line with the objective of the policy: to decrease the share of cars with big engine sizes in the country. We also estimate the DD model for this variable by controlling for other economics characteristics of the province and found evidence towards this argument[2].

Furthermore, is also important to show how the emissions of each pollutant are behaving during these periods. Figure 3 shows a multi-paneled graph with the evolution by year of the eight pollutants we consider. Again, vertical lines represent the years of the policy changes. Values shown on this graphs are the yearly mean in all of the provinces. As expected, the emissions for both large and small displacement cars are increasing overtime but this increase is more notable in certain pollutants. This graph is also important because it informs that the assumption of parallel trends is satisfying for some of the pollutants.

Figure 4 is equally important as it shows the log difference in emissions, which is approximately equal to the growth rate of emissions by each pollutant. Even though this rate is positive for all years, it is surprisingly decreasing over time for both high and low engine size cars. We also present estimations in Table 5 to interpret the coefficients as differences in percentages changes while carefully acknowledging that changing the unit measures might contaminate the results as parallel trends are likely not satisfying because common trends in logs rules out common trends in levels and vice versa Angrist and Pischke (2008).

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[2] The results are available upon request

Table 3: Descriptive Statistics by Pollutant

			Low Engine Size		
Variable	Obs	Mean	Std.Dev.	Min	Max
PM25	337	0.000129	0.000124	2.74E-06	0.000706
VOC Emiss	337	0.00416	0.00369	5.21E-05	0.0199
PM10 Emiss	337	0.000223	0.000215	4.69E-06	0.00123
PM exhaust s	337	2.23E-05	2.02E-05	5.33E-07	0.000106
NOX Emiss	337	0.00274	0.00232	6.20E-05	0.0118
NO Emiss	337	0.00263	0.00223	5.95E-05	0.0114
NMVOC Emiss	337	0.00386	0.00343	4.91E-05	0.0184
CO Emiss	337	0.0295	0.0276	0.000388	0.152

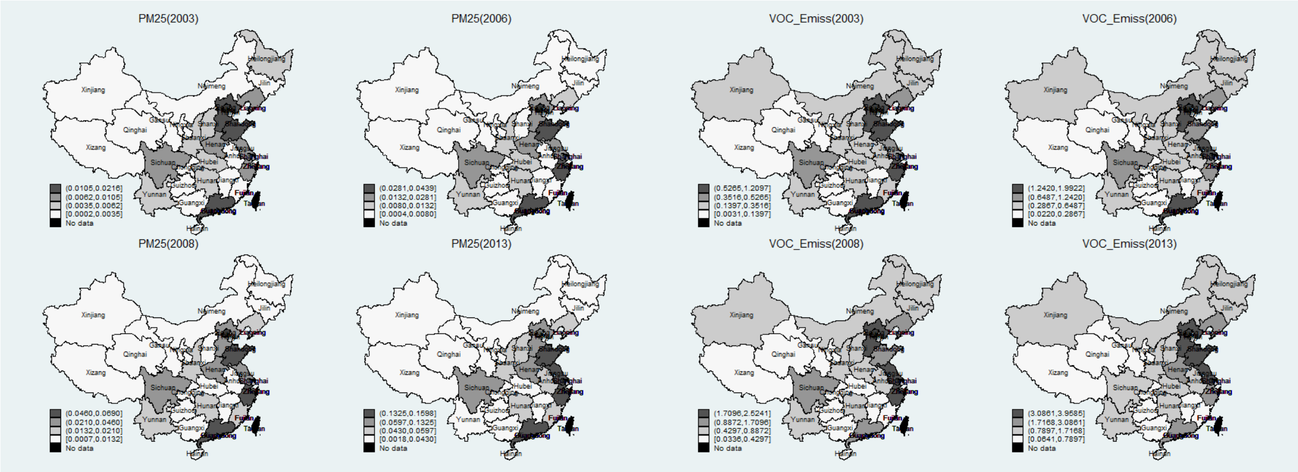
			High Engine Size		
Variable	Obs	Mean	Std.Dev.	Min	Max
PM25	337	0.024	0.0283	0.000278	0.159
VOC Emiss	337	0.774	0.784	0.0145	3.946
PM10 Emiss	337	0.0414	0.0492	0.000471	0.277
PM exhaust s	337	0.00416	0.00456	5.79E-05	0.0247
NOX Emiss	337	0.468	0.474	0.00828	2.507
NO Emiss	337	0.449	0.455	0.00794	2.406
NMVOC Emiss	337	0.722	0.727	0.0136	3.696
CO Emiss	337	5.856	6.49	0.0809	39.48

			Province		
Variable	Obs	Mean	Std.Dev.	Min	Max
PM25	337	0.0241	0.0284	0.000287	0.16
VOC Emiss	337	0.778	0.787	0.0145	3.958
PM10 Emiss	337	0.0416	0.0494	0.000487	0.279
PM exhaust s	337	0.00419	0.00457	5.97E-05	0.0248
NOX Emiss	337	0.471	0.476	0.0085	2.519
NO Emiss	337	0.451	0.457	0.00815	2.418
NMVOC Emiss	337	0.725	0.729	0.0136	3.708
CO Emiss	337	5.886	6.512	0.0813	39.58

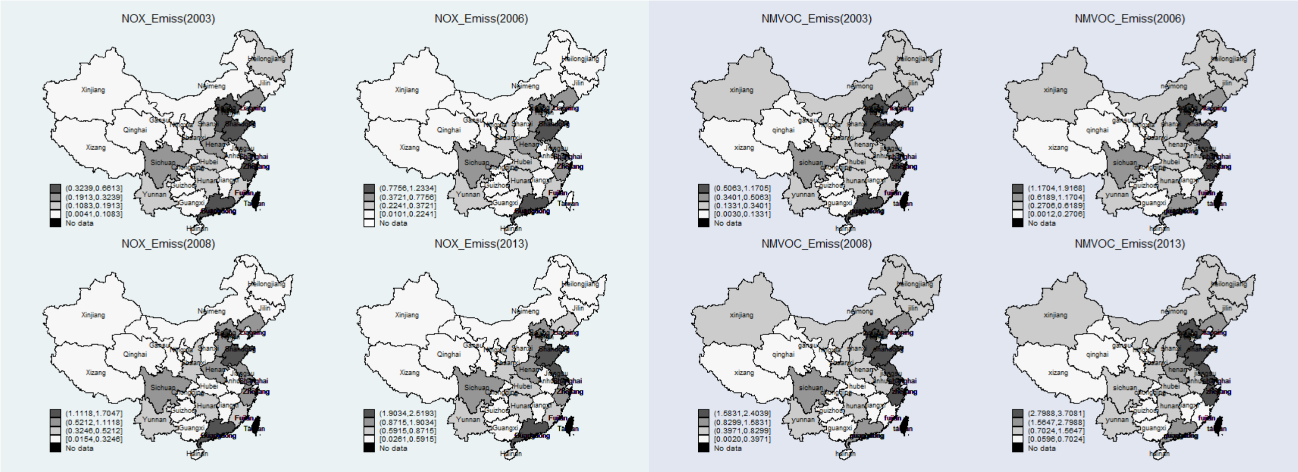
			China		
Variable	Obs	Mean	Std.Dev.	Min	Max
PM25	11	0.739	0.521	0.172	1.724
VOC Emiss	11	23.94	10.9	8.967	42.27
PM10 Emiss	11	1.276	0.915	0.292	3.015
PM exhaust s	11	0.128	0.0739	0.0355	0.257
NOX Emiss	11	14.45	6.485	5.298	24.86
NO Emiss	11	13.86	6.224	5.081	23.85
NMVOC Emiss	11	22.32	9.75	8.637	38.59
CO Emiss	11	181.1	97.63	61.11	345.1

Notes: Panel ”Low Engine Size” and ”High Engine Size” are emissions of low and high displacement cars. Panel ”Province” uses all the information form both groups and panel ”China” is the average information collapse by Province and cylinder capacity.

