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Does high gasoline price spur electric vehicle adoption? Evidence from Chinese cities

Yinxin Fei [a], Ping Qin [a], Yanlai Chu [b,*], Huanhuan Zheng [c], Jie-Sheng Tan-Soo [c], Xiao-Bing Zhang [d]

[a] *School of Applied Economics, Renmin University of China, China*
[b] *Renmin Business School, Renmin University of China, China*
[c] *Lee Kuan Yew School of Public Policy, National University of Singapore, Singapore*
[d] *DTU Management, Technical University of Denmark, Denmark*

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ABSTRACT

Promoting the adoption of electric vehicles (EVs) is crucial for curbing carbon emissions in the transportation sector and combating climate change. Higher gasoline prices could accelerate the transition to EVs by raising the operating costs of vehicles powered by internal combustion engines (ICEVs). This study examines the impact of gasoline prices on EV adoption by analyzing monthly sales data at the product level from 36 major cities in China over the period of 2017 to 2022. Our analysis reveals that a 1 Chinese Yuan (CNY)/L increase in gasoline prices is associated with a 4.67 % surge in EV sales, indicating that consumers opt for EVs in response to the higher operating costs of ICEVs. Furthermore, we find that the effect is more pronounced for EVs with lower purchase costs, lower electricity consumption, and those within the Mini/Small vehicle segment. Using our results, we simulate the effects of a 1 CNY/L increase in gasoline price and show that it would reduce 1.97 million tons/year of carbon emissions from the vehicle fleet sold annually. This research underscores the efficacy of gasoline taxes as a policy instrument to mitigate carbon emissions by accelerating EV adoption.

1. Introduction

EV adoption is vital for reducing greenhouse gas emissions (Bushnell et al., 2022; Li et al., 2022; Linn, 2022; Linn, 2023; Wang et al., 2024), improving air quality (Xing et al., 2021; Li et al., 2022), and enhancing energy security (Xing et al., 2021; Lin and Wu, 2021). To combat global warming, many countries have put in plans to ban the sales of internal combustion engine vehicles (ICEVs). For example, the European Union announced a ban on the sale of new petrol and diesel cars from 2035.[1] California also regulated that all new passenger cars sold in California will be zero-emission vehicles by 2035.[2] However, EV adoption faces challenges due to high purchase costs (Linn, 2022), necessitating the implementation of financial incentives to encourage purchases.

China is a prime example, where substantial financial backing from both central and local governments has facilitated the rapid adoption of EVs (Wu et al., 2021; Li et al., 2022; Liu et al., 2022). Yet, extensive subsidies have caused a multitude of issues, including financial strain on government budgets (Ma et al., 2019), adverse selection, moral hazard (Wu et al., 2021), and negative EV perceptions (Wang and Xing, 2023). For example, in 2016, each Battery Electric Vehicle (BEV) was eligible for a subsidy ranging from 25,000 to 55,000 Chinese Yuan (CNY). Thus, the government was estimated to spend more than 10 billion CNY on BEV subsidy in 2016 alone, a substantial financial burden. Moreover, the availability of such large subsidies attracted unqualified EV firms into the market. These firms, producing low-quality EVs at low costs, contributed to an adverse selection problem and dampened the reputation of the EV industry, and curbed the growth of the EV industry (Wang and Xing, 2023; Wu et al., 2021).

Additionally, since the government cannot perfectly observe the quality of EVs, some firms exploited this by falsifying vehicle attributes to meet the subsidy requirements, leading to a moral hazard problem. In 2016, Xinhua News Agency, one of China's most prominent official news

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* Corresponding author.
E-mail address: chuyanlai@rmbs.ruc.edu.cn (Y. Chu).

[1] Source: https://www.europarl.europa.eu/topics/en/article/20221019STO44572/eu-ban-on-sale-of-new-petrol-and-diesel-cars-from-2035-explained

[2] Source: https://ww2.arb.ca.gov/resources/documents/cars-and-light-trucks-are-going-zero-frequently-asked-questions

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agencies, reported five severe cases of EV subsidy fraud.[3] The Central Government of the People's Republic of China also highlighted several such cases on its website[4]: Jimuxi Manufacturing Company swindled 261.6 million CNY in EV subsidies through falsifying documents, including production records, sales records, and quality certificates. Another car firm, Jinlong Suzhou Automotive Corporation, claimed subsidies for unsold EVs, involving 519.2 million CNY.

An alternative strategy to promote EV adoption involves using the gasoline price as a policy tool. By implementing measures such as levying taxes on gasoline, policymakers can effectively raise the operating costs of ICEVs. This creates a price discrepancy that underscores the significant cost savings with EVs, thereby enhancing EVs' attractiveness to consumers (Springel, 2021; Bushnell et al., 2022), particularly as gasoline prices escalate (Jing et al., 2022; Sun et al., 2023).

This study examines how gasoline prices affect EV adoption in China from 2017 to 2022, based on three key observations. Firstly, with over 70 % of China's crude oil consumption dependent on imports (source: National Bureau of Statistics (NBS)), the refined oil market in China is also affected by international market dynamics. In 2022, global crude oil prices reached their highest levels since 2008, resulting in record-high gasoline prices in China in June 2022. Secondly, the sales of EVs in China surged in the same period from 1.12 million to 5.01 million units between 2020 and 2022, with their market share growing from 5.9 % to 25.8 %. Measured in sales revenue, the market share of EVs has increased in a similar pattern, rising from 5.8 % to 22.4 % during this period. By 2022, China' EV sales had become a dominant force in the global market, accounting for 38.4 % of global EV sales in 2020 and a commanding 57.8 % in 2022. Thirdly, one significant policy shift that has accompanied this rapid increase in EV adoption is the Chinese government's pronounced scaling back and eventual phase-out of EV subsidies. This strategic move is aimed at promoting a market-driven EV industry. In December 2021, a collaborative announcement was made by the Ministry of Finance, the Ministry of Industry and Information Technology, the Ministry of Science and Technology, and the National Development and Reform Commission, detailing a 30 % reduction in EV subsidies for 2022 compared to 2021. Furthermore, the policy outlined the complete withdrawal of subsidies by the end of December 2022, signaling a transition towards a more self-sustaining and competitive EV market.[5]

Therefore, these observations concerning the surge in EV adoption warrant an investigation into the interplay between gasoline prices and EV adoption. In particular, the volatility in international crude oil prices provides an opportunity to assess the extent to which rising gasoline prices have influenced EV adoption in China, the world's largest and fastest-growing EV market.

To do so, this study utilizes the monthly sales data at the vehicle-model level across 36 cities in China, combined with monthly-level gasoline prices in these cities spanning from 2017 to 2022, to quantitatively investigate the impact of gasoline prices on EV sales. Our findings indicate that an average 1 CNY/L increase in gasoline price is associated with a 4.67 % increase in EV sales. Specifically, the sales of Battery Electric Vehicles (BEVs) see a surge of 9.04 %, while the sales of Plug-in Hybrid Electric Vehicles (PHEVs) experience a modest decline with a 1 CNY/L increase in gasoline price. Further heterogeneity analysis reveals that EVs with lower purchase costs, longer range, and higher energy efficiency experience more significant sales growth. In terms of vehicle segments, the sales of mini and small EVs are particularly bolstered by increases in gasoline prices. Subsequently, we conduct simulations to evaluate the effects of gasoline tax on automobile sales, gasoline use, and electricity consumption, as well as related carbon emissions. The simulation results show that a 1 CNY/L increase in gasoline price could reduce 1.97 million tons/year of carbon emissions for the sold vehicle fleets each year. These findings underscore the potential for carbon emission mitigation through the substituting ICEVs with EVs, a shift that could potentially be accelerated by the implementation of gasoline price-linked taxes.

