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# COVID-19 shock, fiscal subsidies, and consumption resilience of new energy vehicles: evidence from Shanghai, China

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**Abstract**

New energy vehicles are regarded as an important measure for improving air quality, reducing oil dependence, fostering emerging industries, and promoting high-quality development. Since 2009, the Chinese government has been committed to promoting new energy vehicles through various policy measures, such as fiscal subsidies. Meanwhile, the outbreak of the COVID-19 pandemic at the end of 2019 has brought great impact on the economy and society. Thus, it is a topic of research to determine if the fiscal subsidy policy can assist new energy vehicles to resist the pandemic's impact and build consumption resilience. Current researches lack enough attention to the role of fiscal subsidy policy in enhancing consumption resilience under the pandemic impact. By utilizing monthly sales data of new energy vehicles in Shanghai from January 2018 to February 2021, this study employs regression discontinuity (RD) analysis and the combination of the RD with the differences-in-differences (DID) model, to comprehensively evaluate the impact of the COVID-19 pandemic on new energy vehicle consumption and the effectiveness of fiscal subsidy policies in enhancing consumption resilience. The findings reveal that the COVID-19 pandemic shock, with a bandwidth of 3 months, led to a 23% decrease in new energy vehicles sales. In comparison with unsubsidized vehicles, sales of subsidized new energy vehicles significantly increased by 15–80% during the pandemic shock, indicating that fiscal subsidies are crucial in enhancing the consumption resilience of new energy vehicles. Compared with other country-specific new energy vehicles, the subsidy effect of domestic new energy vehicles is relatively inadequate during the pandemic shock. The retreat from subsidy policies has contributed to a decline in the consumption of new energy vehicles in response to the pandemic shock. It is necessary to further improve the consumption resilience of domestic new energy vehicles and pure electric vehicles.

**Keywords** Pandemic shock, Fiscal subsidies, Consumption resilience, New energy vehicles, RD-DID model

## Introduction

The sudden outbreak of the COVID-19 pandemic at the end of 2019 represents the most rapidly spreading, widely infecting, and challenging public health emergency since the founding of the People's Republic of China.[1] Consumption, an important component of gross domestic product (GDP) accounting, is not only a vital indicator of public living standard, but also a

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[1] Source: White paper on "China's actions to combat the new coronary pneumonia pandemic".

major driver of economic growth.[2] The COVID-19 pandemic has led to a substantial decrease in final product spending in China. During the first quarter of 2020, the per capita cash consumption expenditure experienced a notable decline of 12.5% compared to the same period in 2019, marking an 18% decrease from the previous year [72]. The COVID-19 pandemic is estimated to have diminished the capacity of final consumption demand to contribute to GDP growth by approximately 8–10 percentage points, according to He et al. [25]. Utilizing rigorous econometric techniques to evaluate the precise effects of the pandemic on consumer spending and developing strategies to bolster the resilience of consumption are critical issues in the post-pandemic era.

The impact of the COVID-19 pandemic on energy consumption and the new energy vehicle (NEV) sector is multi-dimensional, including consumption levels, consumption patterns, and consumer mindsets. In terms of consumption levels, the pandemic has inflicted a significant blow on the automotive industry [70] and led to a decrease in income levels among individuals, which in turn may result in reduced expenditures on durable goods such as automobiles. Regarding consumption patterns, major disasters like the COVID-19 pandemic can induce structural changes in energy consumption habits [49, 50]. For instance, during the pandemic, both conventional fuel vehicles and NEVs experienced a record low in carbon dioxide emissions. However, post-pandemic, NEVs have shown a quicker rebound in terms of mileage and carbon emissions compared to traditional fuel vehicles [77]. In terms of consumer mindsets, the pandemic has influenced the extent of information consumers can access, potentially altering personal norms and preferences [5, 22, 26], driving a shift towards sustainable and green consumption [17, 62]. This could lead to an increase in NEV consumption. In summary, understanding the impact of the COVID-19 pandemic on the consumption levels and patterns of energy and NEVs remains a subject that warrants further in-depth research.

Developing new energy vehicles is important for many countries due to the advantages in reducing carbon emissions, and protecting the environment [19, 68]. Particularly, the Chinese government has placed a high priority on the development of the NEV industry [14, 42, 64], because NEVs have deeply integrated transformative technologies, such as new energy sources, advanced materials, and big data, which are of importance for promoting the reconstruction of the automotive industry ecosystem.[3] The report from the 20th National Congress of the Communist Party of China emphasizes the promotion of strategic emerging industries through integrated cluster development, aiming to build a new generation of growth engines, including information technology, new energy, advanced materials, high-end equipment, and green environmental protection. The national “14th Five-Year Plan” clearly proposes a focus on strategic emerging industries, such as new energy, NEVs, and green environmental protection to cultivate and strengthen new drivers for industrial development. China has implemented a series of policies, including fiscal subsidies, tax reductions, and government procurement, to promote NEV adoption [71, 75].

Among the series of support measures for NEVs by the government, fiscal subsidy policy is the most direct and highly regarded form [34]. In response to the impact of the pandemic, China has extended the NEV subsidies and exemption from vehicle purchase tax for two additional years, with the aim of continuing to leverage NEVs to expand domestic demand and stimulate consumption. It is essential to consider whether fiscal subsidy policies can effectively stimulate the promotion of NEVs, drive them to recover quickly from adverse shocks, and foster consumer resilience for NEVs. In addition, it is worth contemplating whether there are heterogeneities in the impact of fiscal subsidy policy on the consumer resilience of different types of NEVs. These questions merit further in-depth analysis.

Shanghai is highly representative in the development of the NEV industry and the implementation of related policies. As a leading city in the Yangtze River region, Shanghai boasts a population exceeding 20 million, making it the most densely populated city in China [73]. The city faces significant challenges, such as traffic congestion and severe air pollution, which exert considerable pressure on emission reduction efforts. Shanghai was one of the first cities in China to implement NEV promotion subsidies. The maturity of Shanghai’s automotive industry chain has also provided favorable conditions for the promotion of NEVs. Consequently, Shanghai has been selected as a case study to investigate the effects of fiscal subsidy policies on the consumer resilience of NEVs amidst the COVID-19 pandemic.

In summary, this research examines the consumption resilience of new energy vehicles under the pandemic shock and the role played by the Chinese government in enhancing the consumption resilience of NEVs, taking Shanghai as an example. Specifically, using monthly consumption data of various NEV

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[2] From an expenditure approach perspective, the contribution of final consumption to GDP growth in China was 76.2%, 71.3% and 63.3% in the first quarters of 2017, 2018 and 2019, respectively [25].

[3] See “New Energy Vehicle Industry Development Plan (2021–2035)” issued by the State Council.

models from January 2018 to February 2021, the study employs a combination of event study analysis, regression discontinuity (RD) analysis and the combination of the RD with the differences-in-differences (DID) method to explore the resilience of NEV consumption under the dual influences of the pandemic and government support. On the basis, the study conducts a robustness analysis and heterogeneity examination. Finally, it delves into the special impact of subsidy retreat policy and the sustainability of the pandemic's effects. Researching these issues contributes to a quantitative assessment of the economic impact of the COVID-19 pandemic and provides a basis for decision-making in formulating NEV support policies and low-carbon transition strategies in other regions.

This study makes three distinct contributions to the existing literature. First, this study integrates the COVID-19 pandemic shock, fiscal subsidies, and the resilience of new energy vehicle consumption into a single analytical framework. This approach enriches our understanding of the effect of fiscal subsidies during major public health crises and provides insights into enhancing consumption resilience. This study focuses on the impact of fiscal subsidy policy on the resilience of new energy vehicles, offering valuable insights for policymakers in assessing policy effectiveness and informing policy implementation in other regions or countries.

Second, this study departs from the conventional use of national or city-level sales data [70] by employing a unique database to analyze monthly sales figures of new energy vehicles in Shanghai. This micro-level analysis reveals detailed insights into consumer behavior and resilience. Moreover, the use of vehicle series data enables a more precise examination of fiscal subsidy effects, providing robust data support for assessing the role of subsidies in bolstering new energy vehicle consumption resilience. To our knowledge, only Li et al. [36] has previously utilized this dataset to study the demand incentive effects of government support policies.

Finally, this study introduces an innovative regression discontinuity with differences-in-differences (RD–DID) methodology, which allows for a more accurate assessment of the interplay between the COVID-19 pandemic shock, fiscal subsidies, and the resilience of new energy vehicle consumption.

This paper is organized as follows. Sect. "Literature review" provides a brief overview of the related literature. Sect. "Methodology and data" presents the study design, explaining the econometric model, variable selection, and data sources. Sect. "Preliminary Evidence and Characteristic Facts" presents the preliminary evidence and characteristic facts. Sect. "Empirical Results" presents empirical evidence that supports the importance of fiscal subsidies for the enhancement of consumption resilience. Sect. "Further discussion" provides further discussion and Sect. "Conclusion and inspiration" summarizes our results and conclutions.

## Literature review

Since the seventeenth century, human society has endured numerous public health crises and major disaster events, such as the plague in Italy in 1629–1630, "Asian flu" outbreak in 1967, SARS in China in 2003, the Ebola epidemic in 2014, and the COVID-19 pandemic in 2019 [43]. The COVID-19 pandemic, however, has had an unprecedented impact on the socio-economic fabric of nations, creating a level of global economic complexity without historical parallel [20, 24, 47, 51]. Academic research has delved into the macro-, meso-, and micro-effects of such catastrophic events, including the COVID-19 pandemic. The existing literature related to this study can be broadly categorized into four main streams. The first one focuses on the impact of the COVID-19 pandemic on consumer attitudes. The second one emphasizes the influence of the COVID-19 pandemic and other significant disaster events on energy transition. The third one investigates the effects of the COVID-19 pandemic on the automotive industry's development. The last stream explores the influence of government supportive policies for new energy vehicles.

Whether the COVID-19 pandemic can stimulate green consumption is currently a matter of interest among scholars. Although the scientific question of the origins of the novel coronavirus remains unresolved, the outbreak of COVID-19 is not a natural disaster but a human-induced one. Human destruction of the natural environment and illegal hunting and trade of wild animals are significant contributors to the pandemic [29, 38]. Extensive researches have suggested that the pandemic can enhance environmental awareness among people, prompting a transition to sustainable and green consumption [17, 29, 59, 61]. Severo et al. [55], based on survey data from Brazilian and Portuguese consumers, confirmed that the COVID-19 pandemic had a significant impact on public environmental awareness, green consumption, and social responsibility. Sun [62], using experimental methods, found that the awe associated with COVID-19 positively influences green consumption behavior, a view that aligns with the perspective of Chen et al. [13].

