Study on the impact of online car-hailing services on urban air pollution

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Abstract: *Online car-hailing service is an emerging mode of transportation, which has been widely concerned by the public since its popularity. The motor vehicle travel mode represented by online car booking is developed based on the background of shared travel, and its original intention is to improve the use of vehicles through efficient matching, thereby reducing energy consumption and vehicle exhaust emissions. However, with the popularity of ride-hailing, people who used to travel by bus, foot and bicycle are turning to ride-hailing, which may increase fuel consumption and carbon emissions. Whether the online car-hailing service alleviates or intensifies environmental pollution has become a major practical issue that needs to be solved. Based on this, this paper selects the panel data of 151 cities at or above the prefecture level in China from 2008 to 2016, takes the entry of online car-hailing services as a quasi-natural experiment, takes the cities with Online car-hailing services as the experimental group, and the cities without online car hailing services as the control group. The net effect of the entry of online car-hailing services on urban air pollution level was investigated empirically by using the Difference-in-Differences method, and a series of robustness tests were conducted. According to the conclusions, the corresponding policy recommendations are put forward. The findings are as follows: (1) Compared with cities without ride-hailing services, the PM2.5 surface concentration in cities with ride-hailing services decreased by 3.3% on average; (2) A series of subsequent robustness tests supported the conclusion that there was a causal effect between online car-hailing services and reduced air pollution levels; This paper has enriched the relevant research on online car-hailing services and environmental pollution, and provided environmental evidence for the assessment of economic and social benefits of online car-hailing services from the perspective of air pollution.*

Keywords: *Online car-hailing services; Difference-in-Differences method; Air pollution*

1. Introduction

Online car-hailing services are developed from shared travel, and its original intention is to improve vehicle utilization through efficient matching, thereby reducing energy consumption and exhaust emissions. However, with the popularity of online car-hailing, people who used to travel by bus, on foot and bicycle are turning to online car-hailing, which may increase fuel consumption and carbon emissions. There is a great debate on the impact of motor vehicle travel, represented by online car-hailing, on urban air quality, which has attracted the attention of relevant government departments and scholars. The voice in support of online car-hailing services said that the introduction of online car-hailing has reduced urban energy consumption and gas emissions, for example, Liu Xiaoming, Vice Minister of Transport, once issued the "*Guiding Opinions on Deepening reform and Promoting the Healthy Development of the Taxi Industry*" in The General Office of the State Council, clearly stated that in order to promote the development of the sharing economy and facilitate public travel, to alleviate urban traffic congestion and improve air pollution, the people's government should support private minibus sharing. Yang Chuantang, Minister of Transport, said at a press conference held at the Fourth Session of the 12th National People's Congress that free and mutual aid rides and carpooling during traffic commutes are a form of travel under the sharing economy, which is conducive to the alleviation of urban traffic congestion and the improvement of air quality. Those who oppose online car-hailing say it exacerbates traffic congestion and worsens air pollution. For example, according to foreign media reports, the nonprofit Union of Concerned Scientists released a survey showing that the entry of online car-hailing services has increased carbon emissions. These new forms of travel cause more pollution than private cars, and can even lead citizens away from public transport. Whether the impact of online car-hailing services on air quality is "good" or "bad" has become a major practical issue that needs to be solved. Based on this, this paper will analyze the impact of online car-hailing services on the environment, which will help establish an analytical framework for the evaluation of the effect of online car-hailing services, an emerging mode of

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travel, and empirically-test the environmental impact of online car-hailing services.

This paper selects the panel data of 151 cities at or above the prefecture level in China from 2008 to 2016, takes the entry of online ride-hailing services as a quasi-natural experiment, takes the cities with online car-hailing services as the experimental group, and the cities without online car-hailing services as the control group, and uses the Difference-in-Differences method to investigate the net effect of the entry of online car-hailing services on urban air pollution. A series of robustness tests were carried out.