Figure 1: Heat map of emissions by selected pollutants



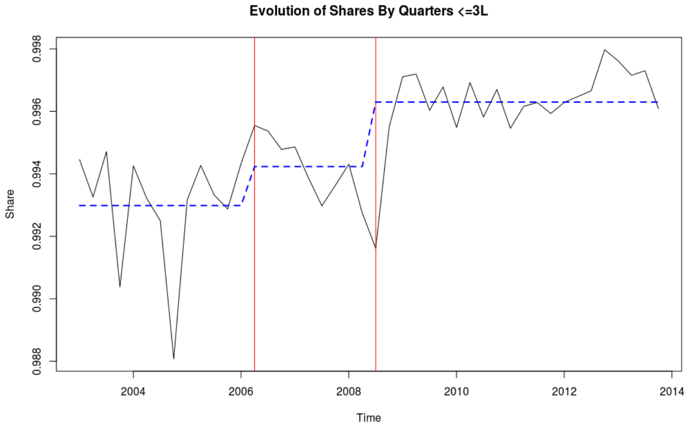
(a) PM2.5 (b) VOC



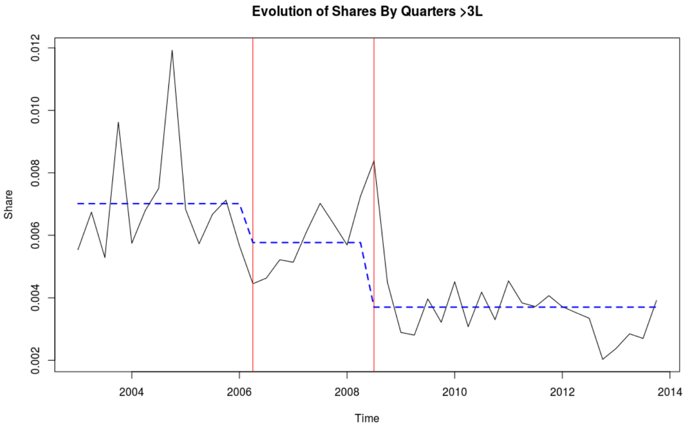
(c) NOx (d) NMVOC

Notes: Each graph in each panel represents the emissions by province in 2003, 2006, 2008 and 2013 respectively for PM2.5, VOC, NOX and NMVOC emissions.

