

Research Article

Emission Reduction Effect and Mechanism of Auto-Purchase Tax Preference

Kai Lisa Lo , Yaqi Fan , Congzhi Zhang , and Jackson Jinhong Mi 

School of Economics and Management, Shanghai Maritime University, Shanghai, China

Correspondence should be addressed to Jackson Jinhong Mi; jhmi@shmtu.edu.cn

Received 21 July 2021; Revised 31 August 2021; Accepted 14 September 2021; Published 7 October 2021

Academic Editor: Guo Wei

Copyright © 2021 Kai Lisa Lo et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

As a modern means of transportation, the automobile plays an important role in people's travel. However, the environmental and energy problems brought by the automobile industry cannot be ignored. Based on unique Chinese urban and new car registration data, this paper empirically analyzes the emission reduction effect of car purchase tax incentives, its spatial heterogeneity, and impact on car consumption structure using difference-in-difference model, regression discontinuity design model, and other methods. We find that the tax incentives can effectively suppress the emission of urban pollutants. The quantile regression shows that the emission reduction effect of the tax incentives shows a dynamic change characteristic of weakening as the pollution level in cities increases. In addition, tax incentives for the purchase of low-energy consumption vehicles increase the market share of small-emission vehicles and change the consumption structure.

1. Introduction

Since 1978, China has maintained high economic growth and become the second-largest economy in the world. The economic development, rising per capita income, and extensive development model have brought serious environmental problems to China. For example, in 2017, China emitted 8.7540 million tons of SO₂, 6.966.1 million tons of wastewater, and 7.962.6 million tons of soot (<http://www.stats.gov.cn/tjsj/ndsj/2018/indexch.htm>). In 2018, among 338 cities in China, only 121 cities met the Ambient Air Quality Standards, accounting for 35.8% of the total number of cities (http://www.mee.gov.cn/xxgk2018/xxgk/xxgk15/201903/t20190318_696301.html). Environmental pollution not only restricts the sustainable development of China's economy but also endangers human health. Hence, how to improve the quality of the ecological environment and promote the green development of the economy has become a difficult and important task in the development process of China.

The improvement of environmental quality cannot be achieved without a well-developed and environmentally friendly transportation sector. As the most important

modern means of transportation, automobiles not only have a huge role in driving China's economic development but also have a profound impact on the ecological environment. Existing studies provide a preliminary analysis of the environmental effects of the automotive market. The emission of automobile exhaust pollutes the air. The road transport sector is by far the largest source of pollution in the transport sector [1]. Passenger cars and heavy-duty trucks constitute the majority of future CO₂ emission saving potential [2].

Starting with the automobile market, scholars have found that tax policies are critical to environmental improvements and changes in consumer behavior. For example, fuel taxes prompt high-mileage consumers to purchase more fuel-efficient vehicles [3]; countries that tax CO₂ vehicles are more likely to achieve greater CO₂ reductions [4]. This reduction is due to a 12% decrease in the share of highly intensive vehicles and an increase of about 20% in the market share of diesel vehicles. The year 2008 saw a change in car tax rates in Ireland, and Leinert et al. [5] use the COPERT model to predict a 7% reduction in CO₂ emissions associated with private cars in Ireland in 2020. Choisealbhá et al. [6] also conclude that economic incentives can indeed change consumer choice and may even

potentially promote sustainable consumption. Thus, changes in tax incentives in the vehicle market are important in terms of their impact on the environment and consumer behavior.

The existing literature largely affirms the impact of tax policies in the automobile market on improving the environment and changing consumer behavior, but there is still room for expansion. For example, when analyzing the effect of tax incentives on environmental improvement, most studies usually empirically investigate the effect of CO₂ emissions from automobiles as the dependent variable, but CO₂ emissions are not the only variable measuring the degree of urban pollution. Second, there is little literature analyzing the heterogeneity of the effects of tax incentives on cities with different levels of pollution. Finally, although extensive research has been done on the effects of tax incentives on consumer behavior, little attention has been placed on the heterogeneity analysis.

In this paper, we focus on analyzing the impact of the 50% purchase tax incentives on environmental improvements and changes in consumer behavior for new vehicles with displacement less than 1.6L registered in China in 2015–2016. Based on the literature gap, this paper adds to the existing literature in the following three aspects. First, in terms of the research object, we choose SO₂, wastewater, and soot emissions as urban pollution level metrics. Second, in terms of research content, this paper not only investigates the impact of tax incentives on the urban environment but also analyzes the heterogeneous impact of tax incentives on urban pollutant emissions under different pollution levels. Third, in terms of research methods, we use OLS regression to examine the emission reduction effect of purchase tax incentives; quantile regression is used to measure the dynamic trajectory of tax incentives on urban pollutant emissions as urban pollution levels increase; DID and RDD methods are used to explore the impact of tax incentives on the structure of automobile consumption. The empirical results show that the purchase tax incentives do have an emission reduction effect, and the marginal impact of tax incentives decreases as the level of urban pollution increases. The purchase tax incentives for small-displacement vehicles change the consumption structure of the auto market and expand the market share of small-displacement vehicles.

The rest of the paper is organized as follows. Section 2 reviews the main literature available on fiscal policy in the car sector and presents the hypotheses. Section 3 introduces the model and data. Section 4 presents the results of the econometric analysis. Section 5 is the robustness test. Section 6 concludes the paper and makes recommendations.

2. Literature Review and Hypothesis

2.1. Literature Review. On the role of tax policy in reducing emissions, Ryan et al. [7] used a panel data set to investigate the relationship between fuel taxes and fleet CO₂ emission intensity in 15 EU countries from 1995 to 2004. The results found that national fuel taxes reduced the CO₂ emission intensity of vehicles. The purchase tax incentives for new passenger cars that had been introduced in the Netherlands led to a reduction of 4.6 million tons of CO₂ emissions [8].

Using panel data for 29 Chinese provinces in 2001 and 2012, Xu and Lin [9] found that tax policy was an important driver of PM_{2.5} emission reduction in China. Fridström and Østli [10] demonstrate that one of the benefits of a car purchase tax in Norway is the reduction of energy consumption and greenhouse gas emissions. A study done by Zimmer and Koch [11] found that the introduction of a tax based on carbon content could prevent significant emissions of air pollutants that are harmful to health. In 2021, a study done by Bergantino et al. [12] found that the *Superbollo* tax on high-powered cars in Italy has an important role in reducing CO₂ emissions.

Previous literature has analyzed the heterogeneous impact of fiscal policy on urban environmental governance from different perspectives. One study by Dong et al. [13] estimates the direction of technological change and the dynamic process of environmental quality under heterogeneous subsidies in the Chinese automotive industry. Bergantino et al. [12] investigate the impact of additional fuel taxes on the heterogeneity of energy-consuming vehicles in southern, central, and western Italy using data related to Italian car registrations from 2008 to 2017.

