

## Research Article

# Motorcycle Ban and Traffic Safety: Evidence from a Quasi-Experiment at Zhejiang, China

Jingjing Chen <sup>1</sup>, Qian Wang <sup>1</sup> and Jie Huang <sup>2</sup>

<sup>1</sup>School of Economics, Hangzhou Normal University, Hangzhou 311121, China

<sup>2</sup>School of Public Affairs, Zhejiang University, Hangzhou 310012, China

Correspondence should be addressed to Jingjing Chen; 16502233@qq.com

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Motorcycle bans have been implemented in many cities across China for long time, one of the main reasons for which is the high death rate of the traffic accidents related to motorcycles' fast speed and weak safety. This study applies a quasi-experiment on whether or not and when motorcycle bans are implemented in the 11 prefecture cities in Zhejiang Province, taking the prefecture-level cities with motorcycle bans as the experimental group and the others as the control group, so as to identify whether such bans can effectively reduce the number of traffic accidents and deaths, as well as the related internal mechanism. This study concludes that the effect of the motorcycle bans on reducing the number of traffic accident deaths is significant, and their impact does not decrease over time due to the diversity of policies. Further, the mechanism analysis shows that the motorcycle bans have not only reduced the number of motorcycles and thus may improve the traffic safety but also diminished the traffic accidents by reducing the fatality rate. Finally, this study proposes to optimize the motorcycle bans by planning special lanes and strengthening motorcycle management.

## 1. Introduction

Under a series of traffic safety regulations enacted by the state, the level of road traffic safety has been continuously improved, as shown in the continuous decline of road traffic accidents over recent years. By 2019, the number of road traffic accidents had dropped to 247,646 from 773,137 in 2002, decreased by 67.96%; the casualties had fallen by 52.51% from 671,455 to 318,864; and direct economic losses had fallen from 3,088 to 1,346 million yuan, decreased by 56.40%. However, it is clear that traffic accidents still cause a large number of casualties and huge property losses, so road traffic accidents are an important public safety issue and a main cause of deaths and injuries worldwide [1]. The risk of personnel, vehicles, and road environment has become the most important factors for deaths in China [2].

As a transport tool with the convenient, fast, and low-cost characteristics, motorcycles have entered tens of millions of families in China. Although motorcycles bring convenience for people to travel, a series of problems related

to motorcycles are becoming more and more serious, for example: illegally operating motorcycles, soliciting passengers at will, ignoring traffic orders to compete for business, and disrupting the normal operation of public transport and the road traffic order. As a result, the safety problems caused by motorcycles are on debate frequently since the increasing traffic accidents and high death rates are related to motorcycles. The proportion of motorcycle-related traffic accidents in all traffic accidents (in terms of times, deaths, injuries, and property losses) had been on the rise until 2000, and the motorcycle-related deaths rate per 100 accidents reached 35 persons in 1996, which is much higher than the average. With the implementation of the motorcycle bans since early 1990s, the proportion of motorcycle-related accidents and the deaths per 100 accidents began to decrease.

Therefore, in order to alleviate the traffic safety problems caused by motorcycles, some local governments have formulated relevant regulations to restrict or prohibit motorcycles from being registered with license plates and running in certain prescribed areas or the whole urban roads. As the

motorcycle bans impair part of the road rights of motorcycle owners to some extent, there are many studies on such regulations' legitimacy [3]; meanwhile, there are statistics on the improvement of traffic safety after implementation of the motorcycle bans, as shown in many local governments' reports. However, there is still a lack of research on the causal relationship between such bans and traffic safety. This study intends to use a quasi-natural experiment in Zhejiang Province to discuss their impact on traffic accidents and make an in-depth analysis of its internal mechanism, by taking the 4 prefecture-level cities with motorcycle bans (Hangzhou, Ningbo, Shaoxing, and Wenzhou) as the experimental group and the others as the control group. It may provide a theoretical basis for the formulation of relevant traffic safety laws and regulations in the future.

## 2. Literature Review

It has long attracted the attention of the government and academia, and the study on the impact factors of traffic accidents is the focus of many research studies.

One of the branches is about how to assess the direct loss of traffic accidents. It is well known that people are most related to the direct property loss in traffic accidents. Oyetubo et al. [4] found that road traffic accidents are the most important cause of death, leading to many premature deaths and delivering great losses. But traffic accident losses are not caused by a single factor, and such accidents are often the result of a combination of multiple factors [5].