Our study contributes to the existing literature in three main aspects. Firstly, it expands upon previous investigations by exploring the impact of gasoline prices on accelerating the adoption of EVs. While current studies extensively discuss how elevated gasoline prices motivate fleet fuel economy improvements, either through the consumer preference for fuel-efficient vehicles (Li et al., 2009; Klier and Linn, 2010; Klier and Linn, 2013; Busse et al., 2013; Barla et al., 2016; Knittel and Tanaka, 2021; Xu et al., 2023) or through the manufacturers' adoption of fuel-saving technologies (Klier et al., 2020), there is scarce research examining the impact of gasoline prices specifically on the proliferation of EVs (Bushnell et al., 2022; Sun et al., 2023). Our work fills in this gap by utilizing the most up-to-date data on EV sales and gasoline prices to investigate the role of gasoline prices in stimulating the adoption of EVs during a period marked by volatile gasoline prices.

Secondly, this study enriches the EV adoption literature by focusing on China, the largest and fastest-growing EV market globally. China has seen a remarkable surge in both EV production and sales, establishing itself as one of the most significant EV manufacturers and consumers on the world stage. Therefore, this research provides contemporary insights into the vigorous growth of China's EV market and its underlying driving factors. Additionally, taking advantage of the extensive monthly model-level dataset, we can control for a rich set of fixed effects in the empirical analysis, which allows for a more precise identification of the impact of gasoline prices on EV adoption trends.

Thirdly, our study delves into the heterogeneity analyses on the impact of gasoline prices, highlighting the important role of both purchase and operational costs in consumers' decision to shift to EVs. The heterogeneity analyses reveal diverse effects of gasoline price on the sales of EV in different categories, an aspect previously unexplored in the existing literature. Heterogeneity analyses demonstrate that low-priced EVs, long-range EVs, low energy-consuming EVs, and those within Mini/Small segments, are particularly sensitive to gasoline price increases. As gasoline prices rise, consumers shift towards more cost-effective, affordable, low energy-consuming, and compact ones.

The rest of this paper is structured as follows: Section 2 reviews related literature. Section 3 introduces datasets and presents data statistics. Section 4 outlines the empirical strategy we used. Section 5 discusses the results and implications. Finally, Section 6 concludes.

2. Literature review

This study is built on two branches of literature. First, it is related to extensive studies that examine how gasoline price affects the adoption of fuel-efficient ICEVs. These studies are aligned with the rationale that higher gasoline prices can encourage consumers to switch from ICEVs to EVs to reduce driving costs. Second, our paper adds to a relatively smaller corpus of literature that explores the impact of gasoline prices on the adoption of EVs and hybrid vehicles.

A substantial body of research has examined the relationship between gasoline prices and the adoption of fuel-efficient ICEVs, as well as the implications on carbon emissions reduction (Li et al., 2009; Bonilla, 2009; Klier and Linn, 2010; Klier and Linn, 2013; Busse et al., 2013; Burke and Nishitateno, 2013; Barla et al., 2016; Du and Lin, 2017; Rivers and Schaufele, 2017; Klier et al., 2020; Knittel and Tanaka, 2021; Xu et al., 2023). This research has largely centered on developed nations, particularly the United States. These investigations are instrumental in understanding the influence of gasoline price on consumers' vehicle preferences, and in assessing the efficacy of gasoline taxes in promoting

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[3] Source: https://www.gov.cn/xinwen/2016-12/20/content_5150704.htm

[4] Source: https://www.gov.cn/xinwen/2016-09/09/content_5106700.htm

[5] Ministry of Finance, 2021, The notification on financial subsidy policy for EV promotion and application in 2022, accessed at https://www.gov.cn/zhengceku/zhengceku/2021-12/31/content_5665857.htm?utm_medium=Email&utm_campaign=IEA+newsletters

fuel efficiency and reducing gasoline consumption.

In a seminal paper, Berry et al. (1995) established that gasoline prices affect consumers' vehicle choices by altering their travel costs, a conclusion that has been supported by numerous subsequent studies (e.g., Whitefoot and Skerlos, 2012; Klier and Linn, 2012; Allcott and Wozny, 2014; Sallee et al., 2015; Grigolon et al., 2018; Leard et al., 2019; Lin and Linn, 2023). Li et al. (2009) identified two channels through which higher gasoline prices affect fleet fuel economy, using vehicle registration data from 20 U.S. Metropolitan Statistical Areas (MSAs) from 1997 to 2005: by stimulating the purchase of fuel-efficient vehicles, and by hastening the scrapping of inefficiently used vehicles. Klier and Linn (2010) found that a $1 increase in gasoline prices corresponded to an average increase in fuel economy of 0.8–1 MPG, by utilizing monthly sales data at vehicle-model level from 1978 to 2007 in the U.S. In a subsequent comparative analysis, Klier and Linn (2013) highlighted the differential market responses to gasoline price fluctuations in the U.S. versus Europe between 2002 and 2007, attributing these differences to varying consumer expectations of the permanence of gasoline price change. Rivers and Schaufele (2017) estimated the elasticity of fuel economy to gasoline price: a 10 % increase in gasoline price led to a 0.8 % improvement in fuel economy. They also found that consumers living in urban areas are more responsive to gasoline price. Research by Busse et al. (2013) and Barla et al. (2016) further confirmed that higher gasoline prices increased sales of fuel-efficient vehicles and decreased sales of less fuel-efficient vehicles. Among the few studies on the Chinese automobile market, Xu et al. (2023) showed that rising gasoline prices discouraged overall vehicle sales, while also prompting a shift towards more fuel-efficient vehicles in the fleet composition.

In sum, these studies show that consumers react to rising gasoline prices by prioritizing energy-efficiency of their vehicles purchase (opting for ICEVs with superior fuel economy). This implies that a comparable trend may be anticipated with EVs given they are inherently more energy-efficient than ICEVs (given EV motors reaching over 85 % efficiency, compared to the typical 20 % efficiency of ICEVs). However, research examining the impact of gasoline prices on the sales of EVs remains relatively sparse. Notably, Diamond (2009) studied hybrid vehicle adoption in the U.S. from 2001 to 2006, uncovering a robust relationship between gasoline prices and hybrid vehicle adoption: a 10 % increase in gasoline prices corresponded to a 72 % to 93 % increase in the market share of hybrid vehicles. Beresteanu and Li (2011) evaluated the determinants of hybrid vehicle demand in the U.S. from 1999 to 2006 and found that gasoline price increases accounted for 37 % of hybrid vehicle sales. Bushnell et al. (2022) utilized a monthly panel dataset of EV registrations and detailed gasoline and electricity prices in California from 2014 to 2017, concluding that gasoline prices exerted a significantly greater influence on EV demand than electricity prices.