The examination of the effects of pandemics and other major public emergencies on energy systems and low-carbon transition is a focal point for contemporary scholars.

The COVID-19 pandemic has inflicted substantial shocks on the energy sector and energy consumption [23], and hindered the progress of economic transformation. Despite these challenges, the crisis has also underscored the importance of energy transitions and the potential for accelerated development of renewable energy post-pandemic [21, 33, 35, 66]. It is anticipated that, in the long term, the pandemic will contribute to a decrease in fossil fuel reliance [31] and drive transformative changes in socio-economic sustainability [54, 60]. The influence of major emergencies on energy transitions is not unique to the COVID-19 pandemic. Historically, such events have prompted significant policy shifts. For instance, the Great East Japan Earthquake and the subsequent nuclear accident led to a reevaluation of Japan's energy policy. Otsuka [49, 50] from a regional perspective, has shown that this disaster prompted a structural shift in Japan's energy consumption patterns. These examples underscore the potential for crises to catalyze systemic changes in the energy sector, steering economies towards more sustainable and resilient energy systems.

The literature examining the COVID-19 pandemic's impact on NEV market presents a nuanced view of the short-term disruptions and long-term implications. The consensus among researchers is that the initial response to the pandemic, including lockdowns and travel restrictions, has altered consumer behavior, and disrupted industrial operations, leading to considerable setbacks for the automotive sector [67, 70]. Internationally, O'Garra and Fouquet [48], based on survey data from UK car drivers and pilots, reported a 24–30% decrease in car usage and a 20–26% decrease in air travel post-pandemic. Specifically, for China's NEV market, the pandemic's travel restrictions interrupted the supply of imported raw materials, leading to supply chain disruptions. Zhang et al. [77], in their analysis of China's transportation sector, observed a notable decrease in energy consumption and $CO_2$ emissions in February 2020, the onset of the pandemic, with effects surpassing those of the SARS outbreak. However, these challenges have also spurred innovation, leading to the development of alternative supply strategies and a consolidation of the electric vehicle market [70]. This suggests that while the economic recession caused by COVID-19 initially led to a decline in car sales in the short term, the pandemic's long-term effects are likely to favor the adoption of NEVs [31, 70] .

The analysis of the COVID-19 pandemic's effect on NEV consumption has been a focal point for scholarly research, with studies revealing varied outcomes across different market segments and transportation modes. Klein et al. [32] argued that the impact of COVID-19 on car demand in Central and Eastern Europe varied by market segment. Consumers tended to purchase smaller cars during economic downturns, while maintaining robust interest in electric vehicles, in contrast to a sharp decline in demand for traditional fuel-powered cars [46, 65]. Sai et al. [53] focused on the differential impacts of the pandemic on public, private, and shared transportation. Public transport saw reduced capacity and frequency, leading to a preference for private vehicles for medium-to-long-distance travel due to concerns over safety and the desire for flexibility, despite the associated higher costs and environmental impact. Shared electric vehicles, as an alternative to public and private transportation, also received considerable attention [53]. Furthermore, research has identified factors such as travel safety and green consumption concepts as catalysts for the post-pandemic surge in NEV demand [39].

In addition to the literature on the impact of major emergencies on the new energy vehicle sector, the influence of government subsidy policies is also a significant area of scholarly inquiry. Subsidies, as well as tax exemptions, are recognized as key fiscal tools for fostering the adoption of NEVs, with numerous countries, including the United States, Japan, and France, implementing such measures to incentivize their use [8, 12, 27]. Research has extensively evaluated the effects of these policies on the growth of the NEV market and their broader macroeconomic implications [40, 69]. Some scholars argue that subsidy policies are instrumental in addressing market failures, alleviating information asymmetry, and easing credit constraints [2, 3]. For instance, Shafiei et al. [56] demonstrated the economic benefits of Iceland's fiscal policies in promoting NEVs. Li et al. [36] highlighted the significant positive effect of fiscal policies on the demand for new energy vehicles.

However, fiscal policies can also lead to structural changes within the automotive market. Chandra et al. [9] noted that the sales of high-performance vehicles were crowded out due to the subsidization of hybrid vehicles. Chen et al. [10] observed that China's subsidy program increased sales for subsidized vehicle models, but most of the subsidies benefited inframarginal consumers. Moreover, fiscal subsidies can increase the fiscal burden on governments and potentially lead to social welfare losses [37]. These policies may inadvertently encourage fraudulent practices in the production of NEVs or lead to shortsighted decision-making by enterprises, prioritizing scale expansion over technology research and development [37, 76]. Boombower and Davis [4] demonstrated through a regression discontinuity design that many participants in Mexico's energy efficiency program were free-riders. Barwick et al. [3] examined the local protectionism inherent in China's NEV subsidy program, which resulted in significant choice distortions and a loss of 18.7

billion RMB[4], which was equivalent to 40% of the total subsidy allocated.

Considering these limitations, Li et al. [37] explored the substitution effect of NEV credit program and corporate average fuel consumption regulation for green car subsidy. Chen et al. [12] emphasized that the promotion of NEVs involved a diverse set of policy measures, and it was important to examine the synergistic effects of subsidy policies and credit regulations on the technological development of NEVs.

In summary, existing research can be further improved in the following three aspects:

First, current studies have focused on the impact of COVID-19 on energy transitions and the NEV market, and some scholars have explored the supply and demand incentive effects of government support policies. However, there is a notable gap in the literature when it comes to integrating the effects of the COVID-19 shock, government support, and NEV consumption within a single framework.[5] This study aims to fill this void by examining the shock effect of the pandemic on NEV consumption and the resilience-enhancing effect of government support policies in response to the pandemic.

Second, descriptive analysis [32, 41, 67, 70] and estimation methods [77] are commonly used in exploring the impact of the COVID-19 pandemic in the existing literature. Econometric methods such as logistic models [63], differences-in-differences [8], and regression discontinuity [28, 57] are commonly used approaches in analyzing the effect of fiscal subsides. However, there is a scarcity of research that combines RD and DID to investigate the impact of the pandemic shock and government supportive policies on NEV consumption.

Third, as the post-pandemic era unfolds, academic discourse on socio-economic resilience and recovery has intensified, with a particular emphasis on the ability of systems to maintain stability and recover from external shocks [45]. These studies cover areas, such as regional resilience [15], Brakman [6], economic resilience [18, 44, 45, 58], supply chain resilience [30], and other areas. However, research on consumer resilience during the pandemic and the role of government support policies in enhancing this resilience is relatively limited.

In conclusion, this study empirically examines the shock effect of the COVID-19 pandemic on NEV consumption and the resilience-enhancing effect of fiscal subsidies on NEV consumption, using a combination of RD and DID based on monthly sales data of new energy vehicles in Shanghai, China, from January 2018 to February 2021. Furthermore, this study also incorporates robustness checks and heterogeneity analysis to ensure the validity of the findings. On the basis, the impact of subsidy retreat policy on NEV consumption under the pandemic shock and the sustainability of the impact of the pandemic shock on NEV consumption are conducted.

## Methodology and data

### Econometric model

#### *Regression discontinuity model*

The regression discontinuity (RD) deign has emerged as a prevalent approach in economics for nonparametrically estimating causal effects from observational data. These causal effects are identified at the point of discontinuity that distinguishes those observations that do or do not receive the treatment [52]. Based on the basic idea of RD analysis, we examine the impact of the COVID-19 pandemic shock on NEV consumption in Shanghai, China, using monthly sales data of the series of NEVs from January 2018 to February 2021. Because the outbreak of this pandemic is a deterministic event, we employ an accurate RD analysis to estimate the average treatment effect for the experimental group. We set the outcome variable as a linear model:

$$\begin{aligned} y_{it} = \alpha T_t + \beta f(\mathit{mondiff})T_t + \gamma f(\mathit{mondiff})(1-T_t) \\ + \phi X_{it} + \theta_i + \tau_t + \varepsilon_{it} \end{aligned} \tag{1}$$

In Eq. (1), $i$ denotes the 253 series of new energy vehicles, and $t$ denotes the period, specifically from January 2018 to February 2021. The variable $T$ is a dummy variable for the treatment group, where $T=1$ indicates the period after the COVID-19 outbreak, starting from December 2019, and $T=0$ for the period before the outbreak. The outcome variable, denoted as $y$, captures the sales of new energy vehicles, with $y(0)$ indicating the sales before the pandemic and y(1) representing the sales after the pandemic. The average impact ($\alpha$) of the pandemic shock on new energy vehicles sales is calculated by determining the difference between the expected sales post-pandemic (E[y(1)]) and pre-pandemic (E[y(0)]), that is $\alpha=$E[y(1)]−E[y(0)]. Here, E denotes the expectation operator. The variable *mondiff* is running variable, representing the distance in months from the COVID-19 pandemic shock. It is negative before the shock, zero on the month of the shock, and positive thereafter. The function *f*(*mondiff*) represents a polynomial function of the running variable to allow for different effects on either side of the cutoff. We primarily employ the linear form of the polynomial function *f*(*mondiff*) in our empirical specifications, while also incorporating the quadratic form to conduct a robustness check. $X$ denotes other factors

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[4] Approximately 2.41 billion Euros at an annual exchange rate of 7.76.

[5] It should be noted that the consumption referred to in this study specifically pertains to private consumption, not public consumption. We are deeply grateful for the professional insights provided by the reviewers.

affecting NEV sales, primarily the observable product characteristics, and is included as control variables in Eq. (1). $\theta_i$ represents individual fixed effect, $\tau_t$ represents time fixed effect, $\varepsilon$ is the random error term.

### *Differences-in-differences model*

The differences-in-differences (DID) method is employed to evaluate the impact of fiscal subsidy policies on NEV consumption. This method is a prevalent approach in policy evaluation. It is commonly used to estimate the net effect of a policy by comparing the changes in outcomes between the treatment group, which experiences the policy, and the control group, which does not [11]. The DID model is formulated as follows:

$$y_{it} = \alpha' + \beta' T_t \times Policy_i + \gamma' T_t + \phi' X_{it} + \theta_i' + \tau_t' + \varepsilon_{it}' \tag{2}$$

In Eq. (2), the variable *Policy* is defined, such that it equals 1 if a new energy vehicle model receives fiscal subsidies and 0 otherwise. The coefficient of *Policy* $\beta'$ represents the effect of the fiscal subsidy policy on the outcome variable $y$. The interpretation of other variables remains consistent with those described in Eq. (1).