In recent years, a growing number of articles have examined the impact of tax policies on consumer behavior. In 2014, Alhulail and Takeuchi [14] found that the eco-car purchase tax credit and eco-car subsidy introduced in Japan in 2009 increased the market share of eco-cars and reduced the market share of internal combustion engine cars. Mabit [15] used a logit model to conclude that the tax reform only slightly increased the demand for more fuel-efficient cars. The new passenger car purchase tax incentives implemented in the Netherlands between 2008 and 2013 led to a shift in car consumer purchasing behavior, that is, more consumers switched to low-carbon vehicles [8]. Thomassen [16] conducted a counterfactual analysis showing that if the Norwegian government imposed the same car tax on electric cars as on fuel cars, the market share of electric cars would fall by 23%–24%, and Tesla's sales would decrease by nearly 100 times. In 2017, an analysis by Østli et al. [17] concluded that a CO₂-rated vehicle purchase tax plays a large role in encouraging car buyers to prioritize low- and zero-emission vehicles. Yan [18] studied 10 pairs of BEVs and their internal combustion engine vehicle (ICEV) counterparts in 28 European countries from 2012 to 2014. The results show that tax incentives led to an average increase of about 3% in the share of sales of small electric vehicles. Jing [19] argues that the implementation of tax incentives for new energy vehicles changed the consumption structure of consumers, with an increase in new energy vehicles and a decrease in the consumption of traditional fuel vehicles. A study done by Cerruti et al. [20] proves that the UK car consumption tax increased the adoption of low-emission vehicles and discouraged the purchase of heavy polluting vehicles. Tian et al. [21] found that financial subsidies given to new energy vehicles increased consumers' willingness to purchase them.

The above studies affirm that tax policies such as purchase taxes have an important role in both environmental improvement and changes in car consumer behavior. However, in the study of environmental improvement, the

environmental indicators are mostly selected as CO₂ emissions, and the different effects of taxes on cities with different pollution levels are also ignored. In addition, heterogeneity of consumer behavior change has been less analyzed. This paper adds to address these gaps.

2.2. Hypotheses. The impact of policies on environmental improvements cannot be ignored. Automobile taxation is a powerful tool for GHG emission reduction [22]. Tax policies can give directional guidance in various aspects of the automotive industry. For example, in production R&D mitigation, the government can set tax policies to encourage the development of low-displacement vehicles and restrict vehicles with high pollution emissions. In automobile sales, a clear tax incentive will motivate the automobile industry to develop toward energy-efficient and environmentally friendly vehicles, which in turn will have an improvement effect on the environment. The policy of halving the purchase tax studied in this paper belongs to the tax policy of auto sales, that is, the purchase tax levied on 1.6 L small-displacement cars is reduced from 10% to 5%, which will promote the sales of small-displacement cars and reduce the emission of pollutants, thus improving the environment of the whole society. In summary, we obtain hypothesis 1.

H1: tax incentives for car purchases have an emission-reducing effect and can reduce pollution emissions in cities.

China has a vast landmass with more than 300 cities. Different cities have great differences in industrial structure and economic development levels, which can lead to huge variations in urban environmental quality. The urban ecological environment depends to a large extent on the local economic development model. On the one hand, cities with high pollution levels have relatively high levels of economic development and a wide variety of industries compared to cities with low pollution levels. Therefore, pollution from the automobile industry is not their main source of pollution. On the other hand, cities with high pollution levels have relatively sound policies to reduce pollution. Thus, only the change of automobile purchase tax has less impact on the emission reduction of the whole city. The two reasons lead to a relatively small marginal impact of pollution abatement policies in the automotive industry on cities with high pollution levels. In summary, this paper proposes hypothesis 2.

H2: the promotion effect of vehicle purchase tax incentives on urban emission reduction shows a dynamic characteristic of continuous weakening as the level of urban pollution increases.

The tax system is an important macroeconomic variable that can have a substantial impact on the demand for all categories of goods. Taxation, as a typical fiscal policy, is an important tool to influence consumer behavior. Theoretically, when a purchase tax incentive is applied to a taxable good as a fiscal policy, it will have a substitution effect and an income effect on the demand for the good. Therefore, when the vehicle purchase tax incentive is implemented, the actual cost of purchasing a vehicle will be reduced, and both the substitution and income effects will promote the sale of vehicles. In addition, due to the time limit of the incentives,

consumers predict that the cost of purchasing a vehicle will return to its normal level after the tax policy is eliminated; hence, some consumers will choose to spend earlier. Under the simultaneous influence of these two aspects, the purchase tax reduction lowers the cost of purchasing a small-displacement vehicle, thus promoting a significant increase in the sales of such vehicles. Based on the above analysis, we establish hypothesis 3.

H3: the purchase tax incentive reduces the purchase cost of low-emission vehicles, thus increasing the market share of low-displacement vehicles and thereby achieving the goal of improving the environment.

3. Methodology and Data

3.1. Methodology. Based on the panel data of Chinese cities, we examine the changes in urban pollutant emissions after the enactment of the purchase tax incentives using an OLS model. To test hypothesis 1, that is, whether the enactment of the purchase tax incentives would suppress urban pollutant emissions, the following model was set up:

$$\text{Pollution}_{it} = \alpha_0 + \alpha_1 \text{Time}_t + \sum \alpha_j X_{jit} + u_i + v_t + \varepsilon_{it}, \quad (1)$$

where Pollution_{it} denotes the pollutant emissions of city i in year t , including city SO₂ emissions, wastewater emissions, and soot emissions. Time_t is a time variable indicating whether the purchase tax incentives are implemented in year t . If the year is after 2015, then Time_t is equal to 1, 0 otherwise. The regression coefficient α_1 of Time_t is the core parameter of interest, reflecting the effect of tax incentives on urban pollutant emissions. If α_1 is significantly positive, then the tax incentives will increase urban pollutant emissions; if it is significantly negative, then the tax incentives will suppress urban pollutant emissions. X_j is the control variables that affect urban pollutant emissions including GDP and population number and so on. u_i and v_t denote the individual characteristics of cities that do not vary with time and the time trend characteristics that do not vary with cities, respectively. ε_{it} is random error terms.

To test hypothesis 2, which examines the dynamic characteristics of the marginal impact of purchase tax incentives on city pollutant emissions as the level of urban pollution changes, a panel quantile regression model shown below is set up in this paper:

$$\text{Pollution}_{it,q} = \alpha_{0,q} + \alpha_{1,q} \text{Time}_{t,q} + \sum \alpha_{j,q} X_{jit,q} + u_{i,q} + v_{t,q} + \varepsilon_{it,q}, \quad (2)$$

where q is the quantile. $\alpha_{i,q}$ denotes the marginal effect of the purchase tax incentives on urban pollutant emissions at the q quantile. The differences in the magnitude and significance of $\alpha_{i,q}$ at different quartiles reflect the differentiated characteristics of tax incentives under different levels of urban pollution.