The existing research on the influence of gasoline prices on the adoption of EVs and hybrid vehicles display several key features. Firstly, the majority of these studies focus on the automobile market in the U.S. or in Europe, with limited investigation extending to developing countries such as China. A notable exception is the recent study by Wang et al. (2022), which devolves into the Chinese automobile market. Wang et al. (2022) identified a positive correlation between oil prices and the sales of both BEVs and PHEVs using national-level aggregated sales data from 2012 to 2021. Our research delves deeper into this topic by utilizing detailed model-level sales data across multiple Chinese cities, enabling a robust statistical analysis of the impact of gasoline prices on EV sales. Secondly, existing studies have not yet comprehensively analyzed the impact of the extremely volatile and elevated gasoline prices witnessed in 2022 on the EV market, largely due to the lack of up-to-date data. Our study addresses this gap by integrating the recent disturbances in international crude oil prices during 2021–2022, with a specific focus on discerning how these fluctuations have influenced EV adoption in China, which stands out as a highly promising market for EVs.

3. Data

Our analysis draws on two primary datasets. The first dataset includes monthly sales data for all vehicle models in 36 major cities in China, spanning from January 2017 to December 2022, a time period with remarkable growth in EV sales. These 36 cities include all provincial capitals and several economically developed cities within the provinces, and their collective EV sales constitute over 50 % of the country's total EV sales. This dataset, obtained from JATO, a global provider of automotive business data, categorizes vehicle models at the make-model-model year-version level, offering comprehensive information for heterogeneity tests across various vehicle characteristics.

The second dataset, monitored by NDRC, comprises the monthly gasoline prices for the same 36 major cities from 2017 to 2022. These gasoline prices have been deflated to constant 2015 CNY values to ensure comparability over time. We use the 95-octane gasoline price in the baseline regression, as this is the widely-used fuel for passenger vehicles in China. In the robustness checks, we will examine the sensitivity of our baseline findings to the choice of gasoline price.

Fig. 1 depicts the EV sales in the 36 cities in our sample and each city's contribution to China's total EV sales in 2022. The data reveals that Shanghai emerged with top EV sales of more than 300,000 units, which accounted for 6.52 % of the country's EV sales. Shanghai was followed by Hangzhou, Shenzhen, Guangzhou, and Beijing. Collectively, the 36 cities in our sample accounted for 51.45 % of China's total EV sales for the year 2022.

Fig. 2(a) depicts the annual EV sales in the 36 cities (light grey) alongside the average sales trend (solid blue line). Fig. 2(b) depicts the corresponding market share of EVs in total vehicle sales. Fig. 2(a) shows that EV sales in China exhibited a modest increase from 2017 to 2018, followed by a slight decline in 2019 due to the COVID-19 outbreak, and subsequently experienced a dramatic increase from 2020 to 2022. Meanwhile, as depicted in Fig. 2(b), the share of EV sales in the whole automobile market has also shown substantial growth since 2020.

Fig. 3 presents the monthly 95-octane gasoline price in the 36 cities (light grey) alongside the average price trend (solid orange line) from 2017 to 2022. The data indicates that gasoline prices across these cities followed a consistent pattern, fluctuating between 5 CNY/L and 7 CNY/L from 2017 to 2021. After that, prices consistently rose and exceeded 8 CNY/L in June 2022. The significant fluctuations in gasoline prices provide a valuable basis for analyzing the effect of gasoline prices on EV sales. Figs. 2 and 3 collectively highlight the soaring EV sales and rising gasoline prices since 2020.

Table 1 presents descriptive statistics of variables utilized in our analysis. The data reveals significant variations in the monthly EV sales at the model level across cities, ranging from a minimum of 1 unit to a maximum of 7023 units. The prices of EVs vary widely, from less than 26 thousand CNY to approximately 1.3 million CNY. Table 1 also highlights the substantial volatility in gasoline prices in our sample. For instance, the prices of 95-octane gasoline vary from 4.26 CNY/L to 9.37 CNY/L.

4. Empirical framework

The empirical framework we use is based on Klier and Linn (2010, 2013), Sun et al. (2016), and Xu et al. (2023). In particular, the empirical specification is:

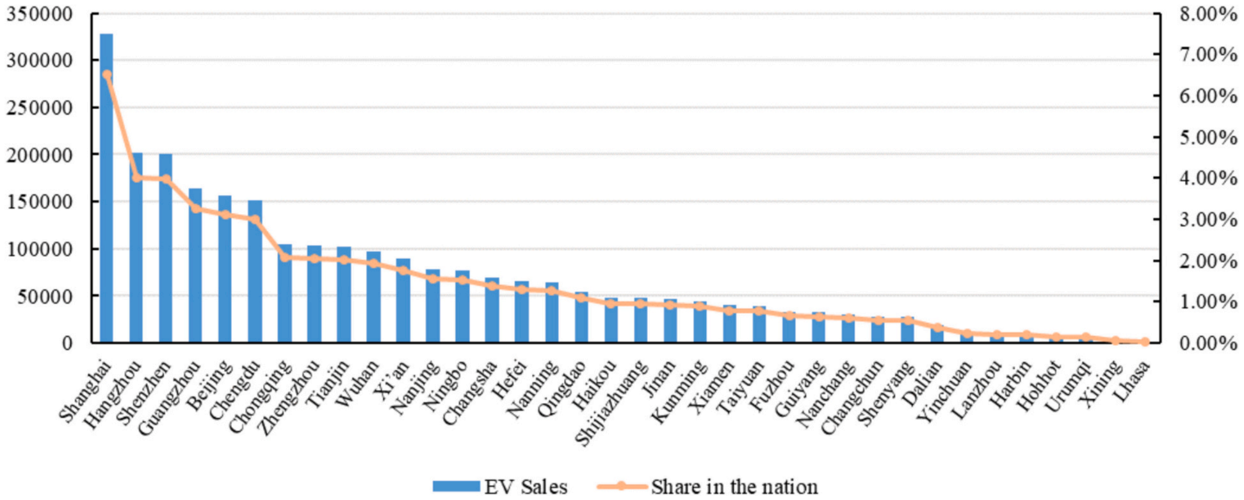
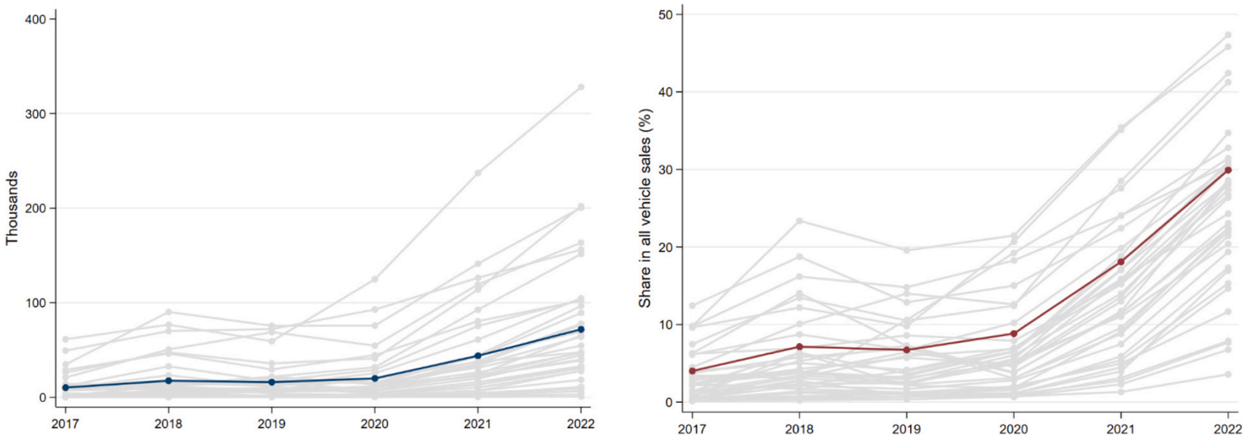


Fig. 1. The EV sales and the share in nationwide EV sales in 2022.