### *RD–DID model*

The RD design is often used to study the causal effects or treatment effects of a policy or intervention on the dependent variable [28]. However, this method only captures the local treatment effect, meaning it reflects changes in NEV sales and resilience within a few months before and after the COVID-19 pandemic. In addition, it does not account for the consumption stimulus effect of subsidy policies. The differences-in-differences (DID) method is commonly used to evaluate the effects of specific policies, but it requires that the treatment group and control group react similarly to environmental shocks and that their outcome variables follow a balanced path over time. Our sample may not meet these conditions because the eligibility of certain NEV models for government subsidies is not random. For instance, according to a State Council document, private purchases of NEVs with a pre-subsidy price exceeding 300,000 RMB [6]are not eligible for subsidy policies.[7] Therefore, using DID estimation may yield biased results.

Based on the analysis, drawing on the work of Clark et al. [16] and Brodeur et al. [7], this study uses an RD–DID model to ensure the accuracy and reliability of our empirical findings. Essentially, the RD–DID model turns the difference between individuals in DID before and after the shock from a difference into an estimate using RD, and then obtains the true treatment effect based on the difference between the RD estimates of the experimental and control groups. In conclusion, the estimation results of the RD–DID model are more reliable than using RD or DID method alone. We merge the models from Eqs. (1) and (2) to formulate the RD–DID model as follows:

$$\begin{aligned} y_{it} = {} & aT_t \times Policy_i + bf(mondiff) \times T_t \\ & \times Policy_i + cf(mondiff) \times (1 - T_t) \\ & \times Policy_i + df(mondiff) \times T_t \\ & + ef(mondiff) \times (1 - T_t) + fT_t \\ & + gX_{it} + \theta_i'' + \tau_t'' + \varepsilon_{it}'' \end{aligned} \tag{3}$$

In Eq. (3), the coefficient $a$ of $T_t \times Policy_i$ is of interest in this paper. It reflects the difference between the sales of new energy vehicles before and after the outbreak of the COVID-19 pandemic. Besides, it also refects the difference between the sales of new energy vehicles with and without fiscal subsidies.

### *Event analysis method*

The RD approach provides an estimate of the local effect of the COVID-19 shock. To analyze the impact of the shock over an extended period, an event study model is employed to test for the adaptation effects resulting from the pandemic shock. The event study model can be formulated as follows:

$$y_{it} = \sum_{m=-3}^{6} \lambda_m T_t \times Policy_i + \pi X_{it} + \varpi_i + \nu_t + \xi_{it} \tag{4}$$

In Eq. (4), to examine the consumption resilience of new energy vehicles, we assume that the impact of the pandemic shock on new energy vehicle consumption lasts for 6 months. For comparison purposes, we also examine the impact of the fiscal subsidy policy on new energy vehicle consumption in 3 months before the pandemic outbreak. So the values of $m$ range from − 3 to 6. $\varpi_i$ 、$\nu_t$ denote the control vehicle fixed effects and time fixed effects, respectively. $\xi$ denotes the random disturbance term.

## Variable selection

### *Dependent variable*

This study utilizes the logarithm of monthly sales (ln*sales*) of various vihicle models in Shanghai from January 2018 to February 2021 as the dependent variable. It is important to note that the sales figures refer exclusively to new energy passenger vehicles and do not include new

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[6] The data is about 38,660 Euros at an annual exchange rate of 7.76.

[7] Source: https://www.gov.cn/zhengce/zhengceku/2021-12/31/content_5665857.htm.

**Table 1** Qualitative description of variables

| Variables | Symbols | Metric or description | Unit |
|---|---|---|---|
| Dependent variables | *lnsales* | Logarithm of monthly sales of vehicle series | Car |
| Core independent variable | *Policy* | The variable is 1 if a new energy vehicle model receives the fiscal subsidy and 0 otherwise | None |
| Control variables | *Price* | Price of vehicle series | Yuan |
| | *Range* | Driving range of each type of NEVs | km |
| | *Engine* | The variable is 1 if the engine of the NEV is naturally aspirated, and 0 if it is turbo charged | None |
| | *Brand* | The variable equals 1 if the NEV is a luxury brand, and 0 otherwise | None |
| | *Typecar* | *typecar* = 1 if the NEV is an MPV or sports car, 2 if it is an SUV, 3 if it is a sedan | None |
| | *Fuel* | The variable is 1 for a PEV, 2 for an AEV, 3 for a PHEV | None |
| | *Firm* | The variable is 1 for a joint venture car, 2 for an imported car, 3 for a wholly foreign-owned car, and 4 for an independent car | None |
| | *Drive* | The variable equals 1 for FWD, 2 for RWD, 3 for AWD and 4 for other drive systems | None |

For all four variables, *Typecar*, *Fuel*, *Firm*, and *Drive* we transformed to the form of dummy variables in the empirical evidence

energy buses or trucks. Due to data availability, the sales of conventional fuel vehicles are not examined.

### *Core independent variable*

The core explanatory variable, *Policy*, is coded as 1 if a new energy vehicle model receive the fiscal subsidy and 0 otherwise. China's NEV promotion policy has gone through three phases: the pilot phase (2009–2012), the demonstration phase (2013–2015), and the full-scale promotion phase (from 2016 onwards). During the pilot phase, only 25 cities enjoyed preferential policies for promoting new energy vehicles, primarily targeting public procurement. Specifically, from June 2010, private purchases of NEVs in six cities—Shanghai, Beijing, Shenzhen, Hangzhou, Hefei, and Changchun—were eligible for subsidies. In the demonstration phase, the number of cities receiving NEV subsidies expanded to 88. However, considering technological advancements and economies of scale, these subsidies had been gradually phased out over time. After 2018, NEV preferential policies were extended nationwide [12]. Shanghai has benefited from fiscal subsidy policies since the pilot phase. It should be clarified that the eligibility for subsidies for NEVs depends on factors such as vehicle type, technical parameters, driving range, and battery power consumption. The subsidy funds come from both central and local governments.

This study primarily relies on the following documents to determine subsidy eligibility: "Notice on the Fiscal Support Policy for the Promotion and Application of New Energy Vehicles from 2016 to 2020", "Notice on the Fiscal Subsidy Policy for the Promotion and Application of New Energy Vehicles in 2022", "Notice on Improving the Fiscal Subsidy Policy for the Promotion and Application of New Energy Vehicles", and various batches of the "Recommended New Energy Vehicle Promotion Application Model Catalogue". During the study period, the average subsidy amount for eligible vehicles was 19,370 RMB, 74.74% of NEVs received subsidies from both the central and Shanghai municipal governments.

### *Control variables*

(1) Price (*Price*): Price is the most important factor affecting sales volume in microeconomic models.
(2) Driving range (*Range*): This variable is measured by the driving range of each type of new energy vehicles.
(3) Engine type (*Engine*): The variable takes the value of 1 if the engine of the NEV is naturally aspirated, and 0 if it is turbocharged.
(4) Brand attributes (*Brand*): This variable equals 1 if the NEV is a luxury brand, and 0 otherwise.
(5) Type of new energy vihicles (*Typecar*): The variable equals 1 if the type of NEVs is a multi-purpose vehicle (MPV) or a sports car, 2 if it is a sport utility vehicle (SUV), and 3 if it is a sedan.
(6) Power source (*Fuel*): The variable equals 1 if the type of NEV is a pure electric vehicle(PEV), 2 if it is an add-on electric vehicle (AEV), and 3 if it is a plug-in hybrid electric vehicle (PHEV).
(7) Manufacturer properties (*Firm*): New energy vehicle manufacturers are classified into four categories: joint venture (1), imported (2), wholly foreign-owned (3), and independent (4).
(8) drivetrain configuration (*Drive*): This variable represents the vehicle's drivetrain setup, with the following values:1 for front-wheel drive (FWD); 2 for rear-wheel drive (RWD); 3 for all-wheel drive (AWD); 4 for other drive systems.

It should be noted that the variables *Price* and *Range* are expressed in interval form in the orginal data and here

**Table 2** Descriptive statistics of variable

| Variables | N | mean | sd | min | p50 | max |
|---|---|---|---|---|---|---|
| lnsales | 3453 | 2.738 | 1.879 | 0 | 2.565 | 8.971 |
| *Policy* | 3453 | 0.747 | 0.435 | 0 | 1 | 1 |
| *Price* | 3453 | 32.811 | 32.926 | 3.38 | 21.13 | 194.4 |
| *Range* | 3453 | 258.261 | 169.656 | 30 | 270 | 745 |
| *Engine* | 3453 | 0.649 | 0.477 | 0 | 1 | 1 |
| *Brand* | 3453 | 0.203 | 0.402 | 0 | 0 | 1 |
| *Typecar* | 3453 | 2.417 | 0.591 | 1 | 2 | 3 |
| *Fuel* | 3453 | 1.847 | 0.98 | 1 | 1 | 3 |
| *Firm* | 3453 | 1.622 | 0.937 | 1 | 1 | 4 |
| *Drive* | 3453 | 1.622 | 0.937 | 1 | 1 | 4 |

we take the mean value. In addition, we have removed the anomalous samples of Shuaihu ES3, Shang EV, and Yinglun TX5 due to their short time on the market or small sales size, which makes their data outliers. The qualitative descriptive information of the these variables is shown in Table 1, while Table 2 presents the descriptive statistics for each variable.

### Sample selection and data sources

New energy vehicles typically encompass PEV, AEV, PHEV, and ordinary power hybrid vehicles. However, since ordinary power hybrid vehicles are not prioritized in China's NEV promotion policies, this study focuses on the first three categories. The monthly sales data for NEVs, spanning from January 2018 to February 2021[8], is sourced from *Dasouchezhiyun database*[9]. This comprehensive platform for China's automotive industry data offers services such as data query, analysis, and reporting, meeting the basic requirements of our research.

Shanghai is chosen as the sample for two main reasons. First, the per capita disposable income and per capita consumption expenditure of Shanghai rank first in China. According to the 2022 Shanghai Statistical Yearbook, these two indicators were 78,024 and 48,876 RMB in 2021, respectively, which indicate a strong capacity for purchasing durable goods, such as automobiles. Second, Shanghai, a mega-city, has implemented a license plate auction system since the 1990s to alleviate traffic congestion, with an average license plate price of 92,217 RMB in 2022.[10] To further promote new energy vehicles, Shanghai has introduced a complimentary special license plate system alongside fiscal subsidies for eligible vehicles. This policy, unrestricted by time or roadways, significantly aids in the consumption of NEVs. The unique support policy for NEVs in Shanghai is a key factor in selecting it as a sample.

It is important to note that while Shanghai is representative, this study may lack generalizability due to this specific focus. The data for the control variables, *Price* and *Range*, are sourced from the website https://www.autohome.com.cn/. The other control variables are derived from the *Dasouchezhiyun database*.