Based on the data from 1997 to 2016 and the VAR model, Sun and Yang [6] found that the total national income has an inhibitory effect on the number of traffic accident related deaths, while the increase in the grade highway mileage and the number of motor vehicle drivers would boost the death rate of traffic accidents. By using panel data of traffic-related indicators from 2004 to 2015, Sun et al. [7] discovered a significant correlation among car ownership, traffic accident deaths, traffic investment, urban population, and direct property losses of traffic accidents in China; especially, car ownership and urban population are positively correlated with direct property losses. This finding is consistent with some former literatures, such as research studies by Wu et al. [8], Dai [9], and Gao [10]. Furthermore, Ma et al. [11] made a regression analysis on the correlation between motorization level and traffic safety indicators in China from 1952 to 2009, finding that, with the improved motorization level, the death rate per 10,000 vehicles in China had continued to decline, but the rate of decline slowed down gradually. Huang et al. [12] demonstrates that the increased motor vehicle ownership is positively correlated with the number of traffic deaths, i.e., the increase in car ownership will lead to a higher number of traffic deaths, thus affecting the direct property losses from traffic accidents. Some scholars have found that more income will inevitably lead to an increase in car ownership, which will result in higher traffic accident mortality and affect the long-term stable development of China's economy [13]. There are also some literatures that discussed the evolution of the intelligent traffic and their effect on traffic accidents [14, 15].

The above research is of great significance for analyzing the current situation of road traffic safety and improving the level of social governance in China. On the contrary, some studies on the motorcycle bans have discussed the rationality and legitimacy of policy formulation [3], as well as the interpretation of equality and property rights [16]. However, few studies have explored the impact of relevant laws and regulations on traffic safety. This study intends to discuss the overall impact, not just the obvious motorcycle-related accidents, and the internal mechanism of the bans in diminishing traffic accidents, especially in reducing casualties, in order to provide theoretical support for formulating traffic safety regulations in the future.

## 3. Background of Motorcycle Bans

*3.1. Motorcycle Bans in China.* Cities in China began to take measures to ban motorcycles in the early 1990s, and the first city to implement such a ban was Beijing, which began to ban motorcycles in 1985. Because of Beijing's special status as well as its political and cultural influence, many cities have followed Beijing's model. So far, a total of 185 cities across the country have joined the camp of banning motorcycles. The implementation of bans on motorcycles has covered a vast majority of large- and medium-sized cities in the country.

Primary evidence shows that the bans have improved the traffic safety. From the second half of the curve in Figure 1, it can be seen that the proportion of motorcycle-related traffic accidents has slightly decreased since 2002; but due to the time difference in the implementation of motorcycle bans by different cities, the downward trend was reversed once. However, since 2005, the numbers of both accidents and deaths/injuries have entered a stable downward channel. Furthermore, besides bans on motorcycles in cities, new requirements have been imposed on production, sales, and safety; therefore, the motorcycle-related death rate per 100 accidents has also reached a turning point. Since 2005, the number of single accident deaths related to motorcycles has become lower than that of other accidents.

On the contrary, the right-of-way of freeways, which are mainly used to connect interregional traffic, is formulated by provincial administrations. Although nationally, the "Regulation on the Implementation of the Road Traffic Safety Law of the People's Republic of China" does not explicitly prohibit motorcycles from driving on freeways, there are provisions on the speed limit for all locomotives on freeways. According to the information collected in this study, there are 19 provinces restricting or prohibiting motorcycles from driving on freeways by means of administrative norms, such as regulations or management methods, with distinct severities detailed listed in Table 1.

*3.2. The Motorcycle Bans in Zhejiang Province.* There are great differences in the time of banning motorcycles on urban roads, and only four prefecture-level cities in Zhejiang Province have announced such bans, namely, Hangzhou, Ningbo, Shaoxing, and Wenzhou. The time and content of their bans are shown in Table 2.