(a) The EV sales

(b) The EV share in all vehicles

Fig. 2. The EV sales and the share of EVs in all vehicle sales (for each city and the average).

$$ln(q_{ict}) = \beta GasolP_{ct} + \mu_i + Year_t \times Month_t + \gamma_c \times Year_t + \varepsilon_{ict} \tag{1}$$

As shown in eq. (1), our specification uses $ln(q_{ict})$ as the dependent variable, representing the logarithmic form of EV sales for model i in city c at time t [6]. The key independent variable, $GasolP_{ct}$, denotes the gasoline price (the 95-octane gasoline price) in city c at time t.[7] We expect a positive coefficient (β) with $GasolP_{ct}$, i.e., rising gasoline prices are likely to increase the driving costs of ICEVs, thereby encouraging consumers to choose EVs instead.

Our specification includes a rich set of fixed effects to address potential confounding factors. First, we include μ_i, a set of fixed effects for each vehicle model, e.g., Tesla Model X 2017, to control for all vehicle attributes common to the specific model. Second, $Year_t \times Month_t$ are year-by-month fixed effects that account for nationwide factors affecting EV sales, such as seasonal sales fluctuations, demand shocks, and policy implementations. Third, since the 36 cities in our sample vary greatly in many aspects, $\gamma_c \times Year_t$ are city-by-year fixed effects where we control for factors unique to each city on an annual basis, such as demographic characteristics, electricity price, local policies, and so on. Finally, ε_{ict} represents the idiosyncratic term clustered at the vehicle model level.

The independent variable, gasoline or petrol price, is potentially endogenous since it may be affected by the sales of ICEVs and EVs. For example, when many consumers in a city purchase ICEVs instead of EVs, the large demand for gasoline will cause a higher gasoline price. It will then seem that low EV adoption is correlated with high gasoline price, which means a downward bias of the ordinary least squares (OLS) estimator for β. To address this concern, we use the average gasoline price for all other cities as an instrumental variable (IV), following Nevo (2001). This instrument correlates with local gasoline prices due to common cost shifters (international crude oil price, tax, etc.) across all cities, as shown in Fig. 3. The assumption for identification relies on the independence of demand shocks among cities, underpinned by the fact that vehicle sales in one city do not impact gasoline prices in another. In China, car purchases are typically localized, and consumers seldom travel to other cities for refueling. A similar instrumental approach for gasoline prices is also utilized by Beresteanu and Li (2011), who used fuel costs in other Metropolitan Statistical Areas as an instrument,

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[6] The granularity of the car model in our dataset is detailed to the exact version of each brand-model-model year.

[7] We use gasoline price in the current period as the explanatory variable, following numerous existing studies (Berry et al., 1995; Klier and Linn, 2010; Li et al., 2009; Busse et al., 2013; Barla et al., 2016; Xu et al., 2023), which assume that consumers forecast future gasoline price simply using current gasoline price (as confirmed by Anderson et al. (2011) and Anderson et al. (2013) using survey data).

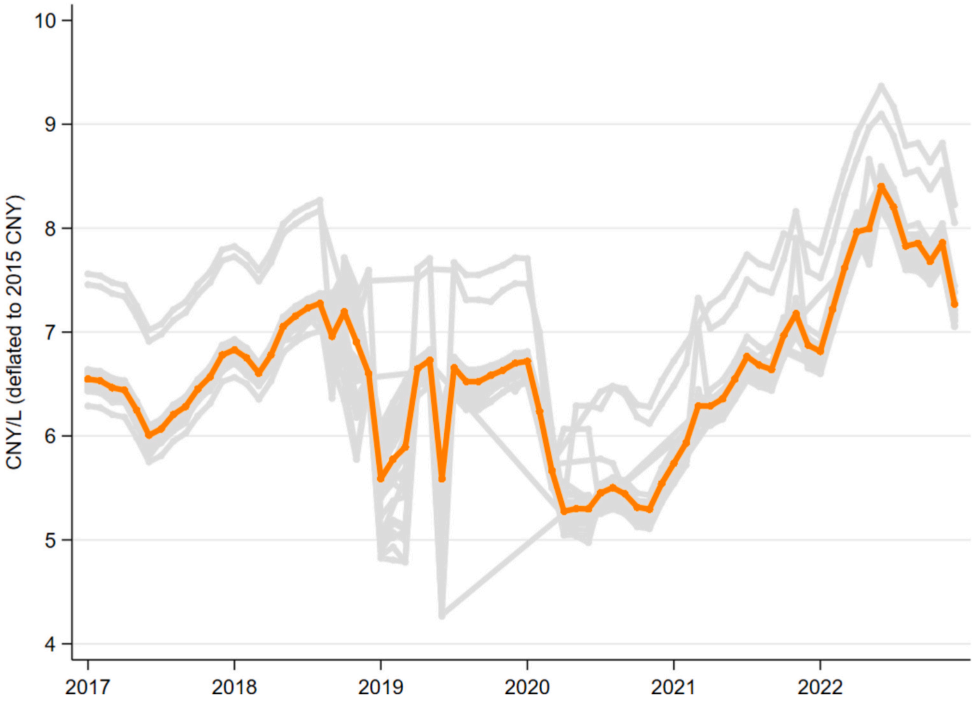

Fig. 3. The monthly 95-octane gasoline price (for each city and the average).

Table 1
Descriptive statistics.

Variable	Obs	Mean	SD	Min	Max
Sales of EV model (monthly)	407,135	13.78	58.69	1	7023
95-octane gasoline price (in CNY/L)	407,135	6.70	0.91	4.26	9.37
92-octane gasoline price (in CNY/L)	407,064	6.25	0.86	4.03	8.81
EV price (in CNY)	407,135	201,699.7	107,803.8	25,074.7	1,299,403.0
Range (in km)	403,194	313.68	191.21	31	1008
Electricity consumption rate (in KWh/100 km)	236,443	13.61	2.30	5.8	23.3

Notes: All the prices in this table are deflated to 2015 CNY. The electricity consumption rate is summarized only for BEVs. 12,015 CNY is equivalent to 0.162015 USD approximately.

Table 2
Baseline estimation results.

	Dependent Variable: $ln(q_{ict})$		
	(1)	(2)	(3)
	OLS	IV	IV
Gasoline price	0.0454**	0.0467**	−0.0239
	(0.0208)	(0.0219)	(0.0330)
Gasoline price×BEV			0.1143**
			(0.0453)
model FE	Yes	Yes	Yes
year-month FE	Yes	Yes	No
city-year FE	Yes	Yes	No
BEV × year-month FE	No	No	Yes
BEV × city-year FE	No	No	Yes
Underidentification statistics		90.19	76.75
Weak identification statistics		8442.72	2901.57
Obs	407,135	407,135	407,135

Standard errors in parentheses, clustered at model level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

alongside related work by Busse et al. (2013), Burke and Nishitateno (2013), and Knittel and Tanaka (2021), which employed the world crude oil price as an instrument[8].

5. Results

5.1. Baseline results

The baseline estimation results for Eq. (1) are reported in Table 2. Column (1) shows the results from OLS estimation, while Column (2) presents estimation results when using the IV method. As expected, the OLS estimator is smaller than the IV estimator in magnitude. The downward bias of the OLS estimator suggests potential endogeneity issues with gasoline prices, and therefore, we will use the IV method in all subsequent sections. We also conducted a baseline estimation using other instrumental variables in the Appendix (Table 1), showing similar results as our current IV estimation.