## Preliminary evidence and characteristic facts

### The characteristic facts of new energy vehicle consumption

This section presents a descriptive analysis to elucidate the characteristics of NEV consumption, providing an intuitive understanding of the impact of the COVID-19 pandemic and fiscal subsidy policies on sales. Figure 1 compares the consumption patterns of new energy vehicle with and without fiscal subsidies before and after the pandemic shock. In Fig. 1a, vehicles with fiscal subsidies exhibited an inverted V-shaped sales trend prior to the pandemic, followed by a sharp decline at the onset of the pandemic and a subsequent robust recovery. In contrast, Fig. 1b shows that sales of unsubsidized new energy vehicles maintained relative stability in 15 months leading up to the pandemic, with a more gradual growth post-pandemic. A comparison of the two figures reveals significant inflection points. Notably, the presence of fiscal subsidies correlated with a downward cutoff point during the pandemic, while unsubsidized vehicles experienced an increase at the same time. This suggests that the pandemic has a negative impact on subsidized vehicles, unlike those without subsidies. Furthermore,

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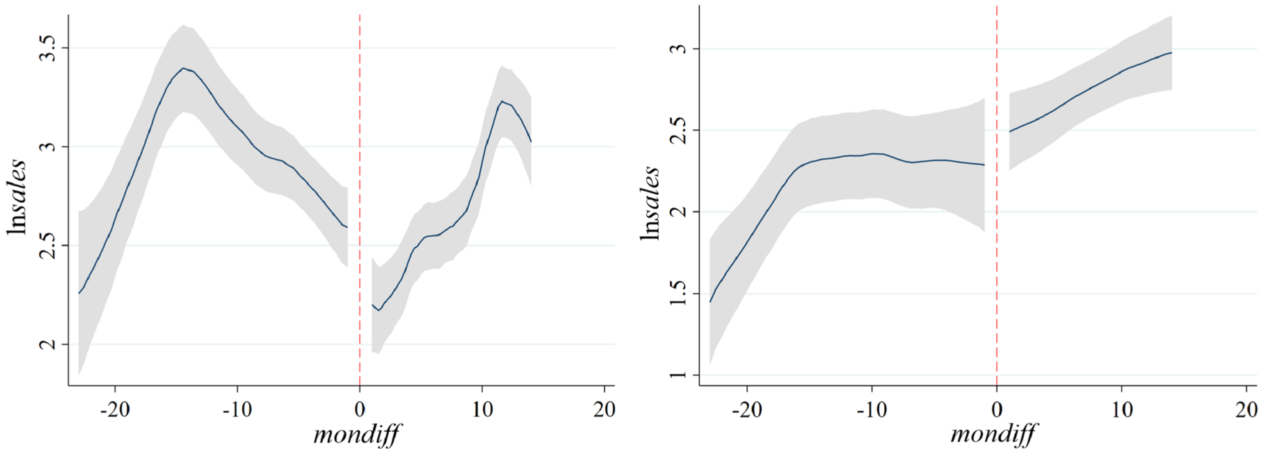
[8] The rationale for selecting January 2018 as the initial period for our data collection is to ensure temporal symmetry around the pandemic's onset. The manuscript was prepared in February 2021, which corresponds to the end of the data.

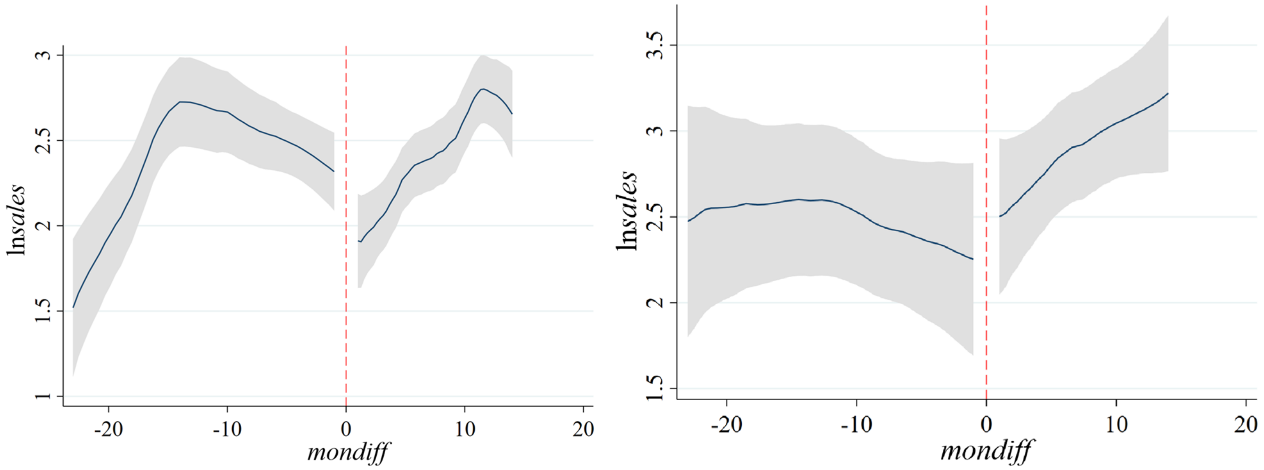
[9] See https://zhiyun.souche.com/welcome. Additionally, the lack of data on fuel cell vehicles is a limitation of our study and suggests a promising direction for future research.

[10] See https://www.meidi.org.cn/hupai/?p=96.



(a) NEVs with fiscal subsidies (b) NEVs without fiscal subsidies

**Fig. 1** Comparison of monthly sales of new energy vehicles with and without fiscal subsidies pre- or-post COVID-19 pandemic. **a** Illustrates the sales trajectory of new energy vehicles that received fiscal subsidies, both before and after the COVID-19 outbreak. For comparative purposes, **b** Shows the sales changes of NEVs that did not receive such subsidies during the same periods. In both figures, the red dashed line, perpendicular to the horizontal axis, marks the onset of the COVID-19 outbreak in December 2019. The left side of this line indicates the pre-pandemic period, while the right side indicates the post-pandemic period. The blue solid line indicates a nonlinear fit of the variable ln*sales* interacted with the variable *mondiff*. The gray area denotes the 95% confidence interval for the fit, Fig. 2 and Fig. 3 follow the same conventions. Source: Authors' computation using STATA 17

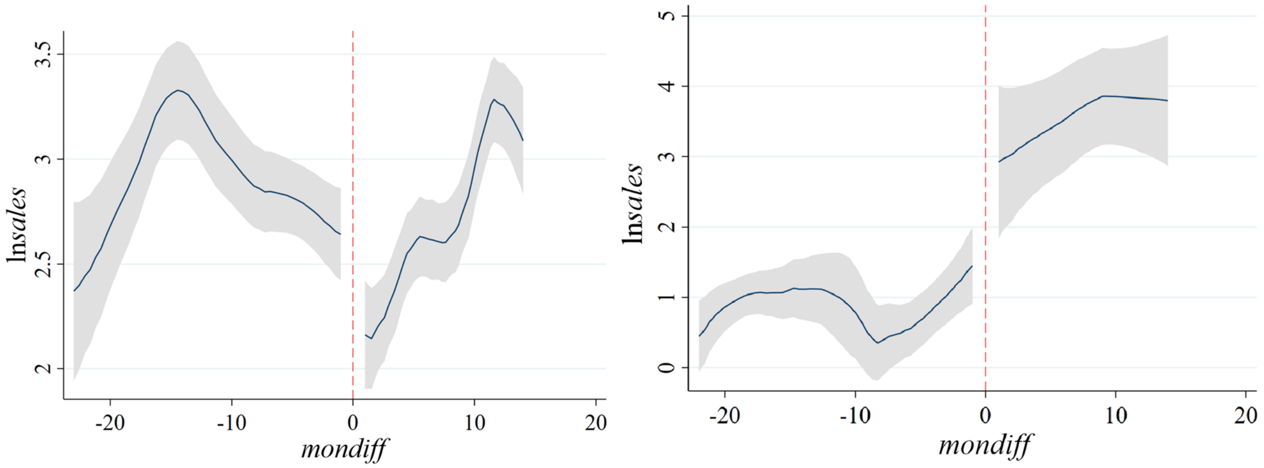


(a) PEVs with fiscal subsidies (b) PEVs without fiscal subsidies

**Fig. 2** Comparison of sales of PEVs with and without fiscal subsidies before and after the COVID-19 pandemic. **a** Illustrates the sales trajectory of PEVs that received fiscal subsidies, both before and after the COVID-19 outbreak. **b** Shows the sales changes of PEVs that did not receive such subsidies during the same periods. Source: Authors' computation using STATA 17

post-pandemic, the sales growth of subsidized vehicles outpaced that of unsubsidized vehicles. The evidence broadly indicates that the fiscal subsidy policy is instrumental in bolstering the resilience of new energy vehicles against pandemic shocks.

In contrast to PHEVs and AEVs, PEVs are perceived to have more favorable market prospects and are more aligned with the low-carbon development trend. Consequently, PEVs are the centerpiece of China's strategy to promote new energy vehicles. Figure 2 provides a detailed analysis of the sales trends of PEVs, both subsidized and unsubsidized, before and after the COVID-19 pandemic. For PEVs with fiscal subsidies, sales initially showed an upward trend followed by a slight dip prior to



(a) Domestic new energy vehicles with fiscal subsidies

(b) Domestic new energy vehicles without fiscal subsidies

**Fig. 3** Comparison of sales of domestic new energy vehicles with or without fiscal subsidies before and after the COVID-19 pandemic. **a** Illustrates the sales trajectory of domestic NEVs that received fiscal subsidies, both before and after the COVID-19 outbreak. **b** Shows the sales changes of domestic NEVs that did not receive such subsidies during the same periods. Source: Authors' computation using STATA 17

the pandemic. At the onset of the COVID-19, there was a noticeable downturn in sales. However, post-pandemic, sales experienced a sharp increase followed by a slight correction. On the other hand, PEVs without fiscal subsidies saw a modest decline in sales in the year leading up to the pandemic. Interestingly, these vehicles did not experience a negative impact from the outbreak; instead, their sales surged significantly afterwards. At the cutoff point, the sales pattern of PEVs largely mirrors that of the overall new energy vehicle market.