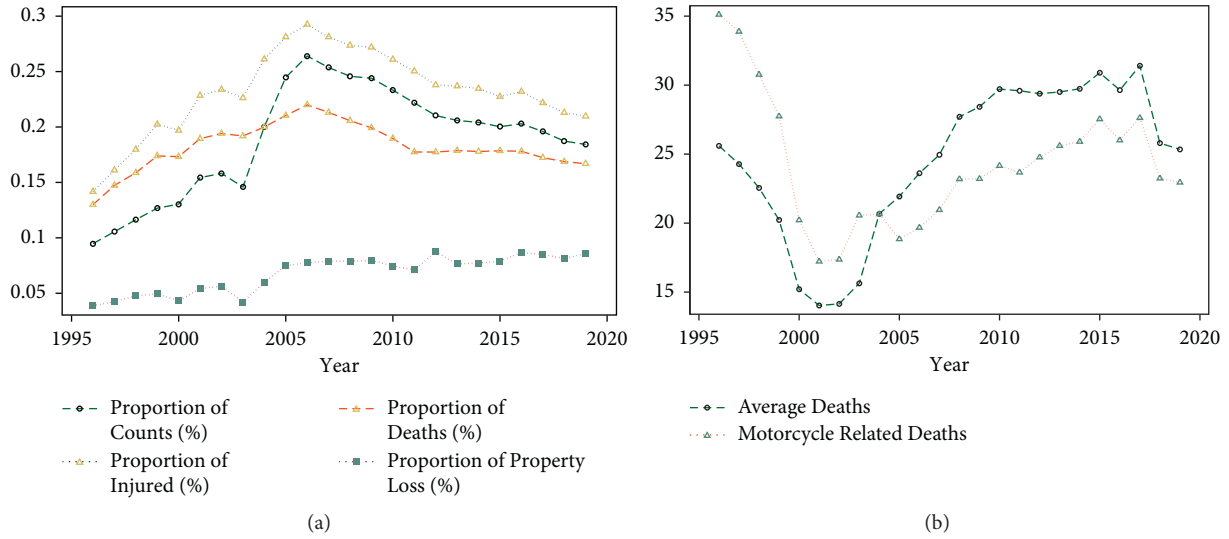


FIGURE 1: The trends of motorcycle-related traffic accidents. (a) Proportions of motorcycle-related. (b) Comparison between motorcycle-related and traffic accident average death rate per 100 accidents.

TABLE 1: Different provinces’ regulations concerning motorcycles on freeways.

Province	Regulations		
	Year	Name	Details and severity
Guangdong	1989	Interim Measures on Expressway Traffic Management of Guangdong Province	60 km per hour
Hebei	1991	Administrative Measures on Expressways of Hebei Province (for Trial Implementation)	70 km per hour
Yunnan	1998	Measures on Traffic Management of High-Grade Highways of Yunnan Province	50 km per hour
Anhui	2004	Regulations on Expressway Management of Anhui Province	70 km per hour
Guizhou	2007	Regulations on Road Traffic Safety of Guizhou Province	60 km per hour
Heilongjiang	2018	Regulations on Expressway Management of Heilongjiang Province	70 km per hour
Shandong	2000	Regulations on Expressways of Shandong Province	
Fujian	2003	Regulations on Expressway Management of Fujian Province	
Qinghai	2003	Measures for the Administration of High-Grade Highways in Qinghai Province	
Shanxi	2003	Interim Measures on Expressway Management of Shanxi Province	
Henan	2004	Regulations on Expressways of Henan Province	
Jiangxi	2009	Measures on the Implementation of the Law of “The People’s Republic of China on Road Traffic Safety” in Jiangxi Province	Make clear statement that motorcycles are prohibited on freeways
Ningxia	2013	Regulations on Road Traffic Safety of Ningxia Hui Autonomous Region	
Jiangsu	2014	Regulations on Expressways of Jiangsu Province	
Chongqing	2015	Regulations on Highway Management of Chongqing Municipality	
Shanghai	2016	Regulations on the Administration of Road Traffic of Shanghai Municipality	
Hainan	2017	Measures for Traffic Safety Management of Expressways in Hainan Province	
Zhejiang	2005	Measures for Operation and Management of Expressways in Zhejiang Province	Not only ban motorcycles on freeways, but also on expressways
Sichuan	2015	Regulations on Expressways of Sichuan Province	

TABLE 2: Regulations of motorcycles on urban roads in prefectural cities in Zhejiang Province.

City	First announcement		Latest renewal		
	Year	Content	Year	Regulations	Content
Hangzhou	2002	No new motorcycles will be permitted to be registered in the main urban area of Hangzhou, nor will motorcycles be allowed to pass	2016	Administrative Regulations on Road Traffic Safety of Hangzhou Municipality	Motorcycles are not permitted to be registered in the main districts in Hangzhou. The passage of three-wheeled motorcycles, manpower tricycles, and other vehicles prescribed by the Municipal People's Government is prohibited on the roads of the main districts of Hangzhou
			2017	Notice of the People's Government of Hangzhou Municipality on Prohibiting the Passage of Motorcycles and Manpower Tricycles on the Roads in the Urban Areas of Hangzhou	All kinds of motorcycles are prohibited on the roads of main districts
Ningbo	2010	Restricting the passage of motorcycles in some sections of the urban area	2012	Notice of Ningbo Municipal People's Government on Implementing the New Four Prohibitions of Traffic in the Central District of Ningbo	Motorcycles (except official vehicles of law enforcement departments and otherwise specified) are prohibited from passing on the roads in the central area
Wenzhou	2011	Restricting the passage of motorcycles in some sections of the urban area	2013	Notice on Further Strengthening Urban Traffic Management	No motorcycles are allowed to enter the urban area, and the license plates for motorcycles are suspended at the same time
Shaoxing	2001	(1) Motorcycles are prohibited in the first ring of the main urban area; the time and scope vary according to the registration places for motorcycle license plates (2) Motorcycle license plate registration service will no longer be provided within the main urban area			

#### 4. The Characteristics and Evolution of the Traffic Safety in Zhejiang Province

*4.1. The Evolution and Current Status of Traffic Safety in Zhejiang Province.* Traffic accidents in Zhejiang Province have experienced a reversed U-shape trend, where the peak shows up in 2002 or so (Figure 2(a)). In terms of the absolute number, from 1996 to 2002, traffic accidents increased by 179% from 22,266 to 62,085; deaths by 22.14% and injuries and property losses by more than 1.5 times. After that, accident times, death number, injury number, and property loss were all steadily and continuously declining till 2019, at decline rates of 80.82%, 57.13%, 79.19%, and 92.94%. The proportion of property losses of Zhejiang Province in the whole country exhibits the similar trend in Figure 2(b). However, the proportions of times, death number, and injury number are different, and they basically fluctuated in a small range of 7%–9% before 2015, except for a few abnormal years. After 2015, there was a sustained decline, and the proportion of all indicators had decreased to about 5% by 2019 (Figure 2(b)).