Our estimation results indicate that a 1 CNY/L increase in gasoline price (about 14.9 % relative to the average) is associated with a 4.67 % rise in sales for each EV model on average, aligning with similar research on the impact of gasoline price on the sales of fuel-efficient gasoline vehicles. For example, Busse et al. (2013) demonstrated that a $1/gal increase in gasoline price (50 % relative to the mean gasoline price) leads to a 10.8 %–11.8 % surge in sales of the most fuel-efficient vehicles. Barla et al. (2016) showed that a 10 % increase in gasoline price (around $1/L) stimulates approximately 4 % sales for a Toyota Corolla model with a fuel consumption rate of 6.5 L/100 km. In the Chinese automobile market, Xu et al. (2023) revealed that a 1 CNY/L increase in

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[8] We do not use international oil price as the instrument because it is absorbed by the time fixed effect in the specification.

gasoline price results in a 5.4 % uptick in 2018 Toyota Corolla sales, a notably fuel-efficient vehicle model (5.6 Liters/100 km).

Therefore, our analysis indicates that the elasticity of EV sales to gasoline price suggested by our estimation is closely aligned with the elasticity of fuel-efficient vehicle sales identified by Xu et al. (2023) in the context of the Chinese automobile market but slightly larger than Busse et al. (2013)'s study in the U.S. market. This relatively larger elasticity is supported by existing literature showing consumers in developing countries are more sensitive to fluctuations in gasoline prices (Phoumin and Kimura, 2014; Sun et al., 2016; Tan et al., 2019; Sheldon and Dua, 2021; Sheldon et al., 2023).

Considering that BEVs operate exclusively on electricity while PHEVs rely on a dual energy source of electricity and gasoline, the rise in gasoline prices may affect BEVs and PHEVs differently. We add an interaction term of gasoline price and a dummy indicating whether the vehicle model is a BEV to examine the potential heterogenous effects. The estimation results are illustrated in Column (3) in Table 2, which shows that the sales of PHEVs experience insignificant decrease in response to a 1 CNY/L increase in gasoline price. In contrast, the sales of BEVs increase by about 9.04 % (0.1143–0.0239 = 0.904) under analogous conditions, which is statistically significant at 95 % confidence level. These results are consistent with our notion that gasoline price escalations will not directly affect the driving costs of BEVs, which consume only electricity, but will increase the operation costs of PHEVs, whose fuel includes both electricity and gasoline. Consequently, consumers are likely to opt for BEVs and show less interest in PHEVs, in response to an increase in gasoline price. Our results indicate that driving costs could play an essential role in consumers' vehicle choices.

5.2. Heterogeneity analyses

To assess the heterogeneous impacts of gasoline prices on different EV models, we re-estimate Eq. (1) with different subsamples. The objective of this set of analyses is to pinpoint which EV categories exhibit the most substantial increase in sales in correlation with rising gasoline prices and to discern consumers' responses to these changes across different EV types. The dataset is thus divided into two groups based on median values for several attributes (as in the literature, e.g., Sheldon and Dua (2020), Gu et al. (2021), and Gendron-Carrier et al. (2022)), including purchase price, electric driving range, and electricity consumption per 100 km[9], as well as the vehicle segment (e.g., Mini, Small, SUV, Executive, etc.). We then re-estimated Eq. (1) for each subsample, and the results are detailed in Tables 3–5.

The results in Columns (1) and (2) in Table 3 illustrate the heterogeneous effects of gasoline prices on EVs with different purchase prices. The analysis reveals that low-cost EVs experience a more pronounced increase in sales when gasoline prices rise, compared to their higher-priced counterparts. This suggests that a larger number of consumers are inclined to choose more affordable EVs as substitutes for ICEVs, in response to the rise in gasoline price. A more granular analysis, dividing the sample into five price quintiles, confirms this trend (Table 4). The lowest-priced EV segment (priced under 124,000 CNY) experiences the most significant sales growth in response to a 1 CNY/L increase in gasoline price, with an approximate growth of 13.76 %. The estimated coefficients for gasoline prices are notably smaller for EVs in higher price categories, becoming statistically insignificant in the range of 202,000 CNY to 260,000 CNY. For the highest-priced category, the coefficient is notably negative, indicating a decrease in EV sales with increasing gasoline prices. This can be explained by the presence of PHEVs, which constitute about 20 % of this segment and rely partially on gasoline, leading to a decrease in sales as gasoline prices rise.

The results presented in Columns (3) and (4) of Table 3 reveal that consumers are more likely to opt for long-range EVs over short-range EVs, as gasoline prices rise. It should be noted that the heterogeneity analysis for EVs with varying electricity consumption rates (measured in kWh/100 km) in Table 3 is specific to BEVs, as PHEVs generally require both gasoline and electricity to function. The results in Columns (5) and (6) of Table 3 indicate that sales of BEVs with lower electricity consumption rates experience a more pronounced increase (compared to those with higher rates) in response to an increase in gasoline price. This finding emphasizes the significant impact of driving costs on consumers' vehicle adoption decisions. Since driving costs are crucial in vehicle choice decision, consumers increasingly favor lower energy-consuming EVs.

We delve deeper into the heterogeneous impacts across different EV segments and the results are presented in Table 5. The data reveals that the Mini & Small vehicle segment experiences the most substantial sales increase (16.68 %) in response to a 1 CNY/L rise in gasoline prices. This result is consistent with the above-mentioned heterogeneity results that the sales of lower-priced EVs and lower energy-consuming EVs are more responsive to gasoline prices. Conversely, the coefficients for the remaining vehicle segments are notably smaller and statistically insignificant, likely attributed to their higher prices and greater energy requirements.

In summary, the insights from the heterogeneity analysis highlight the important role of both purchase costs and operational costs in consumers' decision to switch to EVs. As gasoline prices rise, tightening budgetary constraints, consumers instinctively shift towards more economical options, and as such, preferences shift towards more affordable, low-energy-consuming, and compact EVs.

5.3. Robustness checks

In this subsection, we conduct a series of robustness checks to assess whether our results are robust to various specifications. First, we change the measurement of our variable of interest, i.e., gasoline price, from 95-octane gasoline price to the 92-octane gasoline price or the average of 92-octane gasoline price and 95-octane gasoline, respectively. The results are depicted in Column (1) and Column (2) in Table 6. It can be seen that the estimated coefficients in both columns are significant and very close to the baseline estimation in magnitude, which indicates that the estimated result is robust to our choice of 95-octane or 92-octane gasoline price. Second, we use the logarithm of gasoline price as the independent variable (Column (3) in Table 6). The estimated coefficient indicates the elasticity of EV sales to gasoline prices. The result shows a significantly positive elasticity of EV sales to gasoline price with a coefficient of 0.262, further confirming the positive relationship between EV sales and gasoline price. Moreover, we use the robust standard errors and the results are presented in Column (4) in Table 6, which shows an increased significance level in estimated coefficients.

We also change the specifications of fixed effects in our estimation and the results are shown in Column (5) of Table 6, where we substitute the city-by-year fixed effects with the province-by-year fixed effects, considering that cities within the same province share numerous characteristics, e.g., economic development, electricity price, province-level policy, and so on. The estimated coefficient in Column (5) of Table 6 aligns closely with the coefficient reported in Column (2) of Table 2, indicating consistency in our findings.