Figure 2: Evolution of Share for High and Low end Cars

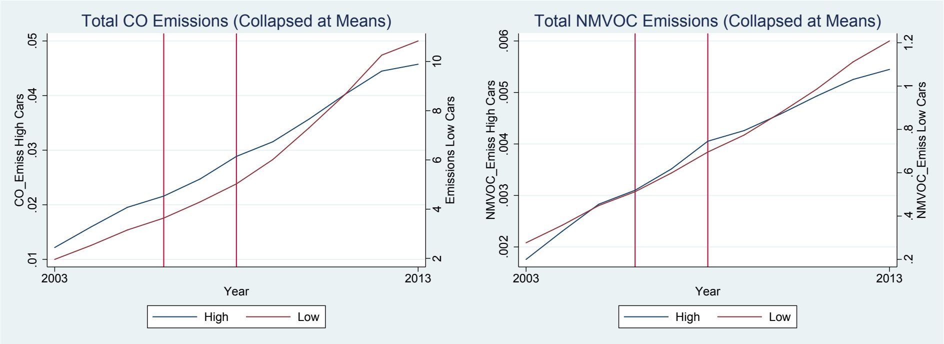


(a) Share less 3L



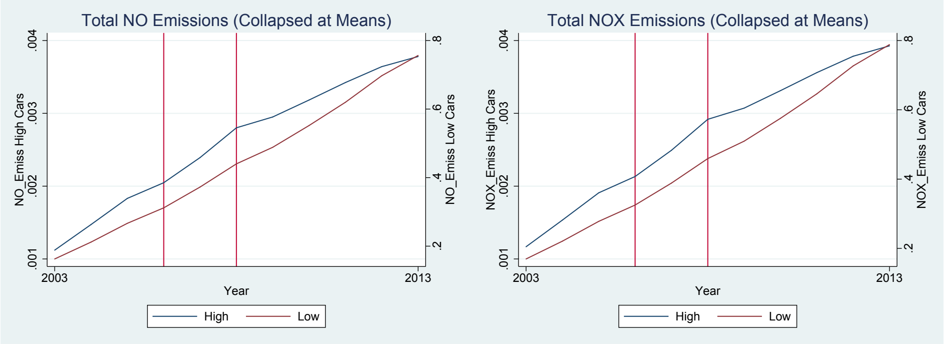
(b) Share bigger 3L

Figure 3: Plots of Total Emissions Average By Provinces



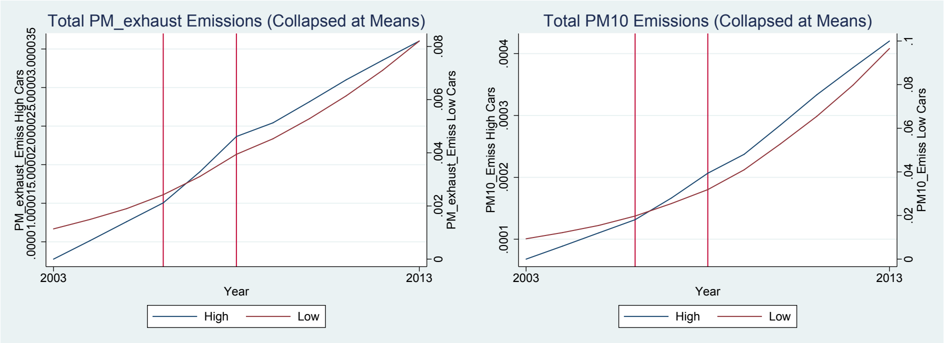
(a) fig 1

(b) fig 2



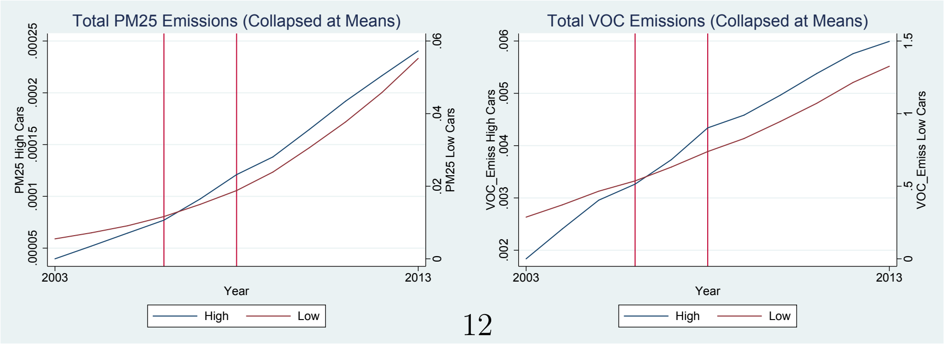
(c) fig 4

(d) fig 5



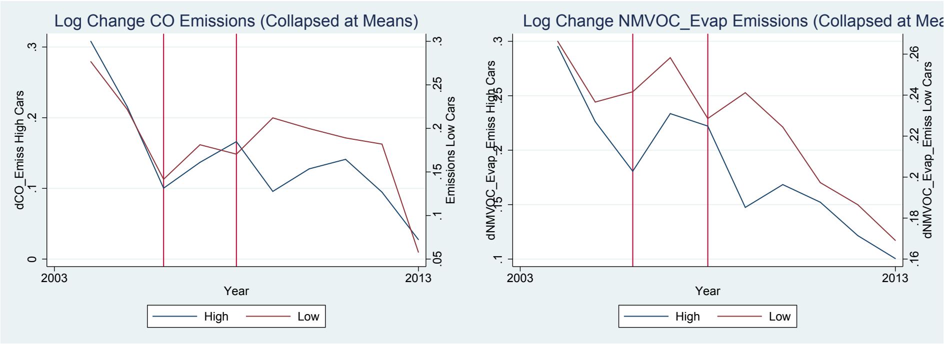
(e) fig 6

(f) fig 7



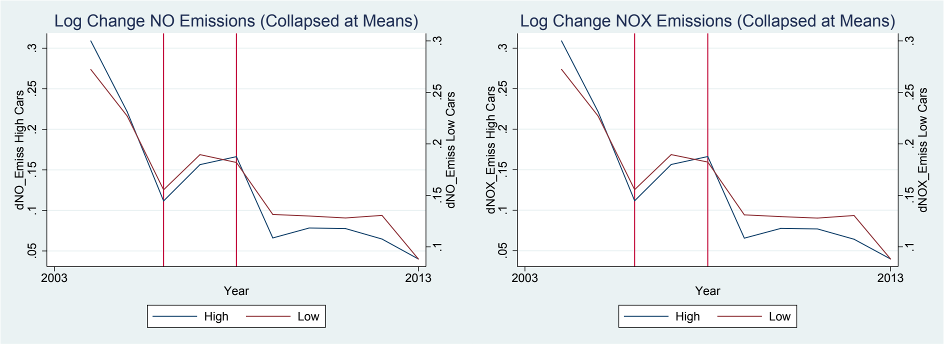
(g) fig 8

(h) fig 9



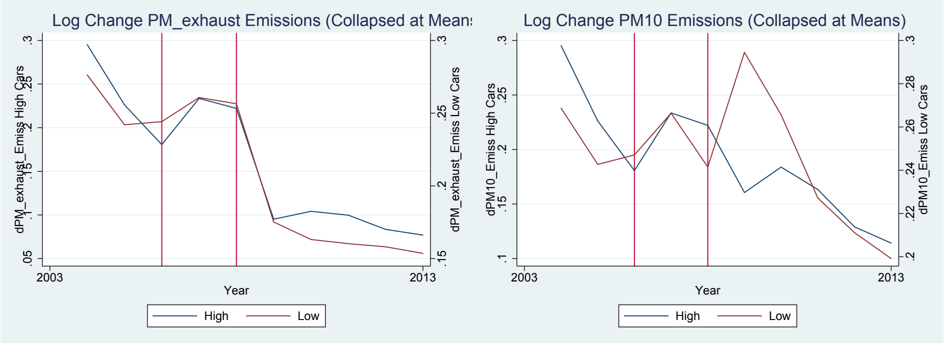
(i) fig 1

(j) fig 2



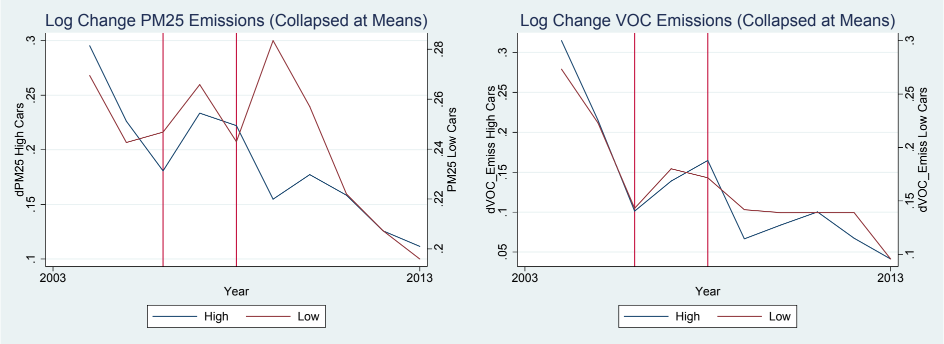
(k) fig 4

(l) fig 5



(m) fig 6

(n) fig 7



(o) fig 8

(p) fig 9

Figure 4: Plots of Log Differences

3 Statistical Analysis and Results

In this section we introduce our identification strategy to estimate the total effect of the consumption tax policy in the total emissions by big cars. Likewise, we present a series of robustness checks to strengthen the core findings of this paper while checking for parallel trends.

The identification in this paper comes from the fact that, by imposing a tax on cars with larger engines, the share of these in the market should decrease while the other group should increase, therefore decreasing the emissions by the treated group. These behavioral effects, that change the composition of the market shares of cars with small and large engine sizes, could also affect the driving conditions and the total distance travel by the cars. In order to estimate emissions we have to calibrate the model so that it matches the average distance traveled, temperature and other variables; as a result, the changes in the response by drivers might also have an effect on the total emissions.

3.1 Econometric Setup

We estimate Difference-in-Difference (DD) models to calculate the change in total emissions after the policy. The general formulation is:

$$y_{pft} = \alpha + \lambda_t + \gamma_1 Policy_t + \gamma_2 Size_f + \gamma_3 Policy_t * Size_f + \mathbf{X}_{tp}\beta + \varepsilon_{pft} \tag{2}$$

Where y_{pft} is the total emission by one of the eight pollutants in the province p by fuel type f in year t. $Policy_t$ is an indicator variable that takes the value of 1 after 2008 and $Size_f$ indicates if the emission is coming from a high cylinder car. λ_t is time control variable and $\mathbf{X}_{tp}$ is a set of controls that includes unemployment rate by province, GDP per-capita by province and a full set of province indicators, ε_{pft} is an econometric error term.