To test hypothesis 3, which demonstrates that the car purchase tax incentives are used to achieve emission reductions by changing consumer behavior and promoting the

sales volume of low-energy vehicles, a differences-in-differences model and a regression discontinuity design model are set up in this paper.

The DID method is an important method to assess the effect of a policy, and its basic idea is to evaluate the influence of a policy by comparing the difference between the affected group (treatment group) and the unaffected group (control group). The application of the DID method requires a grouping variable and a staging variable. In this paper, the staging variable is whether the tax incentives are started or not, and the grouping variable is whether it is a small-emission vehicle of less than 1.6 L. Thus, we choose to apply the DID method to assess the overall effect of the tax incentives on the sales of small-emission vehicles.

$$\text{Insale}_{it} = \beta_0 + \beta_1 \text{Post}_t + \beta_2 \text{Treat}_i + \beta_3 \text{Post}_t \times \text{Treat}_i + \tau \text{Controls}_{ct} + u_i + \nu_t + \varepsilon_{ict}, \quad (3)$$

$$\text{Insale} = \tau_0 + \tau_1 D_t + \tau_2 \text{Date}_t + \tau_1 D_t \times \text{Date}_t + \varepsilon_t, \quad (4)$$

$$\text{Insale} = \lambda_0 + \lambda_1 T + \sum_{k=1}^k \lambda_k \cdot x^k + \sum_{k=1}^k \rho_k \cdot T \cdot x^k + x_k + \varepsilon. \quad (5)$$

We first use the DID method (model (3)) to measure whether there is a significant change in the sales of low-consumption vehicles after the purchase tax incentives come into effect, in which the counterfactual is defined by the period before the introduction of the tax incentives and by the type of vehicles with displacement greater than 1.6 L. Based on the first registration data of new cars in China, we have compiled monthly car sales data for each city in the country. In model (3), Insale_{it} denotes the sales of cars with displacement i at time t . Due to the lag in the effective date of the policy, we have lagged the time by two months. Post_t is an indicator variable measuring the post-December 2015 period. Treat_i is a dichotomous variable indicating whether the displacement of a car is less than 1.6 L. Controls_{ct} is a series of urban control variables.

We then adopt an RDD method to analyze the changes in the consumption structure of cars at different prices and in different cities. Model (4) and model (5) are local linear regression and local polynomial regression equations for the regression discontinuity design, respectively. The core parameters are τ_1 and λ_1 . The outcome variable of RDD is the number of new car registrations in a city in the current month under different prices, brands, and displacement. In this paper, the time is normalized, and the month before the policy is recorded as -1 , the month after as $+1$, and so on. For the order selection of polynomials, this paper follows Gelman and Imbens [23] and uses the order determination using the AIC criterion to finally determine the polynomial order of 3.

3.2. Variables and Data. In Table 1, we summarize the definitions of the variables used in the empirical analysis. Table 2 shows the descriptive statistics of the data.

To analyze in more detail the changes in the sales of small-displacement vehicles in different situations, such as different prices and different cities, we used the RDD method. When applying the RDD method, a variable should exist where individuals accept the disposition if the variable is greater than the critical value, and conversely, individuals do not accept the disposition when the variable is less than the critical value. In the RD design, individuals smaller than the critical value can be used as a control group to reflect the situation where individuals do not accept the disposition. In this paper, if the tax incentive starts to take effect, it means that the small-displacement vehicle accepts the disposition.

(1) *Dependent Variables.* Urban pollutant emissions and vehicle sales are the dependent variables of models (1) and (2). Considering the availability of data and drawing on relevant literature, the logarithmic values of urban SO_2 , wastewater, and soot emissions from 2007 to 2017 are chosen as the indicators of urban pollutant emissions in this paper. Data on urban pollutants were obtained from the National Bureau of Statistics of China. The logarithm of the volume of automobile sales is the dependent variable of models (3)–(5). The automobile data sets were obtained by compiling data on new car registrations in China. The prices of different cars are obtained from the most visited website (*AutoHome*) by Chinese car consumers.

(2) *Independent Variables.* We control for variables of concern that affect urban pollution emissions. Economic size is measured by the logarithm of the city's GDP. Population size is expressed as the logarithm of the number of urban resident population. The degree of urban pollution is measured by the ratio of secondary industry GDP to total industry GDP, with a larger ratio indicating a more polluted city. In addition, there are indicators such as urbanization rate, road mileage, and city residents' disposable income per capita are also controlled. The above data are from the iFinD financial database.

4. Empirical Results

4.1. Baseline Regression. Table 3 presents the results of the baseline regressions of purchase tax incentives on urban pollutant emissions. Regressions (1), (3), and (5) use the

TABLE 1: Variable definition.

Variable	Definition
LnSO ₂	Logarithm of city SO ₂ emissions
LnWater	Logarithm of city wastewater emissions
LnSoot	Logarithm of city soot emissions
Time	Equal to 1 if the year is after 2015, 0 otherwise
Post	Equal to 1 if the time is after December 2015, 0 otherwise
Treat	Equal to 1 if the displacement is less than 1.6 L, 0 otherwise
LnGDP	Logarithm of city GDP
LnPop	Logarithm of city population
Pollution_Degree	Degree of city pollution. The ratio of secondary industry GDP to total industry GDP
LnUrban	Logarithm of urbanization rate
LnMile	Number of road miles by province
LnIncome	Disposable income per capita by province
LnOil_Price	International crude oil prices
Price_Grade	Car price class. For every 50,000 RMB increase in price, the car goes up one level

TABLE 2: Descriptive statistics.

Variable	Obs	Mean	Std. dev.	Min	Max
LnSO ₂	2969	10.413	1.127	0.693	13.434
LnWater	2973	8.401	1.132	1.946	11.421
LnSoot	2926	9.762	1.132	3.526	15.458
Time	3022	.285	0.452	0	1
LnGDP	3022	7.112	1.051	3.502	10.402
LnPop	3022	5.901	0.731	3.022	8.031
Pollution_Degree	3022	0.487	0.111	0	0.91
LnUrban	3022	3.936	0.197	3.453	4.495
LnMile	3022	2.714	0.566	0.113	3.497
LnIncome	3022	8.6	0.356	7.825	9.665
LnSale	54144	4.275	2.419	0	11.164
Price_Grade	54144	3.252	1.8	1	7
LnOil_Price	54144	4.094	0.336	3.439	4.655

TABLE 3: Baseline regression results.