Finally, acknowledging that sales of specific vehicle models can be exceptionally high in certain cities, we exclude the top 0.1 % vehicle sales observations (roughly 400 observations) to mitigate the potential influence of outliers and re-estimate eq. (1) with the winsorized data. The result from this analysis is depicted in Column (6) in Table 6. As illustrated, even with the winsorized data, the estimated coefficient retains its significance and is in close proximity to the coefficient obtained in our baseline regression, reinforcing the robustness of our results.

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[9] The thresholds are 176,405.59 CNY, 351 km and 13.4 kWh/100 km, respectively.

Table 3
Heterogeneous effects across different EV categories.

	Dependent Variable: $ln(q_{ict})$, H=High, L = Low					
	(1)	(2)	(3)	(4)	(5)	(6)
	Price (H)	Price (L)	Range (H)	Range (L)	Electricity consump. (H)	Electricity consump. (L)
Gasoline price	0.0182	0.1097***	0.1063***	0.0222	0.0576	0.1009*
	(0.0288)	(0.0337)	(0.0395)	(0.0268)	(0.0390)	(0.0561)
model FE	Yes	Yes	Yes	Yes	Yes	Yes
year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
city-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs	203,377	203,758	196,020	207,174	118,847	117,596

Standard errors in parentheses, clustered at model level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4
Heterogeneous effects for EVs with different prices.

	Dependent Variable: $ln(q_{ict})$				
	1st price quintile $\leq$124 k	2nd price quintile 124 k ~ 156 k	3rd price quintile 156 k ~ 202 k	4th price quintile 202 k ~ 260 k	5th price quintile >260 k
Gasoline price	0.1376**	0.1214**	0.0804**	0.0383	−0.0744**
	(0.0554)	(0.0505)	(0.0398)	(0.0392)	(0.0368)
Obs	78,611	80,336	84,205	83,471	80,512

Standard errors in parentheses, clustered at model level.* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 5
Heterogeneous effects for different vehicle segments.

	Dependent Variable: $ln(q_{ict})$			
	Mini & Small	Lower Medium & Upper Medium	SUV	Executive & Luxury & Sports
Gasoline price	0.1668***	0.0250	0.0229	−0.0007
	(0.0616)	(0.0370)	(0.0323)	(0.0414)
Obs	61,274	130,070	188,338	27,301

Standard errors in parentheses, clustered at model level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.4. *Mechanism*

To explore the mechanism through which gasoline price spurs EV adoption, we estimated the effect of gasoline price on ICEV sales following Xu et al. (2023), using the monthly vehicle model level sales data in the same 36 Chinese cities during 2017–2022. We still use the average gasoline price for all other cities as the instrument for the gasoline price, considering that local ICEV sales can increase gasoline demand and thus may affect local gasoline prices.

Our assumption is that the gasoline price increases will reduce the ICEV demand and shift demand towards EVs. The estimation results, displayed in Table 7, confirm our hypothesis: a 1 CNY/L gasoline price increases lower the ICEV sales significantly by about 6.17 %. This suggests that high gasoline prices curb ICEV adoption and thus may stimulate consumers to purchase EVs instead. The vehicle demand is shifted to EVs when gasoline price increases.

5.5. *Policy simulations*

Earlier studies have mostly concluded that gasoline tax can effectively curb energy usage and reduce greenhouse gas emissions (Austin and Dinan, 2005; Jacobsen, 2013; Xiao and Ju, 2014; Sallee et al., 2015; Rivers and Schaufele, 2017; Grigolon et al., 2018; Parry and Small, 2018). Here, we contribute to this important policy issue by examining the impact of a 1 CNY/L increase in gasoline price (through, e.g., 1 CNY/L gasoline tax) on carbon emissions through the channel of increasing sales of EV. Our approach can be succinctly described in three main steps: First, we simulate the sales of EVs and ICEVs in the no-tax scenario and the gasoline tax scenario, respectively. Second, we calculate the gasoline consumption and electricity consumption corresponding to the sales of EVs and ICEVs for both scenarios. Third, we further compute the

Table 7
The effect of gasoline price on ICEV sales.

	Dependent Variable: $ln(q_{ict})$	
	(1)	(2)
	OLS	IV
Gasoline price	−0.0507***	−0.0617***
	(0.0062)	(0.0075)
model FE	Yes	Yes
year-month FE	Yes	Yes
city-year FE	Yes	Yes
Underidentification statistics		853.30
Weak identification statistics		1.7×10^6
Obs	5,697,940	5,697,940

Standard errors in parentheses, clustered at model level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6
Robustness check.

	Dependent Variable: $ln(q_{ict})$					
	(1)	(2)	(3)	(4)	(5)	(6)
	92-octane gasoline price	Average gasoline price	logarithm of gasoline price	Robust standard errors	Different fixed effects	Winsorize top 0.1 %
Gasoline price	0.0425*	0.0461**	0.2616**	0.0467***	0.0481**	0.0477**
	(0.0223)	(0.0222)	(0.1320)	(0.0142)	(0.0220)	(0.0214)
model FE	Yes	Yes	Yes	Yes	Yes	Yes
year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
city-year FE	Yes	Yes	Yes	Yes	province-year FE	Yes
Obs	407,064	407,064	407,135	407,135	407,135	406,683

Standard errors in parentheses, clustered at model level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. In the specification of Column (3), we use the average price of 92-octane gasoline 95-octane gasoline as the independent variable.

resulting carbon emissions from gasoline combustion and electricity generation.

To project changes in sales of EVs and ICEVs, we first obtain the changes in EV sales using the estimated coefficient in Column (2) in Table 2, which indicates that 1 CNY/L gasoline tax will lead to a 4.67 % rise in EV sales. Meanwhile, using results from Column (2) in Table 7, a 1 CNY/L rise in gasoline price will lead to an approximately 6.17 % decline in ICEV sales in China. The annual sales of ICEVs and EVs under the no-tax and tax scenarios are listed in Table A2 in the Appendix. We can see that ICEV sales decrease while EV sales increase in the gasoline tax scenario (compared with the no-tax scenario).

We then calculate the changes in gasoline consumption and electricity consumption using the following formulas:

$$\Delta Gasoline\ consumption = (Sales_{Tax} - Sales_{NoTax}) \times Average\ FC \times Average\ VDT \tag{2}$$

$$\Delta Electricity\ consumption = (Sales_{Tax} - Sales_{NoTax}) \times Average\ EC \times Average\ VDT \tag{3}$$

where *FC* refers to fuel consumption rate, and *EC* denotes electricity consumption rate. To emphasize the shift from ICEVs to EVs due to a gasoline tax, we assume that the fuel consumption rates and electricity consumption rates remain unchanged in the tax scenario (compared with no-tax scenario). The average fuel consumption rate of ICEVs and the average electricity consumption rate of EVs in each year are derived from our dataset of automobile sales and are displayed in Fig. A1 in the Appendix. Additionally, we assume, without loss of generality, that the proportion of BEVs and PHEVs within the EV category remains unchanged across both scenarios. We depict the sales of BEV and PHEV in our sample in Fig. A2.

The yearly average vehicle distance traveled (VDT) is obtained from the annual transport reports spanning from 2017 to 2022 (Beijing Transportation Research Center, 2018–2023), a metric also used in Yang et al. (2014). The VDT is illustrated in Fig. A3. In our calculation, we use the mean value of this VDT data across years, which is approximately 11,587 km, to represent the annual distance traveled by each vehicle in a typical year (i.e., *Average VDT* in the formulas). Furthermore, the VDT is assumed to remain constant across the two scenarios. For PHEVs, we utilize the calculation method outlined by MIIT to estimate the proportion of distance driven using gasoline and electricity.