The corresponding changes can also be verified from the growth rate of Zhejiang's traffic accidents. The growth rate of Zhejiang's property loss had been higher than the national average until 2003 (Figure 3(d)), reaching the highest of 16.11% in 2003. And, the growth rates of times, deaths, and injuries in Zhejiang Province were almost

higher than the national average level before 2005 (Figures 3(a)–3(c)).

In terms of deaths and property loss per accident, there are differences between Zhejiang and the whole country. The death per accident in Zhejiang Province was almost all lower than the national average for the whole period, as shown in Figure 4, but the property loss per accident was higher than the national average before 2005; and, after maintaining the average level for five years, it has begun to decrease significantly since 2011.

*4.2. The Differences in Traffic Safety among Cities in Zhejiang Province.* The evolution of Zhejiang's traffic accidents is complicated. As mentioned above, the trends of deaths and property loss are different at the provincial level. The situation at the prefectural city level is described as follows. As shown in Figure 5, Hangzhou delivered the highest proportion of property loss in 2019, while Ningbo delivered the highest proportion of death in that year. Almost all the cities (except Zhoushan) have experienced sustained declines in terms of deaths, and the three prefectural cities with the highest decreasing degrees are Wenzhou, Quzhou, and Taizhou (at  $-4.87\%$ ,  $-4.44\%$ , and  $-3.48\%$ , respectively).

Furthermore, when the cities are divided into two groups based on the year they began to implement the motorcycle

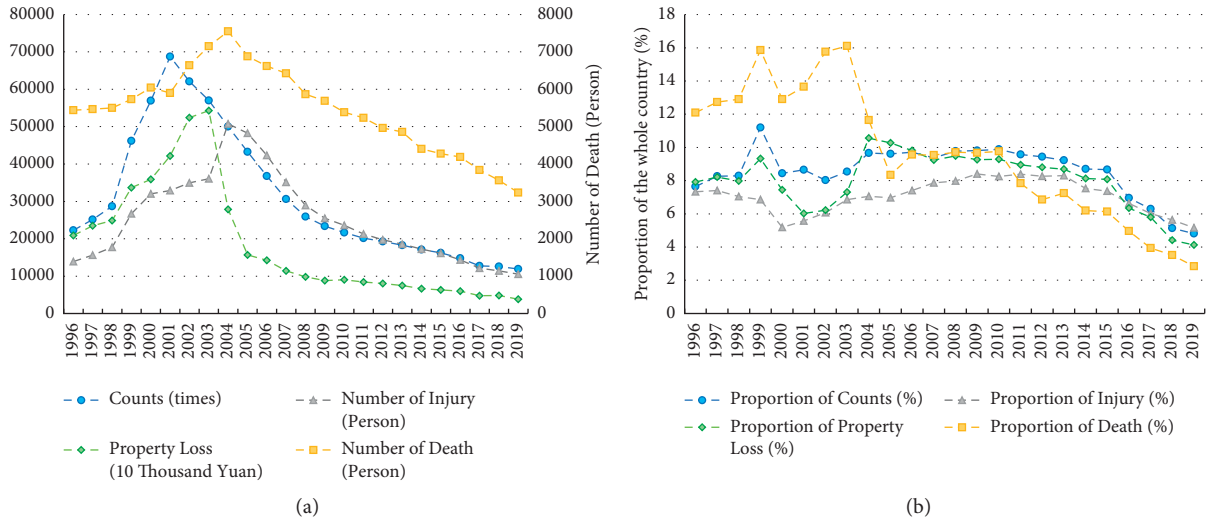


FIGURE 2: The number and proportions of traffic accidents in Zhejiang Province (1996–2019). (a) The number of traffic accidents. (b) The proportions of traffic accidents.



FIGURE 3: Comparison of the growth rate between the national average and Zhejiang Province (1997–2019). (a) Growth rate of counts. (b) Growth rate of deaths. (c) Growth rate of injuries. (d) Growth rate of property loss.