	(1) LnSO ₂	(2) LnSO ₂	(3) LnWater	(4) LnWater	(5) LnSoot	(6) LnSoot
Time	-0.614*** (-27.06)	-0.378*** (-10.82)	-0.305*** (-17.80)	-0.293*** (-11.01)	-0.0726*** (-2.72)	-0.469*** (-11.53)
LnGDP		-0.0956 (-0.97)		0.374*** (4.97)		0.232** (2.04)
Pollution_Degree		1.431*** (4.49)		-1.046*** (-4.30)		-0.493 (-1.34)
LnUrban		1.630*** (4.62)		-0.519* (-1.93)		0.732* (1.80)
LnMile		0.124 (0.48)		-0.934*** (-4.74)		0.585** (1.97)
LnPop		-0.0676 (-0.63)		-0.0542 (-0.67)		-0.0723 (-0.59)
LnIncome		-0.720*** (-4.60)		-0.118 (-0.99)		0.179 (0.99)
Constant	10.58*** (886.80)	10.34*** (9.15)	8.485*** (942.94)	12.24*** (14.20)	9.782*** (691.98)	2.908** (2.23)
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs	2969	2969	2973	2973	2926	2926

t statistics are in parentheses. * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

logarithmic values of urban SO₂ emissions, wastewater emissions, and soot emissions as dependent variables, respectively. These three regressions take only the implementation or not of tax incentives as the independent variable and control for time fixed effect and individual fixed effect. The results show that the regression coefficients of the tax policies are negative at the 1% significance level, indicating that the purchase tax incentives suppress urban emissions of SO₂, wastewater, and soot. Regressions (2), (4), and (6) include control variables that affect urban pollutant emissions, and the results remain negative. The coefficient values for Time_{*t*} are -0.378, -0.293, and -0.469, respectively, meaning that the purchase tax incentives result in the largest reduction in soot emissions (46.9%), followed by SO₂ emissions (37.8%) and wastewater emissions (29.3%). These show that the car purchase tax incentives do have an effect on the improvement of the urban environment.

The above results show that the purchase tax incentives do have an emission reduction effect. Hypothesis 1 is verified. This may stem from the fact that government purchase tax incentives for low-emission vehicles reduce consumers' preference for high-consumption vehicles, that is, purchase tax incentives increase the use of low-consumption vehicles and reduce motor vehicle emissions. In this paper, we will analyze the impact of the purchase tax incentives on the sales of small-emission vehicles at different prices and in different cities in the following section.

4.2. Heterogeneity Analysis Results. To examine the heterogeneous characteristics of the emission reduction effect of the purchase tax incentive in cities with different pollution levels, model (2) is estimated in this paper by choosing 20%, 40%, 60%, and 80% quartiles with urban SO₂ emissions as the dependent variable. The results are shown in Table 4. The absolute value of the regression coefficient of the purchase tax incentive on urban SO₂ emissions decreases with the increase of the quartiles. This indicates that the emission reduction effect of the purchase tax incentive shows a weakening trend with the increase of urban pollution. The marginal effects of the purchase tax incentive policy on urban wastewater emissions and soot emissions at the four quartiles are given in Tables 5 and 6, respectively. The absolute values of the regression coefficients of the purchase tax incentives on urban wastewater and soot emissions keep decreasing with the increase of the quartiles.

In terms of coefficient values, tax incentives applied in the automotive industry have reduced urban SO₂ emissions by 64%–79%, reduced wastewater emissions by 29%–42%, and reduced soot emissions by 12%–28%. These show that the effect of tax incentives for automobile purchases on the improvement of the urban environment decreases as the level of urban pollution rises. In addition, the tax credit resulted in the largest reduction in SO₂, a pollutant, because of the environmental policies of the automobile industry act on air pollutants in the first place.

For more detailed observation of whether the purchase tax incentive is differentiated across cities with different pollution levels, this paper further gives a graph of the

TABLE 4: Quantileregression results of purchase tax incentives on SO₂ emissions.

	(1) 20% LnSO ₂	(2) 40% LnSO ₂	(3) 60% LnSO ₂	(4) 80% LnSO ₂
Time	-0.791*** (-14.27)	-0.792*** (-15.35)	-0.754*** (-16.31)	-0.645*** (-15.15)
Constant	9.844*** (345.48)	10.51*** (396.11)	10.98*** (462.39)	11.42*** (521.61)
Obs	3092	3092	3092	3092

Note: *t* statistics are in parentheses. * < 0.10, ** < 0.05, and *** < 0.01.

TABLE 5: Quantile regression results of purchase tax incentives on wastewater emissions.

	(1) 20% LnWater	(2) 40% LnWater	(3) 60% LnWater	(4) 80% LnWater
Time	-0.422*** (-6.27)	-0.415*** (-7.25)	-0.339*** (-7.67)	-0.296*** (-5.83)
Constant	7.647*** (221.45)	8.281*** (282.26)	8.726*** (385.35)	9.250*** (355.29)
Obs	3095	3095	3095	3095

Note: *t* statistics are in parentheses. * < 0.10, ** < 0.05, and *** < 0.01.

TABLE 6: Quantile regression results of purchase tax incentives on soot emissions.

	(1) 20% LnSoot	(2) 40% LnSoot	(3) 60% LnSoot	(4) 80% LnSoot
Time	-0.282*** (-3.46)	-0.235*** (-4.20)	-0.122** (-2.25)	0.0433 (0.82)
Constant	8.993*** (213.09)	9.636*** (332.20)	10.09*** (359.75)	10.61*** (389.88)
Obs	3041	3041	3041	3041

Note: *t* statistics are in parentheses. * < 0.10, ** < 0.05, and *** < 0.01.

abatment effect of the tax incentive for different quartiles. As shown in Figure 1, the horizontal axis represents the quartile, and the vertical axis is the effect of tax incentives on the improvement of the urban environment. The results show that the marginal effect of purchase tax incentives on urban emission reduction is diminishing.

All the above results show that the promotion effect of car purchase tax incentives on urban emission reduction shows a dynamic change characterized by continuous weakening as urban pollution level increases. Hypothesis 2 is confirmed.

4.3. The Impact of Tax Incentives on the Structure of Auto Consumption

4.3.1. DID Regression Results. To test whether there is an effect of purchase tax incentives on the structure of auto consumption, we further regress model (3) for estimation, as shown in Table 7. Column (1) shows the baseline regression results. Column (2) further shows control variables related to auto consumption, including auto price class, urban road mileage, and disposable income per capita.