The coefficient of the interaction term, γ_3 is the value of interest in this study. It is the DD estimator and that takes the difference in emissions between high and low cylinder cars from the difference between the "before" and "after" periods. This is:

$$\begin{aligned}\gamma_3 = \{&E\left[y_{pft}|f = High, t = Before\right] - E\left[y_{pft}|f = High, t = After\right]\} - \\ &\{E\left[y_{pft}|f = Low, t = Before\right] - E\left[y_{pft}|f = Low, t = After\right]\}\end{aligned}$$

This is a very standard DD set up that allows us to estimate the coefficient of interest by controlling for different variables while easily calculating the standard errors. We would expect that γ_3 would reflect a negative relationship between the emissions and the implementation of the policy if people substitute high cylinder cars with smaller ones.

The intuition behind our estimation strategy is simple. The reason why pollution could change after the adjustment of this tax is through a behavioral response that individuals would face as the high cylinder cars are relatively more expensive than the small ones, thus a higher tax should change the market shares of these cars, decreasing their pollution emissions. By flexibly controlling for nonlinearities in pollution from other factors and using a full set of time dummies, we are able to isolate the change in pollution solely due to the change in the tax system. Our coefficient of interest, γ_3 will estimate the reduced form effect of the tax on air quality and it will strongly depend on the behavioral response of consumers[3]. The next section shows the results of these estimations

3.2 Results

Table 4 shows the estimations from equation 5. Each row is the estimate of γ_3 for one of the pollutants in this study. Every column corresponds to a different regression estimate that includes a linear trend or a full set of year controls plus a full set of province dummies augmented with economic condition variables like GDP per capita and unemployment rates. The estimates are very robust with or without the inclusion of province controls or the choice of linear trends or non-linear ones[4]. All the coefficients are significant at a 1% level and they are also negative, which indicate that the change in the tax structure decreased the emissions of the high cylinder cars.

The results from Table 4 contain two central findings. First, the decrease in the emissions by high cylinder cars is robust with the inclusion of any type of trend and independent as well of the inclusion of province control. Second, the highest change was evident in the emissions of CO and NMVOC. As health consequences of Carbon monoxide are quite significant, this change is notable.

As these raw changes are difficult to interpret, in Table 5 we present the changes in the log of emissions so the results can be seen as differences in percentage changes. Thus, for CO, the emissions of high cylinder cars, after the new tax system, were 11.7% lower than the low cylinder ones. It is also important to note that emissions from PM10 and PM25 were also around 11% lower for the treated group. On the other hand, the smallest change was in NO emissions, which amount to a 6% decrease, something that did not appear in the table using the variables in their levels.

These results point to a very convincing story where the change in the emissions by

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[3] Of course, the behavioral response should not only affect the market shares but also other key variables such as the speed of the cars on the roads (more cars are more likely to create more traffic congestion which affects average speeds and small engine cars are slower than high cylinder cars which could also affect the average speed) and change in the composition of the roads (more highways, different rural roads, etc.). We believe that the key identification comes from the fact that the market shares will change due to the tax and so the emissions by these cars. We also show evidence that other policies that restrict the circulation of cars, implemented in the same time, do not affect the core of our results

[4] Putting in time dummies allows for any kind of trend, of which a linear trend is a special case and the reason why both cannot be in the same regression.

Table 4: Effect on the Total emissions

Pollutant	*(I)*	*(II)*	*(III)*	*(IV)*
VOC	-0.2423	-0.2423	-0.2423	-0.2423
	(0.0390)	(0.0392)	(0.0413)	(0.0412)
PM10	-0.0189	-0.0189	-0.0189	-0.0189
	(0.0029)	(0.0029)	(0.0030)	(0.0030)
PM	-0.0018	-0.0018	-0.0018	-0.0018
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
NOX	-0.1510	-0.1510	-0.1510	-0.1510
	(0.0247)	(0.0248)	(0.0261)	(0.0260)
NO	-0.1449	-0.1449	-0.1449	-0.1449
	(0.0237)	(0.0238)	(0.0251)	(0.0250)
NMVOC	-0.2159	-0.2159	-0.2159	-0.2159
	(0.0353)	(0.0354)	(0.0374)	(0.0372)
CO	-2.0783	-2.0783	-2.0783	-2.0783
	(0.3447)	(0.3459)	(0.3649)	(0.3636)
PM25	-0.0109	-0.0109	-0.0109	-0.0109
	(0.0017)	(0.0017)	(0.0018)	(0.0017)
Linear Trend	*Yes*	*No*	*No*	*Yes*
Year Control	*No*	*Yes*	*Yes*	*No*
Province Control	*No*	*No*	*Yes*	*Yes*
Observations	*304*	*304*	*304*	*304*

Table 5: Effect on the Log of Emissions

Pollutant	*(I)*	*(II)*	*(III)*	*(IV)*
log(VOC)	-0.0910	-0.0910	-0.0910	-0.0910
	(0.0163)	(0.0164)	(0.0173)	(0.0172)
log(PM10)	-0.1193	-0.1193	-0.1193	-0.1193
	(0.0407)	(0.0409)	(0.0431)	(0.0430)
log(PM)	-0.0875	-0.0875	-0.0875	-0.0875
	(0.0393)	(0.0394)	(0.0416)	(0.0414)
log(NOX)	-0.0651	-0.0651	-0.0651	-0.0651
	(0.0326)	(0.0327)	(0.0345)	(0.0343)
log(NO)	-0.0646	-0.0646	-0.0646	-0.0646
	(0.0326)	(0.0327)	(0.0345)	(0.0344)
log(NMVOC)	-0.0914	-0.0914	-0.0914	-0.0914
	(0.0157)	(0.0158)	(0.0167)	(0.0166)
log(CO)	-0.1177	-0.1177	-0.1177	-0.1177
	(0.0189)	(0.0189)	(0.0200)	(0.0199)
log(PM25)	-0.1163	-0.1163	-0.1163	-0.1163
	(0.0406)	(0.0408)	(0.0430)	(0.0428)
Linear Trend	*Yes*	*No*	*No*	*Yes*
Year Control	*No*	*Yes*	*Yes*	*No*
Province Control	*No*	*No*	*Yes*	*Yes*
Observations	*304*	*304*	*304*	*304*

high cylinder cars were significantly lower than the small engine cars. It is therefore important to show that the baseline results are robust to other policies potentially impacting emissions which were implemented at the same time. The next section overviews this.

3.3 Robustness Checks

3.3.1 Beijing is not Driving the Results

Driving restrictions are used in numerous cities around the world to reduce pollution and congestion and during the same period, Beijing, the biggest and most important city in China, implemented a series of policies that restrict the circulation of cars by the plate number. On July 20th, 2008, the restriction, based on license plate numbers, initially prevented driving every other day and then decreased to one day per week. Viard and Fu (2015) show empirical evidence of this driving restrictions' effect on pollution and economic activity. They found that the restrictions significantly reduce particulate matter and found little evidence of inter-temporal substitution of driving.