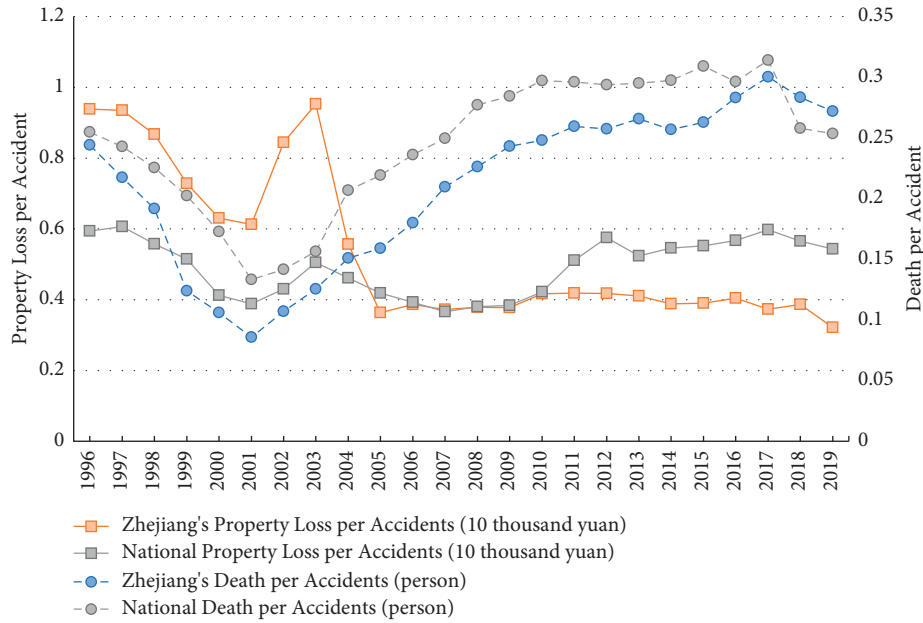


FIGURE 4: Comparison of death number and property loss per accident between the national average and Zhejiang Province.

bans, it can be found that there is a clear decline after the implementation of such bans. As shown in Figure 6(a), for the same city, all the range of the death numbers after the bans were enacted are lower than that before, intuitively indicating the effectiveness of motorcycle bans. Figure 6(b) compares the property loss across the prefectural cities, but the amounts between 2002 and 2004 for all the cities are missing due to the data limit, which lead to the missing of the exhibition of Hangzhou's status before the bans. Averagely, it can be identified that the property losses after the motorcycle bans are also less than before.

## 5. Analysis of the Effect of Motorcycle Bans on the Traffic Safety in Zhejiang Province by Using the DID Method

**5.1. The Empirical Strategy.** As shown in the above sections, there is a correlation between the decrease in death number and property loss and the implementation of motorcycle bans. This section will apply the DID (difference in difference) method to explore the casualty between the motorcycle bans and the reduction of traffic accidents. The basic empirical model is set as follows:

$$\text{Traffic Accident}_{i,t} = \alpha + \beta \text{Policy}_{i,t} + \gamma Z_{i,t} + \lambda_i + \lambda_t + \varepsilon_{i,t}, \quad (1)$$

where  $\text{Traffic Accident}_{i,t}$  implies the death number or property loss from traffic accidents in city “ $i$ ” in year “ $t$ ,” the independent variable  $\text{Policy}_{i,t}$  implies whether or not city “ $i$ ” applied a motorcycle ban in year “ $t$ ,” and  $Z_{i,t}$  are the control variables included. This study also controls the year ( $\lambda_t$ ) and city ( $\lambda_i$ ) fixed effect to reduce the possible influences of unobserved factors.

## 5.2. The Variables and Statistics

**5.2.1. The Independent and Dependent Variables.** The key independent variable ( $\text{Policy}_{i,t}$ ) is constructed according to the releasing years of motorcycle bans in 11 prefectural cities in Zhejiang Province, which are demonstrated clearly in Section 3.2. On the other side, this study constructs two dependent variables ( $ND_{i,t}$  and  $PL_{i,t}$ ) according to the death numbers and property loss of the 11 prefectural cities in Zhejiang Province during 2002–2019. The detail statistics are listed in Table 3.

**5.2.2. Control Variables.** Besides the main variables, this study also includes control variables that may influence the traffic safety as follows:

- (1) Gross value per person: measured by the natural log of the city's gross value, represented by symbol  $\ln\text{GDPP}_{i,t}$
- (2) Population: measured by the natural log of the city's population, represented by symbol  $\ln\text{Pop}_{i,t}$
- (3) Mileage of the graded highway: measured by the natural log of the mileage of the graded highways in a city, represented by symbol  $\ln\text{Highway}_{i,t}$
- (4) Number of cars owned by individuals: measured by the natural log of the number of cars registered in a city by individuals, represented by symbol  $\ln\text{Car}_{i,t}$
- (5) Area of the urban roads: measured by the natural log of the area of the urban roads, represented by symbol  $\ln\text{URoad}_{i,t}$
- (6) Freight volume on highways: measured by the natural log of freight volume divided by mileages of highways, represented by symbol  $\ln\text{FVH}_{i,t}$



FIGURE 5: The proportion of death and property loss, as well as the average growth rate of deaths for 11 cities in Zhejiang Province (2019).