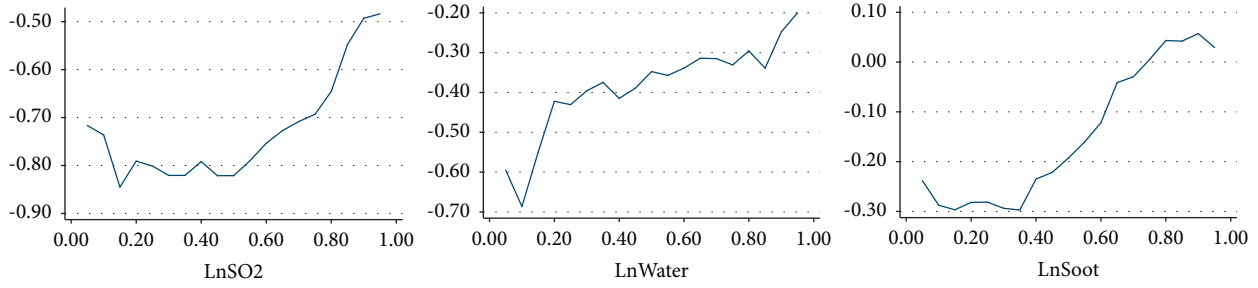


FIGURE 1: Dynamic trajectories of purchase tax incentive emission reduction effects.

TABLE 7: DID regression results.

	(1) Whole sample	(2) Whole sample	(3) Dependent variable: sales share	(4) Exclude new energy vehicles	(5) Symmetric time window	(6) Winsorize
Post* treat	0.190*** (3.26)	0.117*** (2.65)	0.0555*** (5.47)	0.129*** (2.91)	0.0852* (1.86)	0.0791* (1.82)
Post	0.506*** (11.69)	0.482*** (13.71)	-0.000325 (-0.05)	0.483*** (13.75)	1.134*** (17.95)	0.469*** (13.41)
Treat	0.253*** (10.63)	-0.450*** (-25.72)	-0.141*** (-27.83)	-0.449*** (-25.67)	-0.404*** (-18.00)	-0.450*** (-25.71)
Price_Grade		-0.838*** (-227.50)	0.0555*** (5.47)	-0.837*** (-227.47)	-0.796*** (-189.38)	-0.835*** (-228.20)
LnGDP		0.712*** (41.95)	0.0663*** (66.43)	0.712*** (41.95)	0.718*** (34.60)	0.707*** (41.84)
LnPop		0.0940*** (4.84)	-0.0216*** (-6.08)	0.0947*** (4.88)	0.110*** (4.66)	0.0979*** (5.05)
LnUrban		-0.728*** (-8.23)	0.0000644 (0.00)	-0.732*** (-8.26)	-0.777*** (-7.16)	-0.713*** (-8.08)
LnMile		0.0267 (1.52)	0.000167 (0.01)	0.0228 (1.30)	0.0365* (1.67)	0.0238 (1.36)
LnIncome		0.912*** (10.90)	-0.00664* (-1.84)	0.923*** (11.01)	0.944*** (9.27)	0.889*** (10.67)
LnRate		-0.320*** (-8.86)	0.00665 (0.38)	-0.321*** (-8.88)	-0.328*** (-7.58)	-0.312*** (-8.68)
LnOil_Price		-0.307*** (-9.82)	0.00846 (1.07)	-0.307*** (-9.82)	-1.181*** (-15.29)	-0.296*** (-9.53)
Constant	4.382*** (150.98)	-2.851*** (-4.86)	0.0484*** (6.75)	-2.922*** (-4.98)	1.078 (1.40)	-2.731*** (-4.69)
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs	54144	54144	32150	54113	35513	54144

Note: *t* statistics are in parentheses. * < 0.10, ** < 0.05, and *** < 0.01.

The value of the regression coefficient shows that the sales of small-displacement vehicles rise by 11%–19% after the halving of the purchase tax. The DID regression results indicate that in the Chinese auto consumption market, the purchase tax incentives change the structure of auto consumption, that is, promote the sales of small-emission vehicles and curb the sales of large-emission vehicles, thus achieving the goal of energy conservation and emission reduction.

4.3.2. RDD Regression Results. In this section, we use the RDD method to specifically estimate the impact of the purchase tax incentives on the sales structure of low-consumption vehicles at different prices. Based on the sales price of new cars, we classify all cars into five classes, that is, A, B, C, D, and E (representing

sales prices below RMB 50,000, RMB 50,000–RMB 100,000, RMB 100,000–RMB 150,000, RMB 150,000–RMB 200,000, and RMB 200,000 or more, respectively).

- (1) Graphical evidence: the horizontal axis of Figure 2 shows the time before and after the policy took effect (December 2015 is 0, the month before is noted as -1, the month after is noted as +1, and so on), and the vertical axis is the logarithm of sales volume. The figure shows the impact of the purchase tax incentives on the sales of cars with different prices, and it visually reflects the changes in the structure of car consumption before and after the purchase tax incentives. We choose the second month when the purchase tax incentives take effect (December 2015)

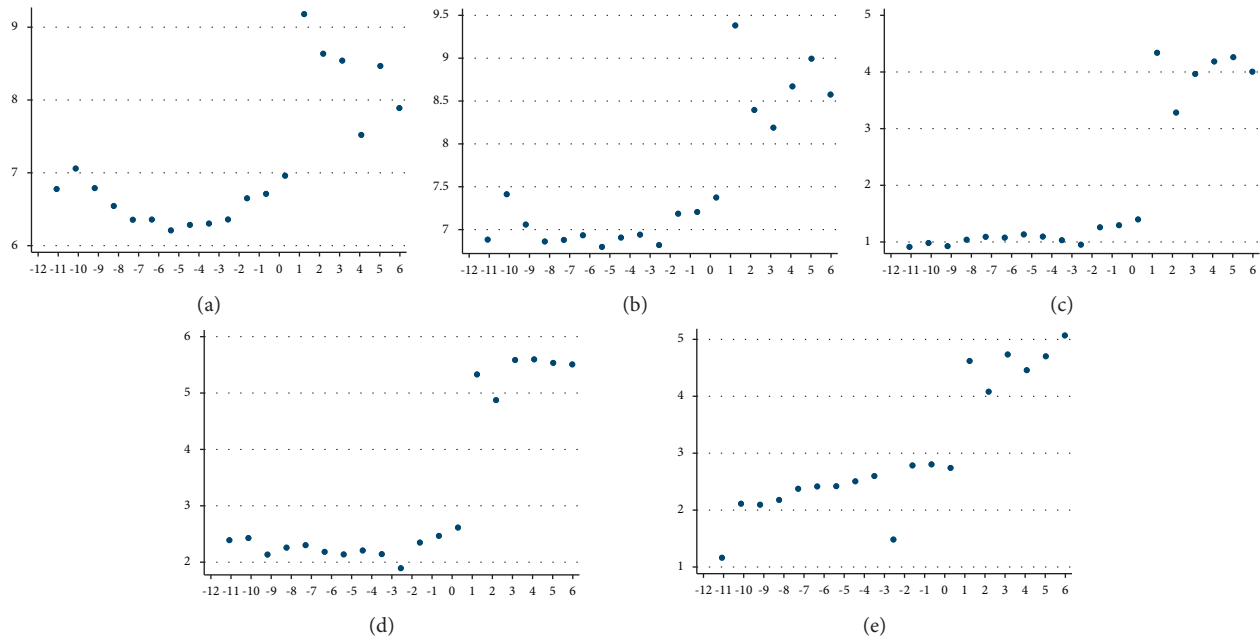


FIGURE 2: Change in sales of cars in different price classes.

as the cut-off point, that is, the right side of the cut-off point is the treatment group affected by the policy (before December 2015) and the left side is the control group not affected by the tax incentives (after December 2015). After the enactment of the purchase tax incentives, the sales of cars in five different price brackets have increased to different degrees. The largest increase is for cars between RMB 100,000 and RMB 150,000, with a rise of about 3%.