2. Research design

2.1 Research sample selection

This paper selects 151 cities at prefecture level and above in southern provinces as the research object. The data of Taiwan (China), Hong Kong (China), Macao (China) and other regions are not available, and the data of Sansha, Tongren, Lhasa, Bijie, Anshun, Liupanshui, Beihai and other cities are missing more values, so the above cities are excluded. Considering the promotion scope of online car-hailing services, this paper takes 2008-2016 as a time period to study the impact of online car-hailing on air pollution. Through local news reports and Baidu search and other Internet channels to obtain the entry information of online car-hailing service, and the city with online car-hailing service into as the experimental group, the city without online car-hailing service into as the control group. There were 79 cities with online car-hailing service before 2015 and 72 cities without online car-hailing service after 2015.

2.2 Metrological model setting

At present, there are many online car service platform companies, such as Uber, Laifu car, Didi travel, Caocao travel, Shouqi online car-hailing and so on. Uber dominates abroad, while Didi Chuxing dominates in China. As the leader of online car-hailing services, Didi Chuxing's arrival time in different cities is different, which provides good conditions for us to establish a natural experiment to examine the causal relationship between the arrival of online car-hailing services in cities and changes in urban air pollution levels.

In 2014, Didi began to land in some large Chinese cities, such as Beijing, Shanghai, Shenzhen, Hangzhou and other cities. With the strong capital support of Tencent, it rose strongly and quickly entered the mainstream. In 2015, Didi private car accounted for a large proportion of China's private car market share, which is enough to represent the Chinese situation of online car-hailing services entering cities. This year, Didi Chuxing developed rapidly, with a large number of online cities, and quickly landed in Fuzhou, Wuhan, Changsha, Sanya, Hefei and many other cities. The entry of "Didi Chuxing" into cities can be regarded as a "quasi-natural experiment". This paper adopts the DID model to empirically investigate the difference in air quality before and after the entry of online car-hailing services into cities. Based on the availability of data, this paper sets the research interval from 2008 to 2016, takes the cities with online car-hailing services as the quasi-" natural experiment "of the cities without online car hailing services, and uses the Difference-in-Differences method (DID) to test whether the pollutant concentration in the cities with online car-hailing services has significantly changed. The specific model is set as follows:

$$Pollution_{it} = \alpha + \beta\, TREAT_i \times T_t + \rho \sum X_{it} + u_i + \lambda_t + \varepsilon_{it} \tag{1}$$

In Equation (1), i and t represent cities and years respectively, and the model explained variable $pollution_{it}$ represents urban air pollution level, which in this paper is measured by the annual value of PM2.5 surface concentration. α represents the constant term, and the dummy variable $TREAT_i$ represents the grouping dummy variable. If city i belongs to the experimental group, then the value $TREAT_i$ is 1, otherwise the value is 0. Virtual variable T_t represents the time virtual variable. The year in which a city has the entry of online car-hailing service and the subsequent years the value is 1, otherwise, the value is 0. In this study, for years 2015 and later, T_t=1 and years before 2015 T_t=0. X_{it} represents a series of control variables. Combined with previous studies on the influencing factors of air pollution, mainly including industrial structure, industrial factors, economic development level, urban population density, urban traffic conditions, natural climate and other factors, the selection of control variables has been introduced in detail in the previous paper. At the same time, this paper adopts the bidirectional fixed effect method, where μ_i represents the urban fixed effect, which is used to control the factors that do not change with time between cities, such as the differences in geographical characteristics, climate conditions, and resource endowments. λ_t represents the time fixed effect, which controls the characteristics of the time level that do not change with the change of the city, such as the macroeconomic fluctuations of the country, the widespread trend of sulfur dioxide emission reduction across the country, etc. ε_{it} is represented as a classical random error term. In order to control potential heteroscedasticity and sequence correlation problems, this paper clusters standard errors to the city level.