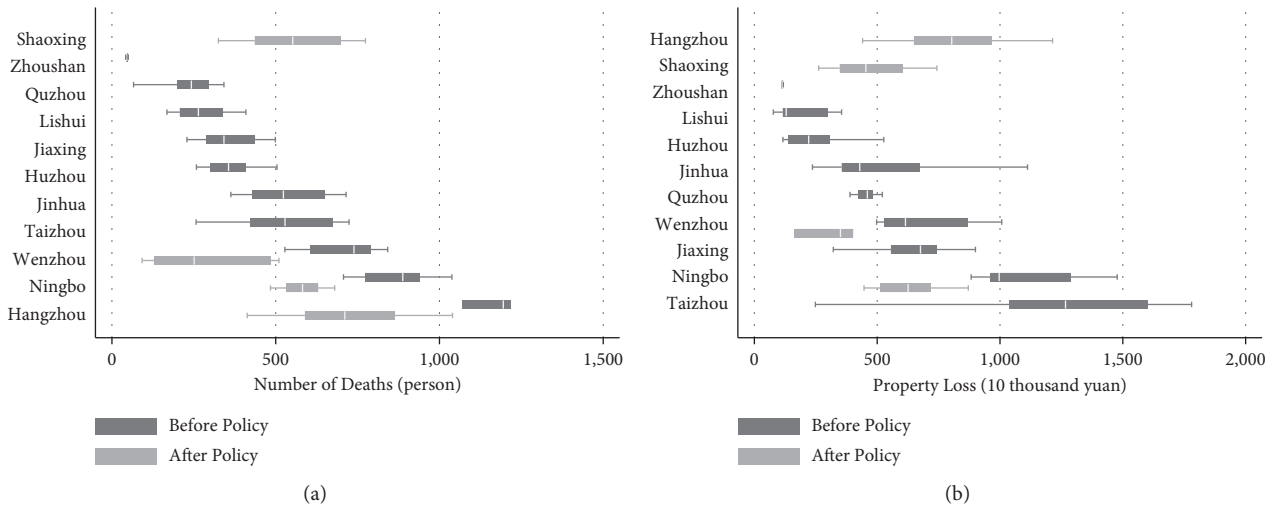


FIGURE 6: Comparison of the death number and property loss before and after the motorcycle bans in 11 cities in Zhejiang Province (2002–2019). (a) Number of deaths. (b) Property loss.

- (7) Passenger volume on highways: measured by the natural log of passenger volume divided by mileages of highways, represented by symbol  $\ln PVH_{i,t}$
- (8) Passenger volume on urban roads: measured by the natural log of passenger volume divided by the road area, represented by symbol  $\ln PVU_{i,t}$

The statistics of control variables are listed in Table 4.

5.3. *The Main Results.* The basic model can be created with two equations:

$$ND_{i,t} = \alpha + \beta Policy_{i,t} + \gamma Z_{i,t} + \lambda_i + \lambda_t + \varepsilon_{i,t}, \quad (2)$$

$$\ln PL_{i,t} = \alpha + \beta Policy_{i,t} + \gamma Z_{i,t} + \lambda_i + \lambda_t + \varepsilon_{i,t}. \quad (3)$$

The results are listed in Table 5. As can be seen, columns (1)–(3) are estimated according to equation (2). It is clearly shown that, after controlling the year and city fixed effect, the motorcycle bans are found to have delivered significantly negative effect on the death number. According to column (3), after the motorcycle bans were implemented, the death number decreased by about 137 persons on average per year. However, these bans have no significant effect on property

loss. This is understandable from the details of the motorcycle bans. As mentioned in Section 3, the regulations related to motorcycle bans are generally safety-guided. For example, the sales with helmets, compulsory annual inspection, and limited-service years would all improve the performance of motorcycles on the road to a certain extent and provide more protection to drivers when an accident happens. However, these regulations have no direct effect on preventing property loss, so it is expected that the regression results are insignificant.

As is known, motorcycle bans will be renewed before the expired date of the current versions, which may lead to weakened executive power during the periods before and after the expired date. This study includes two more variables to explore whether and how the renewal will influence the effectiveness of the bans. First, it includes another policy variable  $\text{Policy2}_{i,t}$ , which is set to 1 if year “ $t$ ” equals to or is larger than the year when the motorcycle bans is renewed in city “ $i$ ,” otherwise, it is set to 0. The results are listed in columns (1) and (2) of Table 6. It is clearly shown that the significance will decrease a lot when the policy variable is changed to  $\text{Policy2}_{i,t}$ ; furthermore, the coefficient of  $\text{Policy2}_{i,t}$  becomes insignificant when both policy variables are included. It suggests that once the motorcycle bans are implemented, they will be carried out in the same manner during the whole covering period, no matter whether or not they are renewed in the middle of the period. Second, this study constructs variable  $\text{Gap}_{i,t}$ , which is measured by the years since implementation, so as to analyze whether the effect will be weakened over time. The results, as listed in column (3), show that, instead of weakening, the bans enhance the effect over time. The negative coefficient of  $\text{Gap}_{i,t}$  in column (3) means that the death number will reduce by 13 more persons on average for each additional year from the date of implementation. It maybe due to the limited service years for each motorcycle. After the implementation of the policies, a certain number of motorcycles will be scrapped every year because they had been used for a long time, with major problems in performance and safety. Therefore, with the increase in the number of mandatory scrap of these motorcycles, the decrease of death number over time can be expected. On the contrary, neither the renewal dates nor the

implementation years have significant effect on the property losses from traffic accidents (columns (4)–(6)), which is consistent with the results before.