Here we want to analyze whether this restriction could be driving our results. For this end, we re-estimate our baseline model excluding the information from Beijing and show the results in table 6.

Estimates from Table 6 are very encouraging. Even though the results are slightly less pronounced than in Table 6, the same story applies as the coefficient of the estimations remain unchanged and statistically significant. This leads us to conclude that it is very unlikely that the restriction on circulation in Beijing is the influential factor driving our results. The fact that Viard and Fu (2015) found little evidence of inter-temporal substitution of driving while simultaneously finding a significant reduction in particulate matter lines up with the results of this paper while also providing evidence for the hypothesis that the change in the tax system for high cylinder cars reduced total emissions, not only for particulate matter (PM) but also for other pollutants emitted by cars.

3.3.2 Including Different Trends by Fuel Type

The key assumption that allows us to use the low engine size group as a correct control group for the preexisting differences between the treated and the control is that the temporal trends of the pollution variables between the pre and post policy periods are the same between the two groups. In other words, the pollution variables evolve in time in the same manner in both groups. In existing literature this is known as the parallel trend assumption and is important for identification. The first way to test for this trend is by graphic inspection of the evolution in time of the pollution information for both groups, which can be seen in Figure 3. For pollutants like NO, NOX and CO,

Table 6: Effect on the Total emissions Excluding Beijing

Pollutant	*(I)*	*(II)*	*(III)*	*(IV)*
VOC	-0.2300	-0.2300	-0.2300	-0.2300
	(0.0377)	(0.0378)	(0.0399)	(0.0398)
PM10	-0.0182	-0.0182	-0.0182	-0.0182
	(0.0029)	(0.0029)	(0.0030)	(0.0030)
PM	-0.0017	-0.0017	-0.0017	-0.0017
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
NOX	-0.1453	-0.1453	-0.1453	-0.1453
	(0.0246)	(0.0246)	(0.0260)	(0.0259)
NO	-0.1394	-0.1394	-0.1394	-0.1394
	(0.0236)	(0.0236)	(0.0249)	(0.0248)
NMVOC	-0.2046	-0.2046	-0.2046	-0.2046
	(0.0340)	(0.0341)	(0.0360)	(0.0359)
CO	-1.9584	-1.9584	-1.9584	-1.9584
	(0.3305)	(0.3317)	(0.3500)	(0.3486)
PM25	-0.0105	-0.0105	-0.0105	-0.0105
	(0.0017)	(0.0017)	(0.0017)	(0.0017)
Linear Trend	*Yes*	*No*	*No*	*Yes*
Year Control	*No*	*Yes*	*Yes*	*No*
Province Control	*No*	*No*	*Yes*	*Yes*
Observations	*294*	*294*	*294*	*294*

it is evident that this assumption is satisfactory but less clear for other pollutants by a simple graphic inspection.

In order to test for parallel trends we augment equation 2 by including fuel specific trends in the equation. This allows treatment and control cars to follow different trends in a potentially revealing way. As a rule, DD estimation with fuel-specific trends is likely to be more robust and convincing when the pretreatment data establishes a clear trend that can be extrapolated into the post-treament period Angrist and Pischke (2008). There is a similar specification used in Besley and Burgess (2004). We estimate the following equation:

$$y_{pft} = \mu_L t + \mu_H t + \gamma_1 Policy_t + \gamma_2 Size_f + \gamma_3 Policy_t * Size_f + \mathbf{X}_{tp}\beta + \varepsilon_{pft} \quad (3)$$

where μ_L and μ_H are low engine size (less than 3 litters) and high engine size (bigger than 3 litters) trend coefficient multiplying a time trend variable. If our estimations do not change after including these specific trends, we are allowed to assume that parallel trends is not an issue here. Table 7 shows the estimations when including these specific trends. Each column represents a estimation that add trends by fuel and a combination of time controls and province dummies. It is important to notice that for most of our specifications and pollutants, the coefficient signs remain unchanged as well as the statistically significant.

In table 8 we follow a similar exercise but we exclude the information from Beijing to control as well for other kinds of policies implemented during the same time period. The core findings remain unchanged[5].

4 Concluding Remarks

Using information about emissions of pollutants gathered from the COPERT 4 model developed by the European Environmental Agency, we found evidence that this policy reduced the emissions of high cylinder cars compared to small ones in all of the eight pollutants considered. These results are robust to the exclusion of large provinces that implemented other policies to reduce car emissions and to the inclusion of engine specific time trends.

Our results showed that Particulate Matter and Carbon Monoxide emissions decreased by around 11%, while Volatile Compound and Nitric Oxide decreased by

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[5] Because the policy change was around the same period of time of the world economic downturn of 2007, a cooling down of the Chinese economy might also decrease the consumption of bigger, more expensive cars. Thus reducing the share of big cylinder cars. We argue this is not the case as the GDP growth of China slowed down during the periods of 2007 to 2009 but recovered itself in the subsequent years. Panel b of figure 2 shows that immediately after the policy implementation, the share of cars with engine size bigger than 3 litters decreased and stayed in the same level thereafter. Suggesting that this effect was not driven by a possible deceleration of the Chinese economy.

Table 7: Effect on the Total emissions Different Engine Trends

Pollutant	*(I)*	*(II)*	*(III)*	*(IV)*
VOC	-0.1159	-0.0980	-0.0087	-0.0087
	(0.0406)	(0.0333)	(0.0122)	(0.0115)
PM10	-0.0132	-0.0059	0.0041	0.0041
	(0.0027)	(0.0026)	(0.0009)	(0.0009)
PM	-0.0011	-0.0008	-0.0002	-0.0002
	(0.0003)	(0.0002)	(0.0001)	(0.0001)
NOX	-0.0739	-0.0692	-0.0168	-0.0168
	(0.0247)	(0.0196)	(0.0081)	(0.0077)
NO	-0.0709	-0.0661	-0.0157	-0.0157
	(0.0237)	(0.0188)	(0.0077)	(0.0073)
NMVOC	-0.0971	-0.0889	-0.0115	-0.0115
	(0.0373)	(0.0300)	(0.0112)	(0.0106)
CO	-1.1731	-0.6128	0.3868	0.3868
	(0.3547)	(0.3205)	(0.1159)	(0.1099)
PM25	-0.0075	-0.0035	0.0021	0.0021
	(0.0016)	(0.0015)	(0.0005)	(0.0005)
Trend by Engine	*Yes*	*Yes*	*Yes*	*Yes*
Time Control	*No*	*No*	*Yes*	*Yes*
Province Control	*No*	*Yes*	*Yes*	*No*
Observations	*304*	*304*	304	*304*

Table 8: Effect on the Total emissions Different Engine Trends (No Beijing)