Lastly, to calculate carbon emissions associated with gasoline consumption, we use an emission factor of 2348 g CO2 per liter of gasoline from Jenn et al. (2016). Additionally, given that approximately 66 % of total electricity generation in 2022 comes from fossil fuels in China (NBS), electricity production thus also results in carbon emissions. The national average emission factor for electricity, obtained from the Ministry of Ecology and Environment, is depicted in Table A3. We use the average of the emission factors over 2017–2022 as the carbon emission factor in a typical year (i.e., $Emission\ factor^{elec}$) to compute the carbon emissions resulting from electricity consumption. The aggregate carbon emissions from gasoline consumption and electricity consumption are thus calculated as:

$$Emission = Gasoline\ consumption \times Emission\ factor^{gasol} + Electricity\ consumption \times Emission\ factor^{elec} \tag{4}$$

Table 8 details the average annual gasoline and electricity consumption of vehicles sold over 2017–2022. In the gasoline tax scenario, annual gasoline consumption of newly sold vehicles in each year reduces by 0.87 billion liters, about 6.12 % less than in the no-tax scenario. This reduction in gasoline usage is expected to lower carbon emissions within the transportation sector. In contrast, annual electricity consumption increases by 0.12 billion kWh, a 4.67 % increase, which is expected to increase carbon emissions from the electricity generation sector.

Based on the changes in energy consumption, annual carbon emissions can be calculated, and the results are presented in the last three columns in Table 8 and Fig. 4. The decrease in carbon emissions due to decreased gasoline consumption amounts to 2.04 million tons/year. Although there is a slight increase in carbon emissions from the electricity production sector, this rise is smaller compared to the reduction in carbon emissions from gasoline consumption (See Fig. 4). In total, a 1 CNY/L gasoline tax is expected to lead to a net reduction of 1.97 million tons of carbon emissions annually. The effect is expected to be larger when the share of renewable energy is larger (thus a lower emission factor for electricity) in the future. Our simulation results underscore that replacing ICEVs with EVs would contribute positively to reducing carbon emissions and mitigating global warming.

6. Conclusions

By leveraging on granular monthly model-level EV sales data from 36 major Chinese cities from 2017 to 2022, we investigate the impact of rising gasoline prices on inducing EV adoption in the world's largest EV market. Our results reveal that a 1 CNY/L increase in gasoline price correlates with a 4.67 % increase in EV sales (the effect on BEV sales is more remarkable than that on PHEV sales). Further heterogeneity analysis demonstrates that low-priced EVs, long-range EVs, low energy-consuming EVs, and those within Mini/Small segments, are particularly sensitive to gasoline price increases. This underscores the significant influences of both vehicle purchase costs and operational costs on consumers' vehicle adoption decisions. To assess the efficacy of increasing gasoline prices or taxes in reducing gasoline consumption and mitigating carbon emissions, we conduct a counterfactual analysis. This simulation of a 1 CNY/L gasoline tax suggests a substantial decrease in carbon emissions. Specifically, this tax policy would lead to a reduction of approximately 1.97 million tons of carbon emissions annually for vehicle fleets sold each year. These results emphasize the potential of promoting EVs as a means to mitigate carbon emissions and suggest that gasoline taxation could be an effective policy tool to achieve this objective.

Our findings suggest that energy pricing can serve as a tool to accelerate the adoption of EVs. To cope with intensive carbon emissions in the transportation sector, numerous countries have set targets for EV market penetration and implemented policies to foster EV adoption. For instance, the European Commission has targeted full electrification of new vehicles by 2035; California's Zero Emission Vehicle (ZEV) program requires that 22 % of the 2025-model-year vehicles should be EVs. These goals signal a major shift towards EVs in the automobile market in the future. China has developed into one of the most flourishing EV markets in the world, offering valuable insights into the factors driving EV penetration. Our research on the Chinese EV market demonstrates that

Table 8
Annual energy consumption and carbon emission of vehicles sold, in no-tax scenario and tax scenario.

	Gasoline consumption (billion liters)	Electricity consumption (billion KWh)	Carbon emission from gasoline consumption (million tons)	Carbon emission from electricity consumption (million tons)	Total carbon emission (million tons)
No-Tax scenario	14.20	2.68	33.35	1.60	34.95
Tax scenario	13.33	2.80	31.31	1.68	32.98
Changes	−6.12 %	4.67 %	−6.12 %	4.67 %	−5.63 %

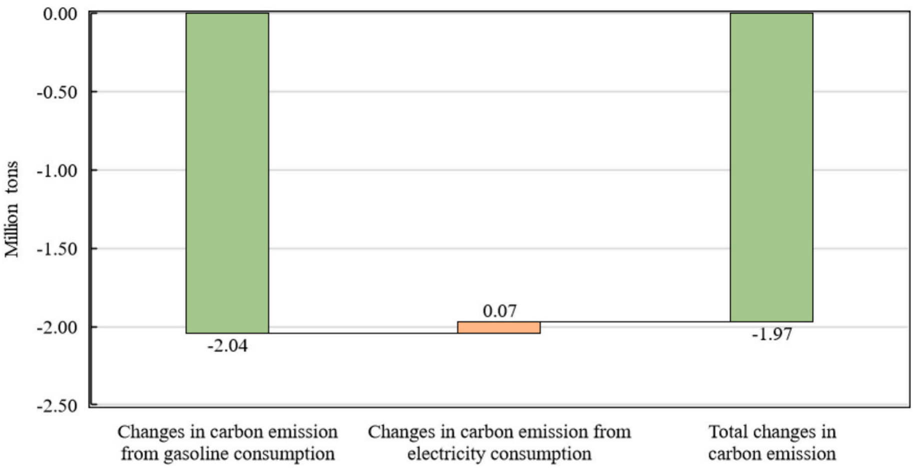

Fig. 4. Changes in carbon emissions.

increasing gasoline prices, such as through imposing gasoline tax, can promote EV sales by raising the driving costs of ICEVs. This provides insights into achieving the goal of EV penetration in a newly developing EV market, which is essential in the context of current shifts towards EVs in the automobile market worldwide. Furthermore, our study adds to the discussion on the impact of gasoline taxes on reducing carbon emissions, providing evidence that higher gasoline prices can shift the vehicle fleet towards EVs, thereby lowering carbon emissions.

Future research could benefit from developing demand models to estimate consumers' preference parameters for factors such as price, driving cost, and other vehicle attributes. Such models would facilitate simulating the effects of different policies to stimulate EV adoption (including gasoline taxes), thereby improving our understanding of vehicle adoption decisions as well as their influence on environmental outcomes.

CRediT authorship contribution statement

Yinxin Fei: Writing – original draft, Visualization, Methodology, Formal analysis. **Ping Qin:** Writing – review & editing, Writing – original draft, Validation, Funding acquisition, Conceptualization. **Yanlai Chu:** Writing – review & editing, Validation, Funding acquisition, Data curation, Conceptualization. **Huanhuan Zheng:** Writing – review & editing, Validation, Methodology, Conceptualization. **Jie-Sheng Tan-Soo:** Writing – review & editing, Writing – original draft, Validation, Funding acquisition, Formal analysis, Conceptualization. **Xiao-Bing Zhang:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

None.