#### 5.4. Analysis of the Mechanism

**5.4.1. The Role of Motorcycle Numbers.** According to Section 3.2, in addition to prohibiting or restricting motorcycles from driving within the corresponding areas, the motorcycle bans also stipulate the compulsory scrapping years of motorcycles and terminate the registration and licensing of motorcycles within certain ranges. These mixed policies will curb the utilization of motorcycles in the short run and finally reduce the number of motorcycles, while improving the performance of motorcycles on road in the long run. The reduction both in the use and the number of motorcycles may have an impact on traffic safety. In order to distinguish the main channel of motorcycle bans’ effect, this study includes the number of motorcycles (expressed by symbol  $\text{RMotor}_{i,t}$  or  $\text{UMotor}_{i,t}$ ) in use to explore the mechanism. First, this study tests whether the motorcycle bans will influence the number of motorcycles in use with the following equations:

$$\ln \text{RMotor}_{i,t} = \alpha + \beta \text{Policy}_{i,t} + \gamma Z_{i,t} + \lambda_i + \lambda_t + \varepsilon_{i,t}, \quad (4)$$

$$\ln \text{UMotor}_{i,t} = \alpha + \beta \text{Policy}_{i,t} + \gamma Z_{i,t} + \lambda_i + \lambda_t + \varepsilon_{i,t}, \quad (5)$$

where  $\ln \text{RMotor}_{i,t}$  is the natural log of the number of motorcycles owned per 100 households in the rural area of city “ $i$ ” in year “ $t$ ” and  $\ln \text{UMotor}_{i,t}$  is the corresponding part in the urban area. This study finds that the bans have significantly reduced the number of motorcycles in rural areas by 39.16% on average per year, but not in urban areas (column (1) in Table 7). This may be due to the fact that, as incomes rise, more people in rural areas have replaced their motorcycles with cars since the bans’ implementation, a trend that has not been observed in urban areas. Next, this study includes the number of motorcycles in the basic regression equations to explore the exact effect of the bans on the traffic safety. The equations are as follows:

$$\text{ND}_{i,t} = \alpha + \beta \text{Policy}_{i,t} + \delta_1 \ln \text{RMotor}_{i,t} + \delta_2 \ln \text{UMotor}_{i,t} + \gamma Z_{i,t} + \lambda_i + \lambda_t + \varepsilon_{i,t}, \quad (6)$$

$$\ln \text{PL}_{i,t} = \alpha + \beta \text{Policy}_{i,t} + \delta_1 \ln \text{RMotor}_{i,t} + \delta_2 \ln \text{UMotor}_{i,t} + \gamma Z_{i,t} + \lambda_i + \lambda_t + \varepsilon_{i,t}. \quad (7)$$

As expected, there is no significant effect of the number of urban motorcycles on either the death number or the property loss (columns (4) and (5) in Table 7). However, in rural areas, the number of motorcycles does have positive effect on the deaths, which means that the more the motorcycles are registered in rural areas, the more the deaths appear in traffic accidents. Furthermore, even when the number of motorcycles is controlled, the bans still

significantly reduce the number of deaths in traffic accidents. Compared to the results in column (3) of Table 5, it can be observed that the number of deaths has been reduced from an average of 131 per year to 114. It is clear that there are two channels for the motorcycle bans to reduce the number of deaths from traffic accidents: one is by reducing the number of motorcycles, and the other is by diminishing the fatality rate of motorcycle-related accidents.



TABLE 3: The statistics of the main variables.

Variables	Symbols	Obs.	Mean	S. D.	$p1$	$p50$	$p99$
Number of deaths	$ND_{i,t}$	198	453.1768	253.1750	42	426.5	1195
Property loss	$PL_{i,t}$	158	565.1606	420.1011	106.48	463.55	1780
Motorcycle ban	$Policy_{i,t}$	198	0.2626	0.4412	0	0	1

TABLE 4: The statistics of the control variables.