Pollutant	*(I)*	*(II)*	*(III)*	*(IV)*
VOC	-0.1143	-0.1011	-0.0084	-0.0084
	(0.0413)	(0.0335)	(0.0117)	(0.0111)
PM10	-0.0116	-0.0060	0.0039	0.0039
	(0.0025)	(0.0027)	(0.0009)	(0.0009)
PM	-0.0009	-0.0008	-0.0002	-0.0002
	(0.0003)	(0.0002)	(0.0001)	(0.0001)
NOX	-0.0586	-0.0700	-0.0162	-0.0162
	(0.0258)	(0.0201)	(0.0080)	(0.0076)
NO	-0.0562	-0.0670	-0.0151	-0.0151
	(0.0248)	(0.0192)	(0.0076)	(0.0072)
NMVOC	-0.0976	-0.0918	-0.0110	-0.0110
	(0.0382)	(0.0301)	(0.0108)	(0.0102)
CO	-1.1879	-0.6535	0.3639	0.3639
	(0.3538)	(0.3212)	(0.1117)	(0.1059)
PM25	-0.0066	-0.0036	0.0020	0.0020
	(0.0015)	(0.0015)	(0.0005)	(0.0005)
Trend by Engine	*Yes*	*Yes*	*Yes*	*Yes*
Time Control	*No*	*No*	*yes*	*Yes*
Province Control	*No*	*Yes*	*Yes*	*No*
Observations	*304*	*304*	*304*	*304*

roughly 7%. These results are robust to the inclusion of province fixed effects, economic conditions by province, different engine size trends and contamination by other possible policies. Further research will need to follow as it is important to compare the results found here with environmental data gathered from weather stations that record pollution when using information generated by environmental software. Even though this information will include combined emissions from multiple sources, such as industry and transportation, thereby preventing us from separating the policy effect on emissions from bigger cars, we believe that the comparison of trends is an important extension to this paper.

Another important extension for this document is to exploit the micro information contained in the registry of cars. Thus far we have used it to calculate the number of cars on the road and total pollution. However, this information can be used to estimate structural models of demand for differentiated goods in the spirit of Berry, Levinsohn, and Pakes (1995) and Li, Xiao, and Liu (2015). These types of models would allow the researcher to compute counterfactual analysis of the impact of the policy on total pollution by estimating a supply and demand system of the automobile industry.

Appendix A Literature Review

There is much research on taxation to reduce pollution. It is a well known problem in public economics but there is still some divergence on how these types of taxes should be implemented. Fullerton and West (2002) argue that automobile consumption tax as a policy tool can stimulate the consumption of low polluting commodities to internalize pollution, which has more advantages than fuel tax as it will produce the substitution effect in the automobile market structure in the long run. On this same line Adda and Cooper (2000); Li et al. (2009); Engers et al. (2009) claim that such tax has more advantages compared with other conventional policy tools, is more easily implemented than fuel taxes while also being more popular among the consumers. Additionally, the implementation of automobile consumption tax will produce the desired substitution effect of automobile market structure in the long run. At the same time, when buying a car, consumers often underestimate future fuel costs, thus deviating from the optimal choice, and making automobile consumption tax an effective supplement to fuel tax Allcott and Wozny (2014).

However, scholars who take a negative view pointed out that the automobile consumption tax will have a direct impact on the resource-intensive margin, as car buyers may choose to travel longer distance given the increase of low energy consumption of the vehicle. Thus with the increase of low energy consumption of the vehicle, car buyers may choose to travel longer distances. The rebound effect will offset the reduction of CO2 emissions when using small cars. If the influence of other factors were ignored when the policy was designed, some opposite effect may be produced Deng and Ma (2010). Moreover, the effect of policy implementation depends largely on price elasticity, which is difficult for policymakers to grasp Peters, Mueller, de Haan, and Scholz (2008). Consumers tend to adjust the current decisions in the short term, while in long-term they will neglect the impact of policies Busse, Simester, and Zettelmeyer (2010). The ultimate goal of implementing an automobile consumption tax is to change the auto market structure in the long term Knittel (2011), so policymakers must fully consider the influence of other factors to ensure that the tax can effectively control consumer's behavior over a sustained period of time Klier and Linn (2010).

Furthermore, with respect to the automobile consumption tax in China, Zhao (2013) claims that while this tax can better embody the function of environmental protection, it is not conducive to improvements in research and development related technology by domestic automobile manufacturers because its design did not take into account CO2 emissions or taxes on them. Nevertheless, Jiang (2009) compared the production and sales volume of different displacement vehicles before and after the tax rate changes and found that the consumption tax only had an impact on the number of flow cars, not stock cars, yet we show here that it did have an impact on the shares of high and low cylinder cars.

As for empirical research, Xiao and Sun (2012) use a structural model to analyze the demand and supply of vehicles and simulate the automobile consumption tax adjustment. The results show that the consumption tax effectively tilts purchases to cars with smaller displacement and improves the utilization of automotive fuel but, as a byproduct, it may cause loss of social welfare. Similarly, Li and Zhu (2017) find that in the short term, the automobile consumption tax restrained CO2 emissions of automobile production and use by the influences of price effects promoting the technological progress of the automobile industry. In the long term, rebound effect, market effect, production effect, substitution effect and sustained effect lead to negative impact on carbon dioxide emissions. In addition, the implementation of the policy increased sales of small displacement cars while also reducing sales of large displacement cars with 3.0-4.0 liter engines. The policy had no significant impact on cars with 4.0 liter engines. These results align with what we found in this paper as we saw a shift in the market share of large displacement cars.

There is also a body of literature that focuses on the consequences of pollution on human health and how new infrastructure affects air quality. For example, Currie and Walker (2011) estimated that the prenatal exposure to traffic congestion reduce welfare in the United Stated by $557 million per year and Ngo (2017) found evidence that maternal exposure to old buses in New York City is associated with reduction in birth weight and gestational age relative to new buses that abide by new emissions policies. Also, Ngo et al. (2018) investigate the effects of changes in intercontinental air pollution associated with the Chinese New Year, a 7-day national holiday and sandstorms from China on air quality and morbidity in California. They found that heavy sandstorms are associated with a modest increase in acute respiratory disease per capita, representing 0.5–4.6% of average weekly hospitalizations in California while there was no significant effect on morbidity in California caused by the Chinese New Year. Additionally Chen and Whalley (2012) find evidence that green infrastructure has a significant impact on pollution reduction. They quantify the effects of one major type of transportation infrastructure — urban rail transit — on air quality using a sharp discontinuity in ridership on the opening day of a new rail transit system in Taipei. They found that the opening of the Metro reduced air pollution from one key tailpipe pollutant, carbon monoxide, from 15 to 5%.

Appendix B The COPERT 4 Model

The reasons for choosing the COPERT 4 model in this study are as follows: (1) The COPERT 4 model is the newest version of the COPERT III model with updated emission factors for different vehicle types, calculation methods of these factors as well as pollutant allocation ratios, which enables the simulation to more closely reflect real world conditions. (2) The COPERT 4 model adopts similar vehicle test conditions and vehicle emission standard systems in China and can be used to study vehicle emissions with different emission standards. (3) The parameters required by the COPERT 4 model are relatively simple and applicable to countries with different emission standards and sparse traffic data. (4) The COPERT4 model can calculate the amount of conventional and unconventional gas pollutants and heavy metal pollutants of hundreds of vehicle types while also calculating their fuel consumption, thereby more fully reflecting the vehicle's pollutant discharge conditions.