Interaction item $TREAT_i \times T_t$ is an important core explanatory variable in this paper, which mainly describes the effect of the entry of online car-hailing services on urban air pollution. The definition of the interaction term automatically generates the double difference between the experimental group cities and the control group cities, as well as the double differences between the network online car-hailing service before and after entering the city. β is a difference in difference statistic that captures the net effect of the entry of online car-hailing services on air pollution levels. If β<0 and is significant, it indicates that the entry of online car-hailing services can significantly reduce air pollution levels; If β > 0 and is significant, it indicates that the entry of online car-hailing services significantly increases air pollution levels; If β is not significant, it indicates that the effect of the entry of ride-hailing services on air pollution is not obvious.

2.3 Selection and description of variables

2.3.1 Selection of explained variables

Air quality proxy variables usually include comprehensive indicators, emission indicators and concentration indicators. Considering the limitation of the research interval and the availability of data, this paper chooses $PM_{2.5}$ as the proxy variable of air pollution level.

2.3.2 Selection of core explanatory variables

The core explanatory variable ($TREAT_i \times T_t$) is the interaction of the group dummy variable ($TREAT_i$) and the time dummy variable (T_t), which reflects the net effect of the introduction of online car-hailing services on air pollution. Grouping dummy variable ($TREAT_i$) takes 1 for cities entered by online car-hailing services (experimental group) and 0 for cities entered by no online car-hailing services (control group). The time dummy variable (T_t) is 1 in the year in which an online car-hailing service enters a city and in subsequent years; otherwise, it is 0.

2.3.3 Control the selection of variables

Although the research objective of this paper is the impact of the entry of online car-hailing services on air quality in pilot cities, it is still necessary to consider other factors affecting air quality, which should be excluded in the empirical study to obtain the real causal relationship between core explanatory variables and urban air quality. The influencing factors of urban air pollution are very complex, which can be divided into natural factors and social economic factors. Based on the research in this paper, social and economic factors generally include industrial structure, industrial factors, economic development level, urban population density, urban traffic conditions, urban industrial structure, environmental regulations and other factors, while natural factors generally include meteorological conditions such as average temperature and precipitation.

Urban industrial structure: Industrial structure is an important factor affecting air pollution, especially the secondary industry dominated by industry is the main cause of serious environmental pollution. The higher the proportion of the secondary industry in the industrial structure is, the more serious air pollution

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tends to be[1]. In this paper, the proportion of the added value of the secondary industry in the GDP of the city is selected as the index of industrial structure, and the influence of industrial structure on urban air quality is discussed.

Economic development level: Many empirical studies and theories show that the relationship between economic development level and environmental pollution presents an "inverted U" shape, that is, the environmental Kuznets curve. Scholars have different opinions on whether the environmental Kuznets curve exists. This paper considers the first monomial per capita GDP and the second power of per capita GDP to test whether there is a Kuznets curve of environmental pollution at the urban level in China during the sample time of this study.

Industrial factors: This paper mainly empirically examines the impact of online car-hailing services on the emission of air pollutants. Considering that industrial pollution is an important source of air pollution, based on the availability of existing data, three industrial factor indicators, namely the total amount of industrial wastewater discharge, the total amount of industrial smoke and dust discharge and the total amount of industrial SO2 discharge, are selected.

Urban population factors: human activities and agglomeration generally affect urban air quality to a certain extent. In this paper, population density index is selected to represent the influence of urban population agglomeration degree on urban air quality.

Urban traffic conditions: Transportation is one of the most critical factors causing air pollution. Combined with the research theme of this paper and referring to relevant references[2,3,4,5], the number of buses, taxis, private car ownership, per capita road area and the opening of urban subway are adopted as control variable indicators in terms of traffic, in which the opening or not of urban subway is represented by virtual variable. The value is 1 in the year in which a city's subway is opened and in subsequent years; otherwise, it is 0.