- (2) Local linear regression and local polynomial regression results: the results of the Local linear regression estimation of model (4) are given in Table 8. The outcomes show that the estimated coefficients of the acquisition tax incentives on car sales are positive, and all of them pass the 1% significance level test. This indicates that the purchase tax incentives have an amplifying effect on the sales of low-consumption vehicles. In terms of the magnitude of the coefficient of interest, the largest increase in sales is observed for low-consumption vehicles between 10 W and 20 W.

The results of the polynomial estimation of model (5) are given in Table 9. The results show that the sales of small-emission cars in different price classes have increased to different degrees. The polynomial regression results are consistent with the local linear estimation results.

From the results of the DID method, we can find that when the government gives tax incentives to consumers for purchasing cars, the behavior of consumers changes, and the consumption structure of the auto market transforms, that is, consumers are more inclined to buy cars with smaller displacement, and the sales of low-emission cars in the whole auto market rises significantly by 11%–19%. We further analyze the sales of low-emission cars in different price

classes using the RDD method and discover that the sales of cars above RMB 100,000 increase the most and the sales of cars below RMB 100,000 increase less. The effectiveness of the tax incentives on consumer behavior change is demonstrated by the two methods jointly. The urban environment is naturally improved by selling more small-emission cars that have less impact on urban pollution.

5. Robustness Test

5.1. Robustness Test of DID Method.

- (1) Parallel trend test. Although the above results indicate that the purchase tax incentives do have a significant increase in the sales of small-emission vehicles, the basic assumption that the previous DID research results hold is that the treated and control groups satisfy the common trend hypothesis, that is, the sales trends of large- and small-emission vehicles remain largely consistent before the tax incentives take effect. Hence, to test whether the results are consistent with the premise of a common trend, we plotted the common trend illustrations for the treatment and control groups. As shown in Figure 3, the horizontal axis indicates the staging variable, that is, the time when the purchase tax incentives take effect (December 2019) is 0, the month after is +1, before is -1, and so on. As can be seen in Figure 3, the sales trend of high-emission vehicles above 1.6 L and small-emission vehicles below 1.6 L remained largely consistent before the purchase tax took effect. After the introduction of the purchase tax incentives, the trend changed, with sales of large-emission vehicles falling abruptly in the first month and then remaining stable and sales of small-emission vehicles rising significantly and consistently.

TABLE 8: Local linear regression results at different price points.

	(1) A	(2) B	(3) C	(4) D	(5) E
D	2.192*** (0.2543)	1.708*** (0.2553)	3.616*** (0.1661)	3.042*** (0.1894)	2.228*** (0.1930)
Date	-0.0141*** (0.0042)	0.00508 (0.0047)	0.0287*** (0.0063)	0.00969 (0.0059)	0.0462*** (0.0062)
D*date	-0.131*** (0.0203)	-0.138*** (0.0206)	-0.281*** (0.0149)	-0.218*** (0.0163)	-0.189*** (0.0167)
Constant	6.295*** (0.0174)	6.726*** (0.0191)	1.129*** (0.0274)	2.178*** (0.0274)	2.229*** (0.0275)
Obs	8168	8156	3701	6049	6836

Note: *t* statistics are in parentheses. * < 0.10, ** < 0.05, and *** < 0.01.

TABLE 9: Localpolynomial regression results at different price points.

	(3) A <i>p</i> = 3	(3) B <i>p</i> = 3	(3) C <i>p</i> = 3	(3) D <i>p</i> = 3	(3) E <i>p</i> = 3
<i>T</i>	2.390** (0.6634)	2.597*** (0.5761)	2.498*** (0.3361)	3.502*** (0.3479)	3.249*** (0.2517)
<i>x</i>	0.275*** (0.0341)	0.255*** (0.0386)	0.125** (0.0527)	0.163*** (0.0506)	-0.0164 (0.0329)
<i>T*x</i>	-0.618* (0.3264)	-0.748** (0.2951)	0.243 (0.1942)	-0.425** (0.2142)	-0.262* (0.1413)
<i>x</i> ²	0.0310*** (0.0066)	0.0355*** (0.0074)	0.0179* (0.0104)	0.0182* (0.0099)	-0.0107 (0.0066)
<i>T*x</i> ²	-0.0416 (0.0483)	-0.0365 (0.0451)	-0.164*** (0.0315)	-0.0780** (0.0350)	-0.0339 (0.0226)
<i>x</i> ³	0.000673* (0.0004)	0.00137*** (0.0004)	0.000898 (0.0006)	0.000499 (0.0005)	-0.000792** (0.0004)
<i>T*x</i> ³	0.00113 (0.0022)	0.000499 (0.0021)	0.00745*** (0.0015)	0.00444*** (0.0017)	0.00471*** (0.0011)
Constant	6.781*** (0.0509)	7.134*** (0.0581)	1.324*** (0.0747)	2.457*** (0.0717)	2.728*** (0.0466)
Obs	8168	8156	3701	6049	24438
AIC	26498.9261	28077.8713	11644.0853	21666.1745	99422.5250

Note: *t* statistics are in parentheses. * < 0.10, ** < 0.05, and *** < 0.01.

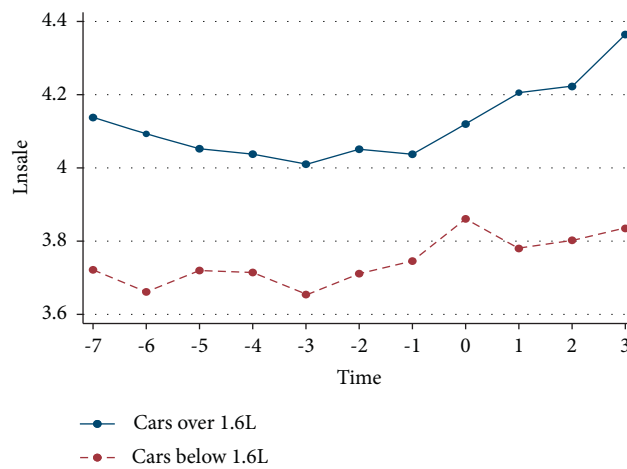


FIGURE 3: Common trend in treated and control groups.