In addition, it is necessary to examine the impact of the COVID-19 pandemic on the consumption of new energy vehicles from domestic independent brands. The intention of the new energy vehicle subsidy policy is obvious. That is to stimulate the independent innovation of NEV enterprises, and to cultivate and strengthen the domestic NEV industry [74]. Consequently, evaluating the efficacy of subsidies and the pandemic's impact on domestic vehicles is imperative. Based on brand attributes, NEVs can be categorized into German, French, Korean, American, European, Japanese, and domestic Chinese brands. Among domestic new energy vehicle brands, 141 models benefit from fiscal subsidies, while only 15 models do not receive such subsidies. In contrast, among non-domestic new energy vehicles, 38 models are subsidized, while 42 models are not eligible for fiscal subsidies. Figure 3 illustrates the contrasting effects of fiscal subsidies on domestic new energy vehicles sales. The sales of domestic new energy vehicles that received fiscal subsidies tended to decrease at the cutoff point. Conversely, the sales of domestic new energy vehicles that did not benefit from these subsidies showed an increase at the same cutoff point. Domestic NEVs with fiscal subsidies exhibited an inverted "V" sales pattern before the pandemic and rapid and volatile rise post-pandemic. In contrast, NEVs without policy subsidies did not exhibit a growth trend before the pandemic. However, they undergone a brief increase during the pandemic, following by a period of steady growth.

### Descriptive analysis of control variables

To ensure the accuracy of regression discontinuity analysis results, it is imperative that the control variables are continuous and exhibit no significant changes before and after the cutoff point. A *t* test for these variables is essential, and the results are shown in Table 3. In addition, it is crucial to verify that control variables do not show significant differences between the group with fiscal subsidies and the group without fiscal subsidies. Compliance with these conditions is necessary for the study sample to adhere to the assumptions of the DID method. As shown in columns (1)–(6) of Table 3, the means of these variables remain relatively stable before and after the pandemic. That indicates there are no notable differences in the control variables' outcome before and after the pandemic shock, for the entire sample set, as well as for the sub sample of subsided NEVs and non-subsided NEVs. Furthermore, column (7) indicates that there is no discernible treatment effect for the control variables near the cutoff points, suggesting an absence of significant shifts, thus, RD method is suitable. Summarizing these

**Table 3** Descriptive statistics of control variables and corresponding t-test results

| Variables | (1) Full sample -Before COVID-19 | (2) Full sample -After COVID-19 | (3) Subsided NEVs -Before COVID-19 | (4) Subsided NEVs -After COVID-19 | (5) Non-subsided NEVs -Before COVID-19 | (6) Non-subsided NEVs -After COVID-19 | (7) Local smoothness test |
|---|---|---|---|---|---|---|---|
| *Price* | 36.202 | 30.213 | 20.296 | 20.424 | 78.871 | 61.309 | 0.297 |
| | (0.937) | (0.691) | (0.277) | (0.225) | (2.315) | (2.215) | (3.667) |
| *Range* | 227.162 | 283.740 | 237.047 | 292.319 | 200.644 | 256.489 | 6.728 |
| | (4.077) | (4.071) | (4.147) | (4.499) | (9.979) | (9.095) | (21.215) |
| *Engine* | 0.617 | 0.673 | 0.699 | 0.700 | 0.399 | 0.587 | 0.002 |
| | (0.012) | (0.011) | (0.014) | (0.012) | (0.024) | (0.024) | (0.068) |
| *Brand* | 0.231 | 0.181 | 0.017 | 0.010 | 0.805 | 0.725 | 0.025 |
| | (0.011) | (0.009) | (0.004) | (0.003) | (0.019) | (0.021) | (0.050) |
| *Firm* | 2.978 | 2.862 | 3.441 | 3.186 | 1.738 | 1.835 | – 0.024 |
| | (0.033) | (0.032) | (0.035) | (0.036) | (0.030) | (0.043) | (0.214) |
| *Typecar* | 2.461 | 2.381 | 2.483 | 2.372 | 2.401 | 2.411 | 0.018 |
| | (0.015) | (0.014) | (0.017) | (0.016) | (0.032) | (0.029) | (0.085) |
| *Fuel* | 1.957 | 1.760 | 1.826 | 1.735 | 2.308 | 1.839 | – 0.019 |
| | (0.025) | (0.023) | (0.029) | (0.026) | (0.046) | (0.046) | (0.130) |
| *Drive* | 1.646 | 1.610 | 1.302 | 1.369 | 2.567 | 2.376 | – 0.023 |
| | (0.024) | (0.022) | (0.022) | (0.022) | (0.038) | (0.043) | (0.116) |

Values without parentheses represent the mean of the variable, while values in parentheses represent standard errors

Source: Authors' computation using STATA 17

findings, the selection of control variables aligns with the fundamental requirements of the DID-RD framework.

## Empirical results

### Impact of the pandemic shock and fiscal subsidies on the consumption of new energy vehicles

Column (1) of Table 4 presents the RD analysis results with a bandwidth of 3 months, covering the period from September 2019 to March 2020. The findings indicate that the COVID-19 pandemic has had a significant negative impact on the consumption of NEVs, leading to a 23% reduction in sales during the sample period. The conclusion is largely consistent with the results depicted in Fig. 1a. To further validate these findings, we have also conducted RD analyses with bandwidths of 4 and 5 months, following the same methodology as in column (1), and the results are consistent with those in column (1)[11].

Column (2) of Table 4 assesses the effect of the fiscal subsidy policy on the NEVs consumption in the context of the COVID-19 pandemic using the DID method. The results reveal that while the estimated coefficient is negative, it is not statistically significant. This suggests that the direction of the fiscal subsidy policy's on NEV consumption cannot be definitively determined based on the DID estimation results.

Column (3) shows the benchmark results using the RD–DID method with a bandwidth of 3 months. The empirical results suggest that under the combined effect of the negative shock from the COVID-19 pandemic and the positive incentive of the fiscal subsidy policy, there was a significant increase in the sales of new energy vehicles in Shanghai during the 3 months preceding and following the pandemic's impact. The estimated coefficient shows that the sales of vehicles eligible for subsidies saw an approximate 73.4% increase compared to those not receiving subsidies.

The choice of bandwidth in RD–DID analysis can influence the estimation results. To obtain more robust research conclusions, we report the RD–DID regression results for bandwidths of 4 months and 2 months in columns (4) and (5), respectively. The results show that the coefficient of the core explanatory variable ($T\times Policy$) is significantly positive in each column, indicating that even in the face of the COVID-19 pandemic shock, fiscal subsidy policies have played a significant role in stimulating the consumption of NEVs and enhancing their consumption resilience. In addition, comparing the coefficients from columns (4) and (5), we observe that the stimulating effect of fiscal subsidy policies on

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[11] Due to space limitations, the empirical results are not presented here.

**Table 4** Empirical results of the impact of pandemic shock and fiscal subsidies on the sales of new energy vehicles

| **Variables** | **RD Bandwidth for 3 months** | **DID** | **RD–DID Bandwidth for 3 months** | **RD–DID Bandwidth for 4 months** | **RD–DID Bandwidth for 2 months** | **RD–DID Bandwidth for 3 months** |
|---|---|---|---|---|---|---|
| | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** |
| $T \times Policy$ | | − 0.210 | 0.734$^{***}$ | 0.164$^{**}$ | 0.808$^{**}$ | 0.763$^{**}$ |
| | | (0.149) | (0.062) | (0.069) | (0.261) | (0.290) |
| $T$ | − 0.229$^{**}$ | − 0.304 | − 1.015$^{***}$ | − 0.763$^{***}$ | 0.385$^{***}$ | 2.628$^{***}$ |
| | (0.046) | (0.220) | (0.134) | (0.162) | (0.038) | (0.292) |
| $Policy$ | | 0.272 | − 1.452$^{***}$ | − 1.143$^{***}$ | − 1.957$^{***}$ | − 2.192$^{***}$ |
| | | (0.364) | (0.218) | (0.166) | (0.245) | (0.377) |
| $(mondiff \times T \times Policy)^2$ | | | | | | − 0.220$^{*}$ |
| | | | | | | (0.096) |
| $mondiff \times T \times Policy$ | | | − 0.287$^{***}$ | − 0.014 | − 0.071 | 0.596 |
| | | | (0.038) | (0.021) | (0.166) | (0.392) |
| $(mondiff \times T)^2$ | | | | | | 1.629$^{***}$ |
| | | | | | | (0.090) |
| $mondiff \times T$ | − 0.206$^{***}$ | | 0.082$^{***}$ | 0.051$^{***}$ | − 1.575$^{***}$ | − 6.437$^{***}$ |
| | (0.008) | | (0.001) | (0.011) | (0.017) | (0.361) |
| $(mondiff \times (1\text{-}T) \times Policy)^2$ | | | | | | − 0.223$^{***}$ |
| | | | | | | (0.025) |
| $mondiff \times (1\text{-}T) \times Policy$ | | | − 0.137$^{***}$ | − 0.045 | − 0.364$^{**}$ | − 1.034$^{***}$ |
| | | | (0.034) | (0.029) | (0.135) | (0.120) |
| $(mondiff \times (1\text{-}T))^2$ | | | | | | 0.552$^{***}$ |
| | | | | | | (0.034) |
| $mondiff \times (1\text{-}T)$ | 0.303$^{**}$ | | 0.483$^{***}$ | 0.402$^{***}$ | 0.697$^{***}$ | 2.235$^{***}$ |
| | (0.054) | | (0.105) | (0.109) | (0.000) | (0.111) |
| *Price* | 0.153$^{*}$ | − 0.126$^{***}$ | 0.153$^{***}$ | 0.063$^{***}$ | 0.185$^{***}$ | 0.153$^{**}$ |
| | (0.054) | (0.034) | (0.005) | (0.013) | (0.022) | (0.052) |
| *Range* | 0.006$^{***}$ | 0.007$^{*}$ | 0.006$^{***}$ | 0.010$^{***}$ | 0.007$^{***}$ | 0.006$^{***}$ |
| | (0.0005) | (0.004) | (0.0004) | (0.001) | (0.0004) | (0.001) |
| *Engine* | − 1.698$^{**}$ | 2.486$^{***}$ | 1.175$^{***}$ | 1.304$^{***}$ | − 1.865$^{***}$ | 1.102 |
| | (0.390) | (0.118) | (0.077) | (0.066) | (0.512) | (0.842) |
| *Brand* | | 0.155 | 0.144 | 4.849$^{***}$ | − 6.119$^{***}$ | − 0.104 |
| | | (1.605) | (1.110) | (0.908) | (0.677) | (2.477) |
| 2. *Firm* | | 10.675$^{***}$ | − 10.521$^{***}$ | − 5.215$^{***}$ | − 12.330$^{***}$ | − 10.584$^{**}$ |
| | | (2.245) | (0.267) | (0.726) | (1.240) | (2.943) |
| 3. *Firm* | | 6.819$^{***}$ | − 1.247 | − 4.261$^{***}$ | 0.681 | − 1.020 |
| | | (1.956) | (0.762) | (0.617) | (0.417) | (1.422) |
| 4. *Firm* | 0.224 | − 1.054$^{**}$ | 3.109$^{***}$ | 3.524$^{***}$ | 0.139 | 3.019$^{**}$ |
| | (0.189) | (0.412) | (0.350) | (0.281) | (0.288) | (1.028) |
| 2. *Typecar* | − 1.835$^{*}$ | − 1.787 | − 1.883$^{***}$ | − 1.412$^{***}$ | − 2.465$^{***}$ | − 1.828$^{**}$ |
| | (0.664) | (1.710) | (0.290) | (0.372) | (0.109) | (0.639) |
| 3. *Typecar* | − 1.456$^{*}$ | − 1.674$^{**}$ | 1.301$^{***}$ | 2.797$^{***}$ | − 1.860$^{***}$ | 1.190 |
| | (0.557) | (0.778) | (0.388) | (0.321) | (0.245) | (1.001) |
| 2. *Fuel* | − 0.053 | 5.248$^{**}$ | 2.810$^{***}$ | 5.008$^{***}$ | 0.295 | 2.693$^{***}$ |
| | (1.047) | (2.261) | (0.480) | (0.354) | (0.411) | (0.571) |
| 3. *Fuel* | 2.450$^{**}$ | 0.696 | 2.582$^{***}$ | 2.837$^{***}$ | 2.535$^{***}$ | 2.581$^{***}$ |
| | (0.560) | (0.569) | (0.422) | (0.382) | (0.292) | (0.481) |
| 2. *Drive* | 6.441$^{***}$ | − 0.218 | 3.677$^{***}$ | 2.034$^{***}$ | 7.008$^{***}$ | 3.794$^{**}$ |
| | (0.654) | (0.730) | (0.445) | (0.388) | (0.243) | (1.113) |