Natural factors: Urban air quality is also affected by natural climate factors. This paper selected two meteorological indicators, temperature and precipitation, to control the influence of different natural climate factors on air pollutants. In terms of natural meteorological factors, this paper chooses annual average temperature and wind speed, because the rise of temperature helps to reduce the degree of air pollution, while wind has the effect of dissipating air pollutants.

Table 1: Variable selection

Variable name	Variable abbreviation	Variable meaning
Fine particle concentration	$PM_{2.5}$	Urban air pollution levels
Grouping dummy variable	TREAT	Cities with online car-hailing services take 1, otherwise take 0
Time dummy variable	T	It was 0 in 2008-2014 and 1 in 2015-2016
Core explanatory variable	TREAT*T	The net effect of the entry of ride-hailing services on urban air pollution
Total industrial emissions of SO_2	SO_2	Industrial factor
Total industrial smoke and dust emissions	yfc	
Total industrial wastewater discharge	gyfs	
Value added of the secondary industry as a share of GDP	errchan	Urban industrial structure
Urban population density	pop	Urban population factor
Urban private car ownership	car	Urban traffic condition
Number of buses in the city	bus	
Number of taxis in the city	taxi	
City subway	rail	
Urban GDP per capita	pergdppp	Economic development level
Urban per capita GDP squared	$pergdppp^2$	
Average annual temperature of the city	tem	Natural factor
Urban mean wind speed	wind	

The air pollutant index $PM_{2.5}$ from 2008 to 2016 used in this paper comes from the environmental database in the China Research Data Service Platform, and the fine particulate matter data in this database comes from the grid data of the global average fine particulate matter concentration published by the Center for Socioeconomic Data and Applications of Columbia University in the United States [6]. Then ArcGIS software was used to analyze the raster data into the average annual concentration data of fine particulate matter in the administrative areas of all cities in China. The annual data of other socio-

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economic indicators came from China City Statistical Yearbook, EPS Database, China Economic Database (CEIC database), China Research Data Service Platform (CNDS), provincial and municipal statistical yearbooks and bulletins. The missing values of some variable indicators were filled with linear interpolation and exponential smoothing methods. The meteorological index data came from the National Greenhouse Data System, NOAA, China's Economic and Social Big Data Research Platform, and EPS database. Table 1 shows the main variables and descriptive statistics.

3. Empirical analysis

3.1 Baseline regression analysis

Table 2 shows the basic regression results of the impact of the entry of online car-hailing services on air pollution levels.

Table 2: Baseline regression result

	(1)	(2)
VARIABLES	$lnPM_{2.5}$	$lnPM_{2.5}$
TREAT×T	-0.029*	-0.033**
	(-1.68)	(-2.01)
lncar		-0.019*
		(-1.83)
lnbus		-0.004
		(-0.39)
lntaxi		-0.016
		(-1.24)
rail		-0.009
		(-0.46)
$lnso_2$		0.009*
		(1.97)
lnyfc		0.013***
		(3.04)
lngyfs		0.012*
		(1.75)
lnerchan		0.008
		(0.24)
lnpop		-0.136*
		(-1.69)
lnpergdppp		-0.187
		(-1.26)
$lnpergdppp^2$		0.015*
		(1.96)
lntem		-0.273**
		(-2.16)
wind		-0.103***
		(-3.78)
Control variable	No	Yes
Constant term	3.630***	5.926***
	(724.85)	(6.43)
Urban fixed effect	Yes	Yes
Time fixed effect	Yes	Yes
Number of observations	1,359	1,359
R-squared	0.465	0.505

Note: *** means significant at the 1% level, ** means significant at the 5% level, * means significant at the 10% level: Cluster heteroscedasticity robust standard error in parentheses.

Among them, the dependent variable of the model in Columns (1) to (2) of Table 2 is the logarithm of the average annual concentration value of $PM_{2.5}$. Column (1) of Table 2 lists the regression results without adding control variables, and Column (2) lists the regression results after adding control variables. In the model without control variables, the coefficient value of the core explanatory variable is -0.029, and is significant at the level of 10%. After adding control variables, the coefficient value of the core explanatory variable was -0.033, which is statistically significant at the 5% level. According to the coefficient of Model (2), the entry of online car-hailing services significantly reduces the urban air pollution level of the corresponding cities by about 3.3%, which indicates that the entry of online car-hailing services can effectively improve urban air pollution.