B.1 Emission Factor Calculation

When the COPERT 4 model is used to calculate an emission factor, the parameters to be inputted are roughly divided into: (1) traveling condition data such as fleet composition, mileage, driving proportion and average driving speed; (2) meteorological parameters such as the highest, lowest and monthly average temperature, air humidity and air pressure; (3) fuel parameters such as the annual consumption of motor gasoline and diesel or their respective parameters of the nature. The values of these parameters ultimately determines emissions factors which are crucial in the study. The following subsections explains the parameters that we used.

B.1.1 Main Parameters

Classification

In the COPERT 4 model, vehicles are classified into PC (passenger car), LCV (light commercial vehicle), HDV (heavy-duty vehicle), MC (Motorcycle), Mopeds and Buses. Vehicles can also be divided into fuel types such aspetrol (leaded and unleaded), diesel, natural gas, lique- fied petroleum gas, biodiesel and bioethanol. According to the emission standards, vehicles are classified into ECE15/00-01, ECE15/02, ECE15/03, ECE15/04, Improved conventional, Open loop Conventional, Eurol-91/441/EEC, Euro2-94/12/EC, Euro3-98/9/EC Stage2000, Euro4-98 Stage2005, Euro5-EC715/2007, Euro6-EC715/2007, and Euro6c-EC715/2007.

Given the displacement, vehicles will be divided into 4 categories for gasoline based cars: small displacement vehicles composed of cars with engine size less than 0.8 liters, medium small vehicles with engine size between 0.8- 1.4 liters, medium vehicles with engine size between 1.4-2.0 liters and big cars for those with displacement more than 2.0 liters. We also subdivide the roads into 3 types: urban area, suburban area and highway. In the COPERT4 model, vehicle are fully classified covering all European modes.

Given their engine displacement, vehicles are divided into 4 categories for gasoline based cars: small displacement vehicles composed of cars with engine sizes less than 0.8 liters, medium small vehicles with an engine size between 0.8- 1.4 liters, medium vehicles with an engine size between 1.4-2.0 liters and big cars for those with engine displacements greater than 2.0 liters. We also subdivide the roads into 3 types: urban area, suburban area and highway. In the COPERT4 model, vehicles are fully classified covering all European modes.

In 1983, China started to promulgate and implement its first domestic vehicle emission standards and regulations. In 1999, it formulated the emission standard GB14761-1999 for automobiles according to the Euro I standards, which is called ”the national 1 standard”. Nowadays, China's emission standards are all formulated with reference to the European standard system, but the implementation time is relatively different than in Europe. The national 2 standard, the equivalent of the European II standard, began to be implemented on July 1st of 2005. From July 1st of 2007, the implementation of the third phase of the national vehicle emission standards started, the national 3 standard. In order to better control the pollution of motor vehicles, the state implemented the fourth phase of the national emission standards in 2011, namely national 4 standards. And in 2013, Beijing began to implement the fifth stage of more stringent national vehicle emissions, namely the national 5 standard. Since then, China's motor vehicle emission standards and regulations are essentially on par with international standards.

To estimate total emissions of passenger cars in all Chinese provinces from 2003 to 2013, vehicles should be classified according to the type of passenger cars in the COPERT 4 model as well as stocks of passenger cars included in the database of the National Transportation Administration of China. To achieve this, we depart from the registration of new cars included in this data set. We determine which emission control standard should be assigned and then calculate the proportion of cars that has this standard in subsequent years. Based on table 9 and taking into account the factor of sales lag time, we identified newly registered gasoline and diesel cars from 2003 to 2005, gasoline and diesel cars from 2006 to 2008, diesel cars from 2009 to the present, gasoline cars from 2009 to 2012, and gasoline cars from 2013 to the present that are the national 1 standard, national 2 standard, national 3 standard, and national 4 standard. Vehicles are then divided into sub-categories based on fuel type, engine displacement and emission control standards (Table 10).

Total emission by pollutant will be the linear sum between the emissions of gasoline and diesel based cars. We need to aggregate these emissions into two groups that have been discussed before: small engine size (cars with displacement less or equal than 3 litters) and big engine size (cars with displacement bigger than 3 litters). To this end, we check what is the proportion of cars with engine technology (EURO 1,2,3 or 4) that are bigger than 2 liters and multiply this fraction by the total emissions of a given pollutant in this same group to calculate the total emissions by the bigger cars. Small cars emissions is the difference between total emissions by pollutant (sum of emissions of all standards) and the emissions of big cars. The following formula explains how we calculate total emissions by pollutant in the two groups

$$Emissions_{PH} = s_{E1}\left(Gas_{(>2,E1,P)} + Diesel_{(>2,E1,P)}\right) + s_{E2}\left(Gas_{(>2,E2,P)} + Diesel_{(>2,E2,P)}\right) + s_{E3}\left(Gas_{(>2,E3,P)} + Diesel_{(>2,E3,P)}\right) + s_{E4}\left(Gas_{(>2,E4,P)}\right) \tag{4}$$

$$Emissions_{PL} = Total_P - Emisssions_{PH} \tag{5}$$

where P is a given pollutant, > 2 represent the cars bigger than 2 litters that could be either from Gasoline or Diesel, $E1..E4$ represents technology Euro 1, 2, 3 or 4 respectively. Then, in this case s_{E1} is the proportion of cars with engine size bigger than 3 litters with engine technology Euro 1, $Gas_{(>2,E1,P)}$ is the total emissions of a pollutant P of a gasoline based car with engine size bigger than 2 and technology standard Euro 1. H, L are high or low engine size. Also note that:

$$Total_P = \sum_i \sum_j \sum_s Pollutant_{pijs}$$

where i is the type of car (gasoline or diesel), j is the technology (Euro 1,2,3,4) s is the size (0.8-2). Thus, this is the linear sum of emissions by each pollutant.