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Appendix A. Estimation results with different instruments

In addition to the instrument variables (IVs) we choose, we also estimate our baseline model with alternative IVs. There are two sets of IVs in our new analysis:

1. Average gasoline price ceiling for all other cities

In China, the National Development and Reform Commission (NDRC) sets gasoline price ceiling every ten working days, taking into account factors such as the transaction cost and taxation. Sun et al. (2022) and Zhang et al. (2020) have both found that the price ceiling significantly influences the gasoline prices in the market. Moreover, this instrument is exogeneous since it leverages the variations in policy-related factors, such as gasoline consumption taxation, which has been previously used as instrument for diesel price in Sun et al. (2022).

2. Monthly city-level weather variables

We also instrument the gasoline prices with a series of monthly city-level weather variables, since weather affects travel and thus influence gasoline demand, as indicated in Waldman et al. (2008). Weather is frequently used as instrument variable because weather is determined by natural process and is not correlated with economic and demographic factors (Munshi, 2003; Miguel et al., 2004). However, weather does affects people's decision to travel outside, thereby affecting gasoline demand. To be specific, the instrumental variables include six weather variables: temperature, rainfall, humidity, hours of sunlight, atmospheric pressure, wind speed, and their quadratic terms.

Table A1
Baseline estimation results using new instrumental variables.

	Dependent Variable: $ln(q_{ict})$
	IV
Gasoline price	0.0474** (0.0218)
model FE	Yes
year-month FE	Yes
city-year FE	Yes
Underidentification statistics	222.75
Weak identification statistics	3087.35
Obs	407,135

Notes
1. Standard errors in parentheses, clustered at model level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
2. Instrumental variables include the average gasoline price ceiling for all other cities, temperature, rainfall, humidity, hours of sunlight, atmospheric pressure, wind speed, and the quadratic terms of the six weather variables.

Table A2
Vehicle sales in no-tax scenario and tax scenario.

	No-tax scenario (million)			Tax scenario (million)		
	ICEV sales	EV sales	Total sales	ICEV sales	EV sales	Total sales
2017	22.82	0.50	23.33	21.39	0.53	21.92
2018	20.53	0.90	21.43	19.24	0.94	20.17
2019	19.53	0.87	20.39	18.30	0.91	19.20
2020	17.81	1.12	18.93	16.70	1.18	17.88
2021	17.31	2.81	20.12	16.23	2.94	19.17
2022	14.44	5.01	19.44	13.51	5.24	18.75

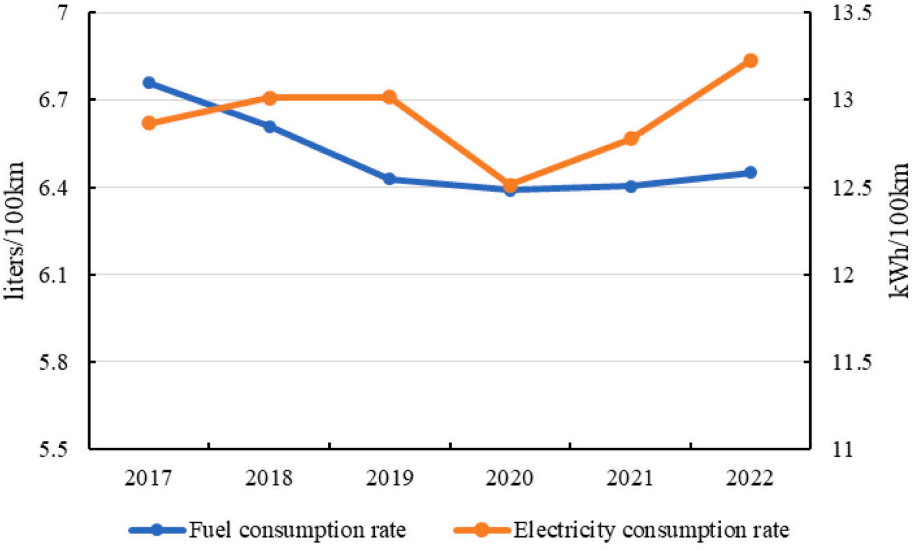

Fig. A1. Average fuel consumption rate and average electricity consumption rate.

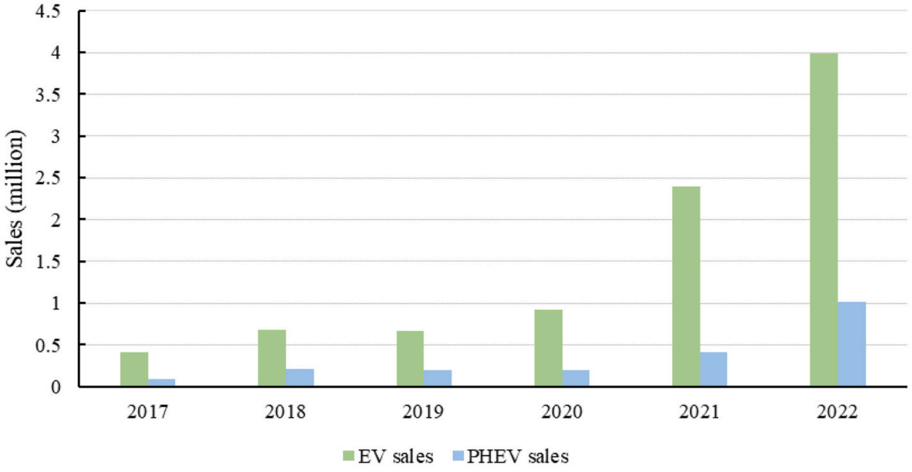

Fig. A2. BEV sales and PHEV sales.

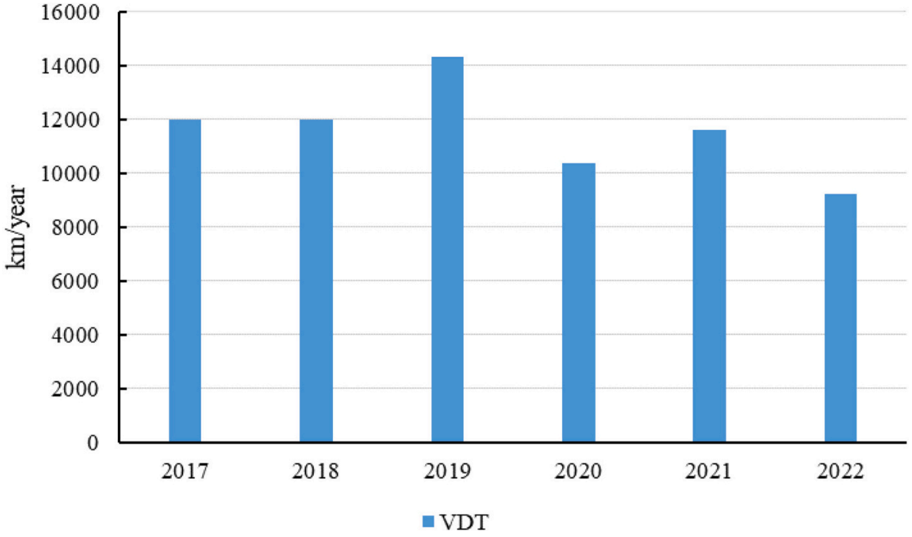

Fig. A3. Average vehicle distance traveled.

Table A3
The national average emission factor for electricity generation from 2017 to 2022.

	2017	2018	2019	2020	2021	2022
Emission factor (ton/MWh)	0.6101	0.6101	0.6101	0.6101	0.5810	0.5703

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2025.108188.

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