From the perspective of other control variables, based on the double fixed effect model in Column (2) of Table 2, this paper finds that the square term of per capita GDP is significantly positive, while the first term is not significantly negative, indicating that there is no environmental Kuznets hypothesis effect in China during the selected sample period, which is similar to the research conclusion of Shao Shuai et al. [7]. The proportion of secondary industry has a negative impact on air pollution, but it is not significant, which may be because the sample cities selected in this study are all southern cities, and the industry in southern China is relatively underdeveloped. The estimated coefficient of population density is significantly negative at the level of 10%, indicating that the improvement of population concentration is conducive to the improvement of air quality, which is consistent with the research results of Lu Ming and Feng Hao [8]. From the analysis of industrial pollution factors, the coefficients of industrial wastewater, industrial sulfur dioxide, industrial smoke and dust are significantly positive, which is basically consistent with common sense in life. From the perspective of traffic factors, only the estimated coefficient of private car ownership passes the significance test. Private car ownership has a significant negative impact on the concentration of fine particulate matter, which is consistent with the conclusion obtained by Guo et al. [9]. In addition, the impact of natural factors such as meteorological factors on urban air quality cannot be ignored. Wind speed will significantly affect urban air quality, because the greater the wind speed is, the more conducive to the diffusion of pollutants in the air is, so the concentration of pollutants will become lower.

3.2 Parallel trend test

In general, if the two groups of samples have the same time trend before the experiment, the DID model can be used for statistical inference of causal effect; otherwise, DID method is not applicable for estimation.

Combined with the research theme of this paper, the parallel trend hypothesis is that there is no systematic difference in the trend of air pollution level between cities with and without online car-hailing services before the introduction of online car-hailing services. That is to say, before online car-hailing services enter the city, the experimental city and the control group have a common trend in air pollution level. Therefore, it can be considered that a city without online car-hailing service is a suitable control group for a city with online car-hailing service, and it is guaranteed that the DID model extracts the policy causal effect. In order to test this common trend hypothesis, we refer to the "Event Study" used by Cai et al., Shao et al. [10,11,12] and other scholars in their studies, which can deeply test the common trend hypothesis of DID model in the form of regression and obtain robust results. The measurement model is constructed as follows:

$$\begin{aligned} ln\,PM_{2.5} &= \alpha + \beta\, TREAT_i \times T_t + ln\,so_2 + lnyfc + lngyfs + lnerrchan + lnpop + lncar \\ &+ lnbus + lntaxi + rail + lnpergdppp + lnpergdppp^2 + lntem + wind + u_i + \lambda_t + \varepsilon_{it} \end{aligned} \tag{2}$$

Equation (2) represents the interaction term between the time dummy variable and the grouping dummy variable for each year from 2008 to 2014, which represents the difference in fine particulate matter concentration between the two groups of cities in each year before the online car-hailing service entered the city. If the coefficient of this interaction term is significant, it indicates that there is a certain relationship between the experimental cities and the air pollution level before the entry of the online car-hailing service, indicating that the parallel trend test is not passed. Conversely, the parallel trend hypothesis holds.