**Table 4** (continued)

| **Variables** | **RD Bandwidth for 3 months** | **DID** | **RD–DID Bandwidth for 3 months** | **RD–DID Bandwidth for 4 months** | **RD–DID Bandwidth for 2 months** | **RD–DID Bandwidth for 3 months** |
|---|---|---|---|---|---|---|
| | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** |
| 3. *Drive* | − 0.296 | 0.192 | − 0.278 | 0.037 | − 0.834$^{***}$ | − 0.288 |
| | (0.538) | (0.478) | (0.258) | (0.209) | (0.183) | (0.563) |
| 4. *Drive* | − 0.074 | 1.507$^{**}$ | − 0.089 | 0.111 | − 0.500 | − 0.069 |
| | (0.580) | (0.612) | (0.287) | (0.402) | (0.313) | (0.545) |
| Cons | − 1.503 | 0.699 | − 5.767$^{***}$ | − 6.707$^{***}$ | 0.174 | − 4.294$^{**}$ |
| | (0.689) | (1.369) | (0.382) | (0.417) | (0.922) | (1.632) |
| Individual FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes |
| *N* | 417 | 3452 | 541 | 731 | 354 | 541 |
| $R^2$ | 0.874 | 0.674 | 0.859 | 0.847 | 0.875 | 0.860 |

The values enclosed in parentheses represent the clustering standard errors, $^{***}$, $^{**}$, $^{*}$ denotes 1%, 5%, and 10% significant levels, respectively

Source: Authors' computation using STATA 17

NEV consumption during the pandemic decreases as the bandwidth increases.[12] Column (6) includes the quadratic term of the assignment variable with a bandwidth of 3 months, and the core explanatory variable remains significantly positive, reaffirming the robustness of the baseline regression results.

In summary, the results in column (1) from the regression discontinuity analysis indicate that the COVID-19 pandemic led to a 23% decrease in NEV sales within 3 months before and after the outbreak. The results from columns (3) to (6) suggest that fiscal subsidy policies are crucial in mitigating the negative impact of the pandemic and enhancing the resilience of new energy vehicle consumption. When the bandwidth is set between 2 and 4 months, the sales of subsidized new energy vehicles increased by approximately 15–80% compared to those without subsidies. This demonstrates the significant importance of fiscal subsidy policies in reducing consumer car purchase costs, increasing consumer enthusiasm for buying vehicles, and improving consumption resilience.

In response to the sudden outbreak of the COVID-19 pandemic, the Chinese government has taken a series of measures on the demand side to promote the adoption of new energy vehicles. In February 2020, the National Development and Reform Commission issued the "Implementation Opinions on Promoting Consumption Expansion and Quality Improvement to Accelerate the Formation of a Strong Domestic Market" which explicitly stated the need to "implement the current central fiscal subsidy policies for the promotion and application of NEVs and the incentive policies for infrastructure construction." The aim of this document is to strengthen the enforcement of subsidy policies. In March 2020, the State Council's executive meeting identified new initiatives to promote automobile consumption and decided to extend the NEV subsidy and exemption from purchase tax exemption policy, which were set to expire at the end of 2020, by 2 years. This policy was implemented in the subsequent release of the "Notice on Improving Fiscal Subsidies for the Promotion and Application of NEVs". This document serves as a crucial basis for determining whether NEVs are eligible for fiscal subsidies and the duration of such subsidies." In July 2020, the Ministry of Industry, and Information Technology, along with two other departments, issued the "Notice on the Launch of New Energy Vehicle Promotion Activities in Countryside". This policy is designed to encourage the adoption of NEVs in rural areas, and NEVs that qualify for promotion in these areas are also eligible for fiscal subsidy benefits.

These three documents represent national-level policy directives. Beyond complying with and implementing the national policy requirements, Shanghai has independently introduced additional fiscal subsidies for consumers purchasing NEVs, supplementing the central government's subsidies. In essence, fiscal incentives and supportive policies have been a crucial factor in the robust consumer resilience of NEVs in Shanghai, especially in the wake of the COVID-19 pandemic's economic impact.

Concurrently, based on the benchmark regression results from column (3), we have analyzed the impact of control variables on the sales of NEVs. The variable *price* shows a significant positive correlation with NEV sales,

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[12] For this issue, we will conduct a more in-depth analysis in the subsequent sections.

**Table 5** Robustness examination

| **Variables** | **Placebo test (6 months ahead of the pandemic)** | | | **Dropping small samples** | | |
|---|---|---|---|---|---|---|
| | **±3** | **±4** | **±2** | **±3** | **±4** | **±2** |
| | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** |
| $T\times Policy$ | 0.252 | − 0.090 | 0.147 | $0.390^{**}$ | $0.1991^{*}$ | $1.1311^{***}$ |
| | (0.227) | (0.142) | (0.215) | (0.132) | (0.136) | (0.289) |
| Cons | $-42.796^{*}$ | $7.545^{***}$ | − 63.513 | 10.540 | − 4.812 | 7.790 |
| | (24.225) | (1.804) | (38.611) | (31.558) | (27.345) | (1.441) |
| Control variables | Yes | Yes | Yes | Yes | Yes | Yes |
| Individual FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes |
| N | 476 | 612 | 319 | 338 | 463 | 215 |
| $R^2$ | 0.833 | 0.813 | 0.834 | 0.873 | 0.851 | 0.897 |

The values enclosed in parentheses represent the clustering standard errors,$^{***}$,$^{**}$,$^{*}$denotes 1%, 5%, and 10% significant levels, respectively

Source*:* Authors' computation using STATA 17

suggesting that in a first-tier city like Shanghai, where per capita disposable income ranks first in the nation, consumers tend to value quality over price when it comes to durable goods like cars, adhering to the principle of "you get what you pay for". The coefficient for *range* is also significantly positive, indicating that consumers prefer NEVs with longer driving ranges, reflecting the widespread phenomenon of "range anxiety". The impact of being a naturally aspirated engine and whether the car is a luxury brand on NEV sales varies with the bandwidth. Under a bandwidth of 2 months, consumers significantly prefer NEVs with turbocharged engines and those that are not luxury brands. Compared to joint venture vehicles, consumers show a preference for independent models and are less inclined towards imported vehicles and those produced by wholly foreign-owned enterprises. Compared to MPVs and sports cars, consumers have a stronger preference for sedans rather than SUVs. When it comes to propulsion types, consumers favor extended-range or plug-in hybrid vehicles over pure electric vehicles. In terms of drivetrain, consumers prefer rear-wheel drive vehicles over front-wheel drive, all-wheel drive, or four-wheel drive options.

### Other robustness examination

In addition to the aforementioned regression analysis, we undertake various robustness checks. First, we conduct a placebo test. The placebo test aims to exclude the potential influence of unobservable non-policy factors on the estimation results. The basic idea is to assume that the COVID-19 outbreak occurred 6 months earlier. Since the timing of the outbreak is set arbitrarily, it is expected that the interaction term between the variable $T$ and $Policy$ should be insignificant, In other words, the pandemic "fake" timing should not lead to a significant consumption stimulus effect of fiscal subsidies. The results of the placebo test based on the RD–DID method are presented in Table 5. From the estimation results of the first three columns, regardless of whether the bandwidth is set to 3 months, 4 months, or 2 months, the coefficients of the core explanatory variable $T\times Policy$ is not significant. This indicates that the impact of unobservable factors on the estimation results is minimal, which also corroborates the credibility of the benchmark regression results.

Second, we perform an analysis by excluding samples with monthly sales less than or equal to 5 units. To account for the potential impact of outliers on the estimation results, we remove these samples. As can be seen from the last three columns of the estimation results in Table 5, even after excluding these specific samples, the coefficient of the core explanatory variable remains significantly positive. This further demonstrates the robustness of the benchmark regression results in column (3) of Table 4.