(2) Substitution of the dependent variable. We replace the dependent variable from the sales volume of a certain displacement of cars to the proportion of

sales of that type of car to the total sales volume of cars in that month, that is, we further examine the effect of tax incentives on the proportion of sales of

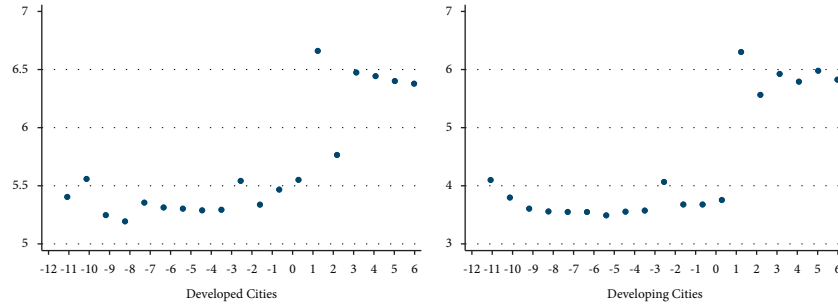


FIGURE 4: Auto sales in developed and developing cities are affected by tax incentives.

TABLE 10: RDD results for different cities.

	(1) Local linear regression			(3) Local polynomial regression	
	Developed cities	Developing cities		Developed cities	Developing cities
D	0.981*** (0.1771)	2.221*** (0.1036)	T	0.950** (0.3877)	3.078*** (0.2384)
Date	0.0157** (0.0072)	0.0147*** (0.0031)	x	-0.0156 (0.0581)	-0.222*** (0.0252)
D*date	-0.0868*** (0.0161)	-0.194*** (0.0088)	T*x	0.0630 (0.2166)	-0.0566 (0.1237)
			x ²	-0.0145 (0.0115)	-0.0623*** (0.0049)
			T*x ²	-0.0300 (0.0348)	0.0218 (0.0191)
			x ³	-0.00109* (0.0006)	-0.00391*** (0.0003)
			T*x ³	0.00399** (0.0017)	0.00751*** (0.0009)
Constant	5.447*** (0.0297)	3.799*** (0.0126)	_Cons	5.518*** (0.0845)	3.687*** (0.0377)
Obs	13731	63842	Obs	13731	63842
			AIC	63166.2077	2.864e + 05

Note: *t* statistics are in parentheses. * < 0.10, ** < 0.05, and *** < 0.01.

small-displacement cars. The regression results are in column (3) of Table 7.

- (3) Regression results indicate that the tax incentives led to a significant increase in the sales share of small-emission vehicles by 4%.
- (4) Exclusion of sample bias. Although the above results suggest that tax incentives can promote the sales of small-displacement vehicles; however, environmental improvement may be achieved due to the steady expansion of the new energy electric vehicle market. New energy electric vehicles are vehicles with zero displacement and increasing the use of new energy vehicles can reduce greenhouse gas and urban pollutant emissions, providing a significant advantage over conventional fuel vehicles in terms of energy efficiency and environmental protection. We removed cars with a displacement of 0 from the sample in order to exclude the effect of new energy vehicles and regressed model (3). The results are in column (4) of Table 7. The findings show that by removing the sample of new energy vehicles, the sales of small-

displacement vehicles are still significantly increased by 12.9% by the motivation of tax incentives.

- (5) Tail shrinkage treatment. We adjust the sample by a 1% tail shrinkage, and the results are in column (5) of Table 7. The coefficient value of the interaction term of DID is 0.0791, and it passes the 1% significance level test, which indicates that the purchase tax incentives contributed to a significant increase of 7.91% in the sales of small-emission vehicles.
- (6) Adjusting the sample period. We control for the six months before and after the implementation of the purchase tax incentives and remove the sample of other months to estimate model (3) again. In terms of values, the sales of small-displacement cars rise by 8.52% motivated by the purchase tax incentives. The results are in column (6) of Table 7.

Through the above robustness tests, we find that the introduction of purchase tax incentives for low-consumption vehicles does change consumer behavior, that, it

promotes consumers to buy more small-emission vehicles and discourages the sale of large-emission vehicles, thus reducing urban pollutant emissions and achieving the goal of environmental improvement.

5.2. Robustness Test of RDD Method. To test the robustness of the RDD results, we further explore the influence of different cities' auto sales structure by tax incentives. Based on the level of economic development, we distinguish cities into developed cities and developing cities. Figure 4 shows that developing cities are more significantly influenced by the purchase tax incentives. Developed cities such as Beijing and Shanghai are a little bit weaker affected by tax incentives, that is, the sales of small-emission vehicles increase less.

Table 10 gives the changes in the sales of low-consumption vehicles in cities of developed and developing countries after the introduction of the purchase tax incentives. Columns (1) and (3) are the results of the local linear regression and local polynomial regression for developed cities, respectively. Columns (2) and (4) show the regression results for cities in developing countries. The results show that tax incentives lead to more new vehicle sales of small-emission vehicles in developing cities compared to developed cities, that is, developing cities are more significantly influenced by the purchase tax incentives.

To sum up, the purchase tax incentives increase the sales of small-emission vehicles in developing cities more. The reason may be that the economic level of developed cities is high, and people are relatively affluent; therefore, consumers will pay more attention to the brand and grade of the car. For these wealthy groups, buying a car is not only for the convenience of transportation but also to satisfy their "vanity." In addition, eight ultradeveloped cities such as Beijing and Shanghai have a limited purchase policy. This policy excludes customers of low-end models from the purchase threshold, whereas customers of high-end models do not care whether the purchase tax is favorable or not. For these reasons, developed cities are less affected by tax incentives than developing cities.

6. Conclusions and Recommendations

Fiscal policy, particularly tax policy, has been widely recognized as being associated with energy efficiency and environmental improvements. This paper first demonstrates, based on an urban panel data set, that applying purchase tax incentives to the automobile market can improve urban environments. Second, using quantile regression, we find that the effect of tax incentives on the urban pollution improvements becomes weaker as urban pollution increases. Finally, based on a unique monthly data set of urban auto sales from 2015 to 2016, taking DID and RDD methods, we find that the purchase tax incentives have a very strong impact on the structure of auto consumption. The 50% purchase tax reduction for low-emission vehicles can reduce the cost of car purchase for consumers and expand the market share of energy-efficient cars, thus achieving the purpose of emission reduction. For cars at different price levels, consumers prefer

RMB 100,000–RMB 200,000 low-emission vehicles after the introduction of the purchase tax incentives. Developed cities are less sensitive to tax incentives than developing cities due to the higher economic level of consumers.