Equation 2 is established on the basis of the previous baseline regression model, in which the explanatory variable of the model $lnPM_{2.5}$ represents the urban air pollution level, which in this paper is measured by the value of the annual value of the surface concentration of $PM_{2.5}$. α represents the constant term, dummy variable $TREAT_i$ represents the grouping dummy variable. If city *i* belongs to the experimental group, the value $TREAT_i$ is 1; otherwise, the value is 0; the virtual variable T_t is the time virtual variable; the year in which a city has an online car-hailing service entering and the subsequent years is 1; otherwise, the value is 0. In this study, for years 2015 and later, T_t=1 and years before 2015, T_t=0. Interaction item $TREAT_i \times T_t$ is an important core explanatory variable in this

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paper, which mainly describes the effect of the entry of online car-hailing services on urban air pollution. The definition of the interaction term automatically generates the experimental group cities and the control group cities, as well as the double difference between the online car-hailing service before and after entering the city. β is a difference in difference statistic that captures the net effect of the entry of online car-hailing services on air pollution levels. If β<0 and is significant, it indicates that the entry of online car-hailing services can significantly reduce air pollution levels; If β > 0 and is significant, it indicates that the entry of online car-hailing services significantly increases air pollution levels; If β is not significant, it indicates that the effect of the entry of online car-hailing services on air pollution is not obvious.

μ_i stands for urban fixed effect, which is used to control factors that do not change over time between cities, such as differences in geographical characteristics, climate conditions, and resource endowments. λ_t represents the time fixed effect, which controls the characteristics of the time level that do not change with the change of the cities, such as the macroeconomic fluctuations of the country, the nationwide widespread sulfur dioxide emission reduction trend, etc. ε_{it} is a classical random error term, and the control variables in the model include $lnso_2$, *lnyfc, lngyfs, lnerrchan, lnpop, lncar, lnbus, lntaxi, rail, lnpergdppp,* $lnpergdppp^2$*, lntem, wind*, etc. $lnso_2$ represents the logarithm of the total industrial sulfur dioxide emission, *lnyfc* represents the logarithm of the total industrial smoke and dust emission, *lngyfs* represents the logarithm of the total industrial wastewater discharge. *lnerrchan* represents the logarithm of the proportion of the added value of the secondary industry in the GDP, and *lnpop* represents the logarithm of the urban population density. *lncar* represents the logarithm of private car ownership in the city; *lnbus* represents the logarithm of the number of buses in the city; *lntaxi* represents the logarithm of the number of taxis in the city; *rail* represents whether the city has subway; *lnpergdppp* represents the logarithm of per capita GDP of the city. $lnpergdppp^2$ represents the logarithm value of the square of the per capita GDP of the city, *lntem* represents the logarithm value of the average annual temperature of the city, and *wind* represents the average wind speed of the city.

Table 3: Test results of parallel trends

	(1)	(2)
VARIABLES	$lnPM_{2.5}$	$lnPM_{2.5}$
The 7th year before the entry of online car-hailing services	0.016	0.022
	(0.84)	(1.22)
The 6th year before the entry of online car-hailing services	0.004	0.006
	(0.20)	(0.33)
The 5th year before the entry of online car-hailing services	0.007	0.009
	(0.32)	(0.41)
The 4th year before the entry of online car-hailing services	0.004	0.011
	(0.21)	(0.59)
The 3rd year before the entry of online car-hailing services	-0.018	-0.011
	(-0.69)	(-0.45)
The 2nd year before the entry of online car-hailing services	0.002	0.007
	(0.11)	(0.41)
The first year before the entry of online car-hailing services	0.009	0.011
	(0.51)	(0.66)
Control variable	No	Yes
Constant term	3.622***	5.940***
	(333.35)	(6.28)
Urban fixed effect	Yes	Yes
Urban fixed effect	Yes	Yes
Number of observations	1,359	1,359
R-squared	0.464	0.503

Note: *** means significant at the 1% level, ** means significant at the 5% level, * means significant at the 10% level: Cluster heteroscedasticity robust standard error in parentheses.

According to the regression results in Table 3, the interaction coefficients of the grouped virtual variables in the column and the time of the virtual variables in each year before the entry of the online car-hailing service are not significant, which indicates that the air quality change trend of the cities in the experimental group and the cities in the control group is consistent before the entry of the online car-hailing service. Therefore, this paper satisfies the parallel trend assumption of the DID model.