### Heterogeneity analysis

First, we have categorized new energy vehicles into two distinct groups: PEVs and hybrid vehicles, which include PHEVs and AEVs. The empirical findings of the RD–DID analysis, which accounts for heterogeneity based on vehicle types with a bandwidth of 3 months, are presented in columns (1) and (2) of Table 6. Column (1) corresponds to PEVs, while column (2) corresponds to hybrid vehicles. The magnitude of the coefficient indicates that the positive impact of the subsidy policy on PEVs consumption during the pandemic shock is greater than its impact on hybrid vehicles. This conclusion is in line with the current state of the new energy vehicle industry's development and the direction of national support for

**Table 6** Heterogeneity analysis

| **Variables** | **Automobile type** | | **Country of origin** | |
|---|---|---|---|---|
| | **PEV** | **Hybrid vehicles** | **Domestic brand** | **Non-domestic brand** |
| | **(1)** | **(2)** | **(3)** | **(4)** |
| $T\times Policy$ | $1.054^{***}$ | $0.371^{**}$ | $-1.224$ | $1.732^{***}$ |
| | (0.118) | (0.054) | (0.722) | (0.376) |
| Cons | $-4.491^{***}$ | $-28.590^{*}$ | $6.883^{***}$ | $-72.708$ |
| | (0.411) | (7.144) | (1.937) | (6.679) |
| Control variables | Yes | Yes | Yes | Yes |
| Individual FE | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes |
| N | 317 | 224 | 353 | 188 |
| $R^2$ | 0.869 | 0.846 | 0.891 | 0.835 |
| **Variables** | **Motorcycle type** | | **Body size** | |
| | **Sedans** | **Other cars** | **Large- and medium-sized vehicles** | **Small vehicles** |
| | **(5)** | **(6)** | **(7)** | **(8)** |
| $T\times Policy$ | $1.370^{***}$ | $0.207^{*}$ | $1.366^{***}$ | 0.305 |
| | (0.087) | (0.102) | (0.258) | (0.204) |
| Cons | $-21.036^{***}$ | $-1.685^{***}$ | $4.019^{***}$ | $5.267^{***}$ |
| | (1.429) | (0.504) | (0.276) | (0.362) |
| Control variables | Yes | Yes | Yes | Yes |
| Individual FE | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes |
| N | 255 | 286 | 176 | 365 |
| $R^2$ | 0.850 | 0.877 | 0.826 | 0.880 |

The values enclosed in parentheses represent the clustering standard errors,$^{***}$,$^{**}$,$^{*}$denotes 1%, 5%, and 10% significant levels, respectively

Source: Authors' computation using STATA 17

new energy vehicles. PHEVs and AEVs are not entirely independence of fossil fuels, whereas PEVs, powered by electricity, offer the benefits of being pollution-free and renewable. Consequently, PEVs are more likely to be favored by businesses and supported by government policies. As a result, despite the pandemic shock, PEVs have experienced rapid growth following the outbreak of the COVID-19 pandemic.

China's subsidy standards for PEVs are more generous than those for hybrid vehicles. For instance, in 2020, the mileage subsidy standards for PEVs (passenger cars) were set at 2087.63 Euros with a range between 300 and 400 km and 2899.48 Euros for those with a range over 400 km. In contrast, hybrid vehicles with a range exceeding 50 km were eligible for a mileage subsidy of 1095.36 Euros.[13] This differential in subsidies is a significant factor contributing to the resilience of PEV consumption.

Second, an analysis of national heterogeneity in new energy vehicles (NEVs) is conducted. NEVs are categorized based on their country of origin into domestic NEVs and foreign NEVs. Columns (3) and (4) of Table 6 report the RD–DID empirical results for these two subsamples, with a bandwidth 3 months. The empirical findings indicate that domestic NEVs with subsidies did not exhibit a notably higher growth rate compared to those without subsidies during the pandemic-induced economic shock. In contrast, foreign NEVs with subsidies experienced notable growth during the COVID-19 pandemic. These conclusions suggest that the fiscal subsidies had an immediate effect on enhancing the consumption resilience of foreign NEVs during the pandemic. Surprisingly, even with government subsidies, domestic NEVs did not demonstrate strong resilience against the impact, which is an unexpected finding.

The development of emerging industries, such as those centered on NEVs, relies on technological innovation and market cultivation. In recent years, there has been

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[13] These figures are not the final subsidy amount, the actual subsidy is calculated using a formula.

**Table 7** Changes in the core explanatory variable's coefficient with respect to the variation in bandwidths

| **Bandwidths** | **±2** | **±3** | **±4** | **±5** | **±6** | **±7** | **±8** | **±9** | **±10** |
|---|---|---|---|---|---|---|---|---|---|
| Coefficients | 0.808$^{**}$ | 0.734$^{***}$ | 0.164$^{**}$ | 0.163$^{**}$ | 0.158 | 0.238$^{*}$ | 0.212$^{*}$ | 0.221$^{**}$ | 0.044 |
| Clustering standard errors | – 0.261 | – 0.062 | – 0.069 | – 0.074 | – 0.133 | – 0.122 | – 0.104 | – 0.1 | – 0.087 |
| Coef. lower limit | 0.219 | 0.595 | 0.008 | – 0.001 | – 0.126 | – 0.023 | – 0.008 | 0.01 | – 0.137 |
| Coef. upper limit | 1.398 | 0.873 | 0.321 | 0.326 | 0.442 | 0.499 | 0.431 | 0.431 | 0.225 |

a surge in global competition in this sector, with numerous countries adopting various policy measures to foster industry growth. The efficacy of these policies is a subject of ongoing academic discussion [1]. In China, traditional NEV manufacturers from Europe and the United States are recognized for their technological and market dominance. A key objective of China's NEV promotion policy is to enable a "leapfrog" in the automotive sector by bolstering domestic brands. However, empirical results show that in the face of the COVID-19 pandemic, the subsidy effect for domestic brand NEVs is not as significant as that for NEVs from other countries. There is a discrepancy between policy intentions and actual outcomes, suggesting that China's NEV subsidies have not only failed to correct market failures but have also led to "government failure". The reasons we believe the fiscal subsidy policy has not achieved the desired subsidy effect are that subsidies aimed at enhancing the competitiveness of domestic brands distort market competition rules, increase transaction costs, policy implementation costs, and corporate development costs, also lead to rent-seeking issues [3].

Third, an analysis of vehicle type heterogeneity is conducted. Based on the type of new energy vehicles, they are categorized into sedans and other types including MPVs, SUVs, and sports cars. The RD–DID estimation results based on vehicle type heterogeneity, with a bandwidth 3 months, are shown in columns (5) and (6) of Table 6. The coefficients of the core explanatory variables indicate that the fiscal subsidies have a greater effect on enhancing the consumption resilience of new energy sedans compared to other vehicle types under the impact of the COVID-19 pandemic. New energy sedans are favored by the majority of the public for their economy efficiency, comfort, and handling, which are perceived advantages over other vehicle types when purchasing NEVs.

Fourth, an analysis of vehicle size heterogeneity is carried out. According to the size of the vehicle body, new energy vehicles are divided into large and medium-sized vehicles and small vehicles.[14] The empirical results of RD–DID model with a bandwidth 3 months are shown in columns (7) and (8) of Table 6, respectively. It can be observed that under the pandemic shock, the sales of large- and medium-sized new energy vehicles with subsidies significantly exceeded those without subsidies. However, the fiscal subsidy policy does not have a significant impact on the sales of small new energy vehicles during the pandemic.

In conclusion, the results of the heterogeneity analysis indicate that the impact of fiscal subsidy policies on NEV sales during the COVID-19 pandemic varies depending on the vehicle category, country of origin, vehicle type and body size. Generally, fiscal subsidies have been more effective in enhancing the resilience and consumer levels of PEVs, new energy sedans, and large and medium-sized NEVs. Notably, the effect of fiscal subsidies on domestic brand NEVs is less pronounced compared to those from other countries. From the empirical research results, two key conclusions can be drawn: first, from the direction of fiscal subsidy policy implementation, although the promotion policy for NEVs is continuously improving, the significant differences in subsidy effects among different types of new energy vehicles suggest that the government should further refine the promotion policy. Second, the relatively muted subsidy effect on domestic NEVs during the pandemic suggests that there are substantial challenges in China's fiscal subsidy policy for fostering the growth of emerging industries. Although the subsidy policy has been progressively phased out and adjusted, the ongoing challenge for policymakers is to devise equitable incentive measures for NEVs that address demand, supply, and public service aspects post-policy exit.

## Further discussion

### An examination of the new energy vehicle subsidy retreat policy

Although the previous analysis has provided a comprehensive examination of the impact of the COVID-19 pandemic and fiscal subsidy policies on new energy vehicle sales, reaching a basic consensus that fiscal subsidies have played a significant role in enhancing the consumption resilience of new energy vehicles during the pandemic, an interesting phenomenon was observed when analyzing

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[14] Specifically, large and medium-sized cars include large sedans, large SUVs, medium and large SUVs, medium and large sedans, medium and large MPVs, medium-sized SUVs, medium-sized sedans and sports cars; small cars include small SUVs, small sedans, micro sedans, compact SUVs, compact sedans and compact MPVs.

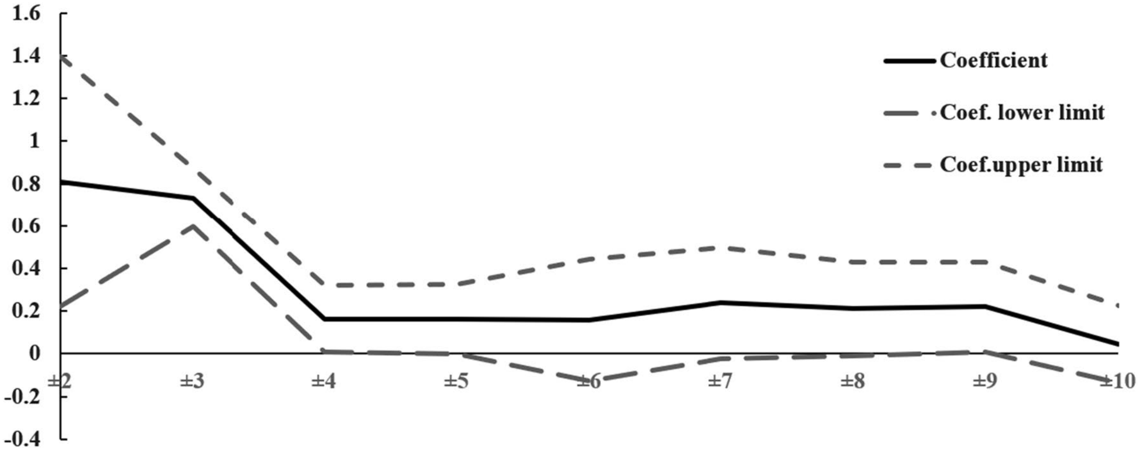

**Fig. 4** Coefficients of core explanatory variables and their confidence intervals with bandwidth changes.$^{***}$,$^{**}$,$^{*}$denotes 1%, 5%, and 10% significant levels, respectively. Source: Authors' computation using STATA 17

columns (3) to (5) of Table 3.When the bandwidth is set to 2 months, the coefficient of the core explanatory variable is 0.808. When the bandwidth is increased to 3 months, the coefficient decreases to 0.734. However, when the bandwidth is extended to 4 months, there is a significant drop in the coefficients of the core explanatory variable, which falls to 0.164. To further investigate this, we employ the RD–DID analysis method to empirically test the variation in the coefficient of the core explanatory variable and its confidence intervals across bandwidths ranging from 2 to10 months, as shown in Table 7 and Fig. 4.