In summary, tax policies in the automobile industry have the effect of emission reduction and can effectively improve the urban environment on the one hand and can also change the preferences of automobile consumers and guide their consumption behavior toward environmental protection on the other hand. This conclusion not only consolidates the research results of previous researchers and enriches and improves the theory of automotive economics and green development but also provides ideas to promote a country to achieve green and healthy economic development and implement energy-saving and emission reduction policies.

First, the government can give tax incentives or subsidies to manufacturers and consumers of low-pollution vehicles to encourage manufacturers to produce more and consumers to buy more. Secondly, for cities with different pollution levels, the emission reduction effects of tax policies differ greatly, so the policies should be tailored to local conditions to reasonably bring into play the emission reduction effects of tax policies. For cities with a low pollution level, mainly in the transportation industry, we should pay full attention to the improvement effect of auto tax incentives on urban environment. For cities with high pollution levels, tax policies should be combined with other measures to improve the urban environment in concert. Finally, consumer behavior will be influenced by tax policies, so the government can give certain tax incentives or subsidies to consumers who buy low-emission vehicles and tax consumers who buy high-emission vehicles more, thus guiding consumer behavior toward environmental protection. In conclusion, taxation should play an important role in the green development of the economy, and taxation should be used to guide consumer behavior change, promote emission reduction with consumer behavior change, and promote environmental improvement with emission reduction.

Data Availability

The data used to support the findings of this study were supplied by iFinD financial database under license and so cannot be made freely available.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (42176217 and 72073086) and National Statistical Science Research (2020LY048).

References

- [1] N. S. Marrero, G. A. Marrero, R. M. González, and J. Rodríguez-López, "Convergence in road transport CO₂ emissions in Europe," *Energy Economics*, vol. 99, 2021.

- [2] A. Gambhir, L. K. C. Tse, D. Tong, and R. Martinez-Botas, "Reducing China's road transport sector CO₂ emissions to 2050: technologies, costs and decomposition analysis," *Applied Energy*, vol. 157, pp. 905–917, 2015.
- [3] L. Grigolon, M. Reynaert, and F. Verboven, "Consumer valuation of fuel costs and tax policy: evidence from the European car market," *American Economic Journal: Economic Policy*, vol. 10, no. 3, pp. 193–225, 2018.
- [4] D. Dineen, L. Ryan, and B. Ó Gallachóir, "Vehicle tax policies and new passenger car CO₂ performance in EU member states," *Climate Policy*, vol. 18, no. 4, pp. 396–412, 2018.
- [5] S. Leinert, H. Daly, B. Hyde, and B. Ó. Gallachóir, "Co-benefits? Not always: quantifying the negative effect of a CO₂-reducing car taxation policy on NO emissions," *Energy Policy*, vol. 63, pp. 1151–1159, 2013.
- [6] Á. Ni Choisdealbha, S. Timmons, and P. D. Lunn, "Experimental evidence for the effects of emissions charges and efficiency information on consumer car choices," *Journal of Cleaner Production*, vol. 254, 2020.
- [7] L. Ryan, S. Ferreira, and F. Convery, "The impact of fiscal and other measures on new passenger car sales and CO₂ emissions intensity: evidence from Europe," *Energy Economics*, vol. 31, no. 3, pp. 365–374, 2009.
- [8] R. Kok, "Six years of CO₂ -based tax incentives for new passenger cars in The Netherlands: impacts on purchasing behavior trends and CO₂ effectiveness," *Transportation Research Part A: Policy and Practice*, vol. 77, pp. 137–153, 2015.
- [9] B. Xu and B. Lin, "Regional differences of pollution emissions in China: contributing factors and mitigation strategies," *Journal of Cleaner Production*, vol. 112, pp. 1454–1463, 2016.
- [10] L. Fridstrøm and V. Østli, "The vehicle purchase tax as a climate policy instrument," *Transportation Research Part A: Policy and Practice*, vol. 96, pp. 168–189, 2017.
- [11] A. Zimmer and N. Koch, "Fuel consumption dynamics in Europe: tax reform implications for air pollution and carbon emissions," *Transportation Research Part A: Policy and Practice*, vol. 106, pp. 22–50, 2017.
- [12] A. S. Bergantino, M. Intini, and M. Percoco, "New car taxation and its unintended environmental consequences," *Transportation Research Part A: Policy and Practice*, vol. 148, pp. 36–48, 2021.
- [13] Z. Dong, Y. He, and H. Wang, "Dynamic effect retest of R&D subsidies policies of China's auto industry on directed technological change and environmental quality," *Journal of Cleaner Production*, vol. 231, pp. 196–206, 2019.
- [14] I. Alhulail and K. Takeuchi, *Effects of Tax Incentives on Sales of Eco-Friendly Vehicles: Evidence from Japan (No. 1412)*, Graduate School of Economics, Kobe University, Kobe, Japan, 2014.
- [15] S. L. Mabit, "Vehicle type choice under the influence of a tax reform and rising fuel prices," *Transportation Research Part A: Policy and Practice*, vol. 64, pp. 32–42, 2014.
- [16] Ø. Thomassen, "The effects of tax exemption on the sale of electric vehicles in Norway," *Economic Discussion*, vol. 56, 2017.
- [17] V. Østli, L. Fridstrøm, K. Johansen, and Y. Tseng, "A generic discrete choice model of automobile purchase," *European Transport Research Review*, vol. 9, pp. 1–20, 2017.
- [18] S. Yan, "The economic and environmental impacts of tax incentives for battery electric vehicles in Europe," *Energy Policy*, vol. 123, pp. 53–63, 2018.
- [19] X. Jing, "Research on tax policy for promoting the transformation and upgrading of China's automobile industry," *Modern Economy*, vol. 10, no. 2, pp. 484–501, 2019.
- [20] D. Cerruti, A. Alberini, and J. Linn, "Charging drivers by the pound: how does the UK vehicle tax system Affect CO₂ emissions?," *Environmental and Resource Economics*, vol. 74, no. 1, pp. 99–129, 2019.
- [21] X. Tian, Q. Zhang, Y. Chi, and Y. Cheng, "Purchase willingness of new energy vehicles: a case study in Jinan City of China," *Regional Sustainability*, vol. 2, no. 1, pp. 12–22, 2021.
- [22] V. Østli, L. Fridstrøm, N. B. Kristensen, and G. Lindberg, "Comparing the Scandinavian automobile taxation systems and their CO₂ mitigation effects," *International Journal of Sustainable Transportation*, pp. 1–18, 2021.
- [23] A. Gelman and G. Imbens, "Why high-order polynomials should not be used in regression discontinuity designs," *Journal of Business & Economic Statistics*, vol. 37, no. 3, pp. 447–456, 2019.