3.3 Robustness test

3.3.1 Placebo test

In this paper, the placebo test is used to analyze the impact of missing variables, trying to prove that in the study design of this paper, the missing variables problem is not serious, and will not pose a major threat to the main estimation results of this paper.

In order to exclude the possibility that the emission reduction effect of online car-hailing services is disturbed by missing variables, and to ensure that the change of urban air quality is indeed caused by the entry of online car-hailing services, this paper takes reference from the practice of Shen Kunrong and Jin Gang, Zhang Hua and Song Hong et al. [13, 14, 15], and conducts placebo test by randomly selecting cities with online car-hailing services. Specifically, 79 cities were randomly selected from 151 cities as the control group and other cities as the treatment group, and a "virtual artificial setting" treatment variable $TREAT_i^{false}$ was constructed. Using the setting in the benchmark regression model, the air pollution index was repeated for 1000 times, and the regression coefficient and P-value distribution of the treatment variable A in the simulation experiment were respectively shown in Figure 1. In the equation taking the concentration of fine particulate matter as the air pollution index, the regression coefficients estimated based on random samples are mostly concentrated near the zero point. Further calculation shows that the mean values of the regression coefficients in the simulation are -0.00078 respectively, while the benchmark regression coefficient in this paper is -0.033, which is greater than most of the simulated values. From the point of view of p-value, among 1000 simulations, 79 estimates are less than -0.033 and p-value is less than or equal to 0.1, which means that the regression result of this paper in this simulation is correct in 92.1% (1-79/1000) probability. We can find that the emission reduction effect of online car-hailing services is not affected by missing variables at least 90% of the time.

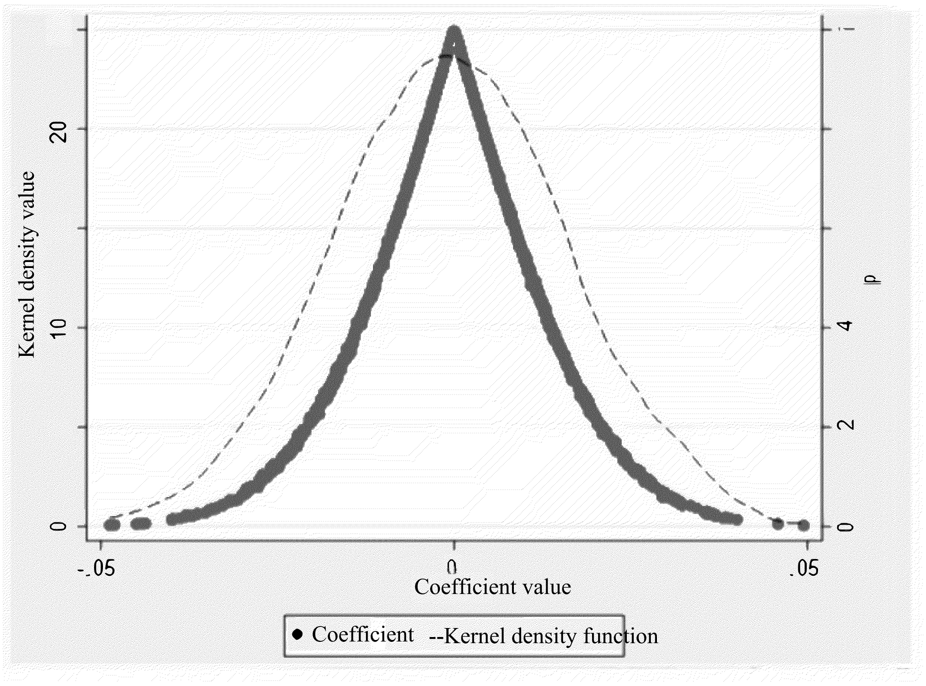

Figure 1: Fine particulate regression coefficient nuclear density distribution (1000 simulations)

From the simulation experiment, it is found that the mean value of 1000 regression coefficients is not significantly different from 0, so it can be concluded that there is no inconsistency of regression coefficients caused by missing variables in the process of model establishment. The construction of the DID model in this paper is appropriate, and the influencing factors have been controlled as much as possible in the model construction, so as to weaken the endogeneity problem caused by missing variables. Therefore, the estimation results obtained by our DID model based on the two-way fixed effect are reliable and robust.