Table 7 and Fig. 4 indicate that as the bandwidth ranges from 1 to 6, there is a discernible trend of decreasing coefficients for the core explanatory variable, accompanied by confidence intervals that initially contract and then expand. As the bandwidth continues to increase, both the magnitude of the coefficients and their confidence intervals tend to stabilize. The variation in the coefficients and their confidence intervals with respect to bandwidth, as depicted in Table 7 and Fig. 4, mirrors the evolving direction of China's new energy vehicle subsidy policy. When the bandwidth is 4–7 months, corresponding to a sample time span from August 2019 to April 2020 or from May 2019 to July 2020, the demand-stimulation effect of the fiscal subsidy policy on new energy vehicles during the pandemic shock shows a notable decrease, although it remains positive. To reduce reliance on the fiscal "crutch" for new energy vehicles, China has been implementing subsidy reduction policies in an orderly manner while promoting the adoption of new energy vehicles. The Ministry of Fiscal and other departments jointly issued a document stipulating that April 23, 2020 to July 22, 2020 was a transition period for the subsidy retreat. During this period, licensed NEVs that met the 2019 technical indicators but not meet the 2020 requirements only got 50% of the standard subsidy. In conclusion, the introduction of the subsidy retreat policy during this period is an important factor contributing to the substantial decrease in the coefficients of the core explanatory variables. This conclusion also indirectly suggests that China's NEVs are overly reliant on government support policies.

### A test of the duration impact of the COVID-19 pandemic

The heterogeneity analysis suggests that with a bandwidth of 3 months, the fiscal subsidy policy does not significantly stimulate the demand for domestic NEVs during the pandemic shock. Given the relatively short time frame of the RD–DID analysis for assessing policy effects, we supplement our study by employing an event study approach to further measure the persistent impact of the COVID-19 pandemic shock on the consumption of domestic NEVs under the support of fiscal subsidy policies. We assume that the impact of the COVID-19 pandemic on the consumption of domestic NEVs would be distinct 6 months after the outbreak and consider the impact differences 3 months prior to the outbreak. The empirical results based on the event analysis method are shown in column (1) of Table 8.

From column (1), it is evidence that prior to the COVID-19 outbreak, the fiscal subsidy policy had a significant stimulating effect on the consumption of domestic NEVs. However, the pandemic's onset, characterized by city lockdowns and business closures, led to a significant decline in sales of domestic new energy vehicles, even with fiscal subsidies in place. The estimated coefficient for the first month after the pandemic shock shows a significant negative impact of fiscal subsidies on

**Table 8** Event analysis

| Variables | (1) | (2) |
|---|---|---|
| Before the 3rd month | 1.998$^{***}$ | −0.938 |
| | (0.770) | (0.595) |
| Before the 2nd month | 1.129$^{***}$ | −0.339 |
| | (0.386) | (0.357) |
| Before the 1st month | 1.689$^{*}$ | −1.670$^{***}$ |
| | (0.960) | (0.412) |
| After the 1st month | −0.568$^{**}$ | −0.845$^{*}$ |
| | (0.283) | (0.449) |
| After the 2nd month | −1.024$^{**}$ | −0.836$^{**}$ |
| | (0.403) | (0.402) |
| After the 3rd month | −0.687 | −1.447$^{***}$ |
| | (0.499) | (0.345) |
| After the 4th month | −0.230 | −0.723$^{**}$ |
| | (0.492) | (0.306) |
| After the 5th month | −0.794$^{***}$ | −0.753$^{**}$ |
| | (0.275) | (0.333) |
| After the 6th month | −0.785$^{**}$ | −0.865$^{**}$ |
| | (0.315) | (0.352) |
| Cons | 1.166 | −1.903 |
| | (0.816) | (1.135) |
| Control variables | Yes | Yes |
| Individual FE | Yes | Yes |
| Time FE | Yes | Yes |
| N | 544 | 540 |
| $R^2$ | 0.887 | 0.843 |

The values enclosed in parentheses represent the clustering standard errors,$^{***}$,$^{**}$,$^{*}$denotes 1%, 5%, and 10% significant levels, respectively

Source: Authors' computation using STATA 17

the sales of domestic new energy vehicles. In the second month following the COVID-19 outbreak, the absolute value of the core explanatory variable's estimated coefficient increased, suggesting an intensification of the negative impact of fiscal subsidies on sales. Two months after the pandemic, lockdowns and quarantine measures across China restricted consumer behavior and introduced significant uncertainty in household income and expenditures, making it difficult for consumers to purchase new energy vehicles despite policy subsidies. In the third and fourth months, although the estimated coefficients of the core explanatory variable were negative, they were not significant, indicating a weakening of the sustained negative effect of fiscal subsidies on domestic NEV sales. During this period, the rapid rise in COVID-19 cases in Hubei Province, the epicenter of the outbreak, was contained, and Wuhan, the hardest-hit city, officially lifted its lockdown. Shanghai also adjusted its COVID-19 emergency response level from level one to level two. China began to enter a phase of pandemic normalization characterized by "internal prevention of resurgence and external prevention of input". The changes in the pandemic situation and the shift in containment policies were significant factors in the reduction of the negative impact of fiscal subsidy policies during this period. In the fifth and sixth months after the COVID-19 pandemic, sales of domestic new energy vehicles in Shanghai experienced another significant decline. In short, the persistent impact of the COVID-19 pandemic reveals that despite enjoying fiscal and tax support, domestic new energy vehicles were heavily impacted after the pandemic, indicating that they are vulnerable to major emergencies.

Column (2) of Table 8 examines the changing impact of fiscal subsidy policies on the PEV consumption in response to the COVID-19 pandemic shock. It can be observed that 2 and 3 months before the pandemic outbreak, the estimated coefficients of the core explanatory variables were not significant. This suggests that the fiscal subsidy policy did not have a significant stimulating effect on PEV consumption before the outbreak. One month before the outbreak, the fiscal subsidy policy had a significant negative impact on PEV sales, which could be attributed to the period being a low season for new energy vehicle sales. From January to June after the outbreak of the COVID-19 pandemic, the negative impact of the COVID-19 shock on PEV consumption exceeded the incentive effect of the fiscal subsidy, as indicated by the results of the estimated coefficients.

In summary, for most countries, the development of domestic NEVs and PEVs holds significant importance. The advancement of NEVs is seen as a crucial means for low-carbon transition and industrial structure upgrading, while PEVs, with their unique characteristics in transportation, energy, and information attributes, are considered the future of the automotive industry. However, the empirical research results presented above indicate that the COVID-19 pandemic has still caused considerable impact on domestic NEVs and PEVs. Moreover, from a long-term perspective, fiscal subsidy policies have not been successful in reversing the trend and enhancing the consumption resilience of domestic NEVs and PEVs post-pandemic.

## Conclusion and inspiration

The COVID-19 outbreak, a major public health emergency, has had a lasting and profound impact on various aspects of the economy and society. Its impact on energy consumption and the development of NEVs has also been a focus for scholars. However, there is a lack of sufficient attention in existing research on the relationship between the pandemic shock, government fiscal policies, and the enhancement of NEV consumption resilience. In this context, this study evaluates the impact of the COVID-19 pandemic on NEV consumption and the effect of fiscal subsidy policies on enhancing the consumption resilience of NEVs based on monthly sales data of NEVs in Shanghai from January 2018 to February 2021. The study employs a combination of methods including RD, RD–DID and event study analysis.

The empirical results show the following: first, when the bandwidth is set to 3 months, the COVID-19 pandemic shock led to an approximate 20% decrease in NEV sales. Compared to unsubsidized NEVs, subsidized NEVs still increase significantly by 15–80% even under the pandemic shock, indicating that the fiscal subsidy policies play a key role in improving the resilience of NEV consumption. This conclusion remains significant after placebo and small sample robustness test. Heterogeneity analysis results suggest that fiscal subsidy policies are more effective in enhancing the consumption resilience of pure electric vehicles, new energy sedans and large and medium-sized NEVs. The subsidy effect of domestic NEVs is less pronounced compared to those from other countries under the pandemic shock. Further analysis indicates that the subsidy retreat policy has led to a decline in the pandemic shock of NEVs. The consumption resilience level of domestic NEVs and PEVs still needs to be improved.

The findings have significant policy implications for refining China's new energy vehicle promotion policies, enhancing the country's consumption resilience, and stimulating economic recovery. They also offer valuable insights for the implementation of new energy vehicle policies in other countries.

First, it is important to seek alternative policies to subsidies to enhance the consumption resilience of new energy vehicles. Although the COVID-19 pandemic has caused a short-term decline in NEV sales, the overall regression indicate that fiscal subsidy policies help to mitigate the impact of the pandemic on NEVs. However, government-provided subsidies may create deadweight loss and impose a significant fiscal burden on the government [10]. In addition, the results of the subsidy phase-out test show that the demand-stimulating effect of fiscal subsidies on NEVs decreases as the bandwidth increases under the pandemic shock. Therefore, the promotion of NEVs cannot rely solely on fiscal subsidies, more efficient methods must be sought. It may be more appropriate to focus on public green advocacy, industry management, improvement of charging infrastructure, and support for corporate technological innovation.

Second, it is crucial to reduce the excessive dependence on fiscal subsidies and enhance the technological innovation capabilities of domestic brands. According to the heterogeneity analysis results, fiscal subsidy policies do not enable domestic new energy vehicles to withstand the impact of the COVID-19 pandemic. Under the strong impact of foreign-owned enterprises like Tesla, even with fiscal and tax incentives, the advantages of domestic new energy vehicles are precarious. Over-reliance on fiscal subsidies is a significant reason why domestic new energy vehicles struggle to form resilience. From this perspective, we believe that the government's fiscal subsidy policies should gradually phase out or even be withdrawn, and enhancing technological innovation capabilities is undoubtedly key to the rise of domestic new energy vehicles.

We have examined the resilience-enhancing effect of fiscal subsidy policies on NEV consumption in Shanghai as a case study. It is important to note that the focus on Shanghai limits the generalizability of our study. In addition to fiscal subsidies, the government has implemented policies such as providing free dedicated license plates, exempting vehicle purchase tax, relaxing vehicle restrictions, and building charging infrastructure during the promotion of new energy vehicles. The impact of the interaction of these policies on the consumption resilience of new energy vehicles remains an important issue to be explored. As data availability improves and the research sample can be expanded to all cities nationwide and refined to each car series, future studies on the relationship between fiscal subsidies and new energy vehicle consumption are expected to increase.

### Author contributions

XL and LS wrote the main manuscript text. GL reviewed the manuscript.

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### Availability of data and materials

The data can be available on request.

## Declarations

### Ethics approval and consent to participate

Not applicable.

### Competing interests

The authors declare no competing interests.

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