Table 9: Implementation Schedule of China's Vehicle Emission Standards

Fuel type	National 1 Euro I	National 2 Euro II	National 3 Euro III	National 4 Euro IV	National 5 Euro V
gasoline	2000.7	2005.7	2007.7	2011.7	2013.7
diesel	2000.7	2005.7	2007.7		

Source: The Authors

Table 10: Classification of Passenger Cars by Fuel Type, Displacement and Emission Standards

Fuel	Engine Size	Technology
Gasoline	Gasoline <0.8 L	PC Euro 4 - 98/69/EC Stage2005
	Gasoline 0.8 - 1.4 L	PC Euro 1 - 91/441/EEC
	Gasoline 0.8 - 1.4 L	PC Euro 2 - 94/12/EEC
	Gasoline 0.8 - 1.4 L	PC Euro 3 - 98/69/EC Stage2000
	Gasoline 0.8 - 1.4 L	PC Euro 4 - 98/69/EC Stage2005
	Gasoline 1.4 - 2.0 L	PC Euro 1 - 91/441/EEC
	Gasoline 1.4 - 2.0 L	PC Euro 2 - 94/12/EEC
	Gasoline 1.4 - 2.0 L	PC Euro 3 - 98/69/EC Stage2000
	Gasoline 1.4 - 2.0 L	PC Euro 4 - 98/69/EC Stage2005
	Gasoline >2.0 L	PC Euro 1 - 91/441/EEC
	Gasoline >2.0 L	PC Euro 2 - 94/12/EEC
	Gasoline >2.0 L	PC Euro 3 - 98/69/EC Stage2000
	Gasoline >2.0 L	PC Euro 4 - 98/69/EC Stage2005
Diesel	Diesel <1.4 L	PC Euro 4 - 98/69/EC Stage2005
	Diesel 1.4 - 2.0 L	PC Euro 1 - 91/441/EEC
	Diesel 1.4 - 2.0 L	PC Euro 2 - 94/12/EEC
	Diesel 1.4 - 2.0 L	PC Euro 3 - 98/69/EC Stage2000
	Diesel >2.0 L	PC Euro 1 - 91/441/EEC
	Diesel >2.0 L	PC Euro 2 - 94/12/EEC
	Diesel >2.0 L	PC Euro 3 - 98/69/EC Stage2000

Source: The Authors and COPERT 4 Model

Mileage and driving ratio

The COPERT4 model requires input of the annual cumulative mileage of vehicles as well as the proportion of vehicles traveling on urban roads, rural roads and highways, all of which directly affect the calculation of the final emission factors. However, since this data cannot be directly obtained from official statistics, reasonable estimations are supposed to be made based on relevant statistics and surveys.

Considering the relevant research results, the average annual mileage of passenger cars in this study is 18,000km, and the average total mileage of passenger cars is 120,000km. The proportion of vehicles driving in urban areas, rural areas and on highways can be estimated as follows: using the data on roads in China's statistical year from 2002, we take the proportion of urban roads and provincial highways in the total number of kilometers traveled as the proportion of vehicles traveling on urban areas and high-ways, then the proportion of suburbs can be calculated also. The results show that: (1) The proportion of driving in urban areas, rural areas and on highways for the 4 municipalities, namely Beijing, Tianjin, Shanghai and Chongqing, is 50%, 10% and 40%; (2) The proportion of traffic from other provinces is 40%, 20% and 40% respectively.

Average speed

The average speed is the basis for the COPERT 4 model operation. According to the related research results and the traffic speed regulations from the China Transportation Department, the average speeds of passenger cars on urban roads, rural roads and highways are 30km/h, 55km/h and 90km/h respectively.

B.2 Other Parameters

Climate parameters

Climate parameters include the highest monthly average temperature, the lowest monthly temperature, air humidity and pressure in all provinces, as obtained from the China Meteorological Data website http://data.cma.cn/data/.

Fuel parameters

Fuel parameters include the vapor pressure of fuel and the content of various components in the fuel. The vapor pressure of a gasoline vehicle is obtained at 74kPa in winter (September to February) and 88kPa in summer (March to August) according to the relevant Chinese fuel standards. Furthermore, gasoline is unleaded (lead content is less than 0.013g/L), and sulfur content of gasoline and diesel is 0.02% and 0.05% respectively.

Average travel length

Average travel length is the average distance traveled by a car during one operation. The COPERT 4 default travel length is 12 km.

Load and slope

Both vehicle load and road slope have an impact on vehicle emission factors. This study uses a model default value, that is to say that the vehicle load is 50% regardless of slope. The calculation of the emission factor in the COPERT4 model mainly includes 7 modules, each of which is used to calculate specific emission factors, including mileage decay, fuel effect, thermal emission factor, cold emission factor, volatile emission factor, air conditioning service factor and CO2 emission factor from lubricating oil. After the above parameters are included into the model, and the parameters that were not mentioned above are taken as the default values of the model, the pollutant emission factors of various types of passenger cars in each province can be calculated.

B.3 Emissions calculation of passenger cars

Based on formula 1, in order to calculate the emissions of various pollutants of different types of passenger cars, in addition to calculating the integrated emission factors of these pollutants, the annual stocks of each type of passenger cars are essentially required. Calculated as follows:

Ownership of a certain car type

The calculation of a certain type of vehicle ownership is given by formula 6

$$P_{i,t} = P_{i,t-1} + N_{i,t} - O_{i,t} \tag{6}$$

Where $P_{i,t}$ represents the stocks of car type i in year t; $P_{i,t-1}$ is the stocks of car type i in year $t-1$; $N_{i,t}$ is the sales of car type i in year t, which can be approximately by the number of yearly new registered passenger cars, which comes from the passenger car database of the China Transportation Administration; $O_{i,t}$ states the number of scrapped car of type i in year t.

According to the car types in Table 10, the total number of the new car registrations in each year is divided into the number of cars in every sub-category, such as the number of new registered cars for a certain type i in 2003. After obtaining the provincial stocks of passenger cars at the end of 2002 from the China Statistics website and using some reasonable assumptions, the stocks of passenger cars in each province in 2002 will be decomposed into the stocks of all types of cars, that is $P_{i,2002}$.

In this process, the following assumptions were made: (1) The stock structure of each type of passenger car in each province in 2002 is equal to the proportion of newly registered passenger cars of various types in each province in 2003; (2) Scrapped cars are zero, that is $O_{i,t} = 0$. Since we only analyze 11 years, and the average lifetime of a passenger car is 12 to 14 years, it is reasonable to assume that the ownership of all types of passenger vehicles in 2002 plus the number of newly registered passenger cars of various types in 2003 are the stocks of all types of passenger cars for 2003. Then, by induction, the stock of each mode in each year can be calculated. (3) As there is no newly registered passenger cars data about Xizang in the database in 2003 and 2004, the numbers of newly registered passenger cars have to be calculated based on the car stocks data that can be retrieved from the Statistical Information website of China. Also, it is assumed that the proportion of newly registered passenger cars in Xizang in 2003 and 2004 is consistent with the proportion of different car types in Xinjiang.

Finally, the passenger car database lacks the types of fuel (mainly gasoline and diesel) of passenger cars from 2003 to 2007. By using the average diesel vehicle share from 2008 to 2013, the share of diesel cars from 2003 to 2007 is set as follows: Almost all passenger cars with no more than 0.8 liters displacement are gasoline cars, meanwhile, diesel cars accounted for 0.4% to 0.6% of the total cars with engine displacements above 0.8 liters. Based on the above assumptions and formula 6, the ownership of all types of cars in all provinces, $P_{i,t}$, can be calculated.

After the integrated emission factors, the number of passenger cars and the annual average mileage are substituted into formula (1), the emissions inventory with respect to 31[6] provinces, various car types and various emissions such as CO, NOx, NO, NMVOC, VOC, PM2.5, PM10 and PM (exhaust) are then calculated.

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[6] The province of Xizang lacks information about the registration of cars and data about unemployment rate for 2003 and the period 2006-2008 which makes us unable to calculate emissions for these years for this province

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