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3.3.2 Robustness test based on propensity score matching—Difference-in-difference method (PSM-DID)

Online car-hailing services may selectively enter cities in the process of promotion, resulting in systematic differences in sample cities. To eliminate this systematic difference, a control group with characteristics as similar as possible to the experimental group should be selected. Therefore, the PSM-DID method, which combines propensity score matching and difference-in-difference method, is used to test the robustness of the results obtained by the difference-in-difference method.

Based on the experimental group and the control group after PSM treatment, the impact of online car-hailing services on urban air quality was empirically analyzed, and the test results were shown in Table 4.

Table 4: Robustness testing based on PSM-DID

	(1)	(2)
VARIABLES	$\ln PM_{2.5}$	$\ln PM_{2.5}$
TREAT×T	-0.0418**	-0.0422**
	(-2.298)	(-2.447)
Constant	3.6093***	5.8027***
	(710.532)	(6.139)
Control variable	No	Yes
Urban fixed effect	Yes	Yes
Time-fixed effect	Yes	Yes
Number of observations	1,227	1,227
R-squared	0.467	0.501

Note: *** means significant at the 1% level, ** means significant at the 5% level, * means significant at the 10% level: Cluster heteroscedasticity robust standard error in parentheses.

From Columns (1) and (2) of Table 4, it can be found that, regardless of whether control variables are added, the differential coefficients between the entry of online car-hailing services and the entry of online car-hailing services are significantly negative, and the obtained results have no essential difference from the regression results in Table 2, indicating that online car-hailing services have indeed improved urban air quality after entering the experimental cities.

3.4 Discussion

In summary, our results show that the arrival of online car-hailing services in some cities has a significant negative impact on air pollution levels. Compared with cities without online car-hailing services, the surface concentration of $PM_{2.5}$ in cities with online car-hailing services is reduced by 3.3% on average, bringing environmental dividends to the cities. As a part of urban vehicle rental services, online car-hailing service has an important impact on the urban environment. Why do online car-hailing services help improve air quality? Online car-hailing service is regarded as an emerging mode of travel, which has been widely concerned by the public since its popularity. The motor vehicle travel mode represented by online car-hailing is developed based on the background of shared travel, and its original intention is to improve the utilization rate of vehicles through efficient matching. The positive impact of online car-hailing services is generally concentrated in areas such as carpooling and sharing. Online car-sharing is an innovative way to travel that can protect the environment, so it has been favored by many consumers. Sometimes referred to as "carpooling," "hitch," or "car sharing," ride-sharing reduces travel costs, reduces idling time and miles traveled by drivers, improves the utilization of transportation resources, and thus alleviates traffic congestion and environmental pollution. Under the premise of not increasing the load of urban vehicles, sharing makes full use of the energy consumption of the same vehicle and the service time of the same express driver, meeting the travel needs of multiple passengers in the same period of time. The urban emission reduction effect brought about by online car-hailing services is the embodiment of urban ride-sharing forms, so the entry of online car hailing services contributes to the improvement of urban air pollution levels.

4. Conclusion

This paper selects the panel data of 151 prefectural level and above in southern provinces from 2008 to 2016, takes the entry of online car-hailing services as an exogenous policy impact, and establishes a DID model to investigate the net impact of the entry of online car-hailing services on urban air pollution. The research found that the entry of online car-hailing services did improve air quality in cities. On the

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one hand, the research results can enrich the theoretical connotation of the social impact of the sharing economy, and on the other hand, it can provide references for government departments to formulate environmental protection policies and related policies of online car-hailing services.

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