Symbols	Obs.	Mean	S. D.	$p1$	$p50$	$p99$
$\lnGDPP_{i,t}$	198	17.0564	0.7794	15.0855	17.2001	18.3787
$\lnPop_{i,t}$	198	6.0399	0.6341	4.6396	6.2037	6.9327
$\lnHighway_{i,t}$	198	8.8816	0.7895	6.7105	9.0031	11.1365
$\lnCar_{i,t}$	198	12.7334	1.2803	9.4676	12.8027	14.8256
$\lnURoad_{i,t}$	177	7.6779	0.8809	5.4596	7.6672	9.1193
$\lnFVH_{i,t}$	198	0.1385	0.6402	-1.3180	0.1930	1.6859
$\lnPVH_{i,t}$	198	0.3878	0.9776	-2.6574	0.5662	2.3016
$\lnPVU_{i,t}$	176	1.9172	0.6569	0.6299	1.8578	3.2883

5.4.2. *The Heterogeneity Analysis.* Given that the number of motorcycles is a channel through which the policy works, we further explore whether the dependence on motorcycles has a heterogeneous impact on the effectiveness of the policy. A variable “MotorCar $_{i,t}$ ” is included to represent the degree of

the dependence on motorcycles. It will be set to 1 if the ratio of the number of motorcycles to that of cars in city “ $i$ ” is higher than the city level average ratio; otherwise, 0. The basic models are modified as follows:

$$ND_{i,t} = \alpha + \beta Policy_{i,t} + MotorCar_{i,t} + MotorCar_{i,t} * Policy_{i,t} + \gamma Z_{i,t} + \lambda_i + \lambda_t + \varepsilon_{i,t}, \quad (8)$$

$$\ln PL_{i,t} = \alpha + \beta Policy_{i,t} + MotorCar_{i,t} + MotorCar_{i,t} * Policy_{i,t} + \gamma Z_{i,t} + \lambda_i + \lambda_t + \varepsilon_{i,t}. \quad (9)$$

The results listed in Table 8 demonstrate that the enforcement of the ban will drive up traffic accidents if the local dependence on motorcycles is high, which maybe because the cities that rely heavily on motorcycles cannot adjust their travel patterns quickly. Therefore, the ban will result in more speeding and driving violations, thus increasing traffic accidents.

## 5.5. The Robust Test

5.5.1. *The Parallel Trend Test.* Motorcycle bans were implemented in different years by these four prefecture cities, so the parallel trend test of multiperiod DID is needed. This study includes dummy variables “Year $_{n,i,t}$ ” and “Yearn $_{i,t}$ ” to represent the intercross term of each time point and the experimental group, which will be set to 1 if the city

“ $i$ ” is among the four cities with motorcycle bans in year “ $t$ .” Due to different dates of implementation of the bans in the four cities, the dummy variables are set in the way of relative time, such as “Year $_{-1,i,t}$ ” representing 1 year before the implementing year and “Year $_{1,i,t}$ ” representing the implementing year. This study considers a 6-year window, spanning from 3 years before motorcycle bans until 2 years after. There are 6 dummy variables, including Year $_{-3,i,t}$ , Year $_{-2,i,t}$ , Year $_{-1,i,t}$ , Year $_{1,i,t}$ , Year $_{2,i,t}$ , and Year $_{3,i,t}$ . Take the dummy variable Year $_{-3,i,t}$  as an example: it will be set to 1 if “ $i$ ” equals to Hangzhou, and “ $t$ ” equals to or is larger than 2002 (the implementing year of Hangzhou is 2005); or it will be set to 1 if “ $i$ ” equals to Wenzhou, and “ $t$ ” equals to or is larger than 2008 (the implementing year of Hangzhou is 2011). Specifically, this study reports the estimated coefficients from the following regression:

$$ND_{i,t} = \alpha + \beta_1 Year_{-3,i,t} + \beta_2 Year_{-2,i,t} + \beta_3 Year_{-1,i,t} + \beta_4 Year_{1,i,t} + \beta_5 Year_{2,i,t} + \beta_6 Year_{3,i,t} + \gamma Z_{i,t} + \lambda_i + \lambda_t + \varepsilon_{i,t}. \quad (10)$$

Figure 7 plots the results at the 95% confidence intervals ( $\beta_1 - \beta_6$ ), which are adjusted for prefectural city-level clustering. As shown, the coefficients of the dummy variables are insignificantly different from zero for all the years before

motorcycle bans are implemented, with no trends shown in traffic accident deaths prior to the bans. Next, it should be noted that the death number falls down immediately since the implementing year; e.g., Year $_{2,i,t}$  is negative and

TABLE 5: The effect of the motorcycle bans on traffic accidents.

	(1) ND <sub>i,t</sub>	(2) ND <sub>i,t</sub>	(3) ND <sub>i,t</sub>	(4) lnPL <sub>i,t</sub>	(5) lnPL <sub>i,t</sub>	(6) lnPL <sub>i,t</sub>
<b>Policy<sub>i,t</sub></b>	174.4186* (92.9615)	-199.9656*** (43.3514)	-131.4144*** (34.1162)	0.3852 (0.3598)	-0.15 (0.1532)	0.1284 (0.2420)
<b>lnGDPP<sub>i,t</sub></b>			266.2070*** (75.9064)			0.2654 (0.5088)
<b>lnPop<sub>i,t</sub></b>			-35.7707 (100.8729)			-0.5261 (2.0302)
<b>lnHighway<sub>i,t</sub></b>			-18.2751 (57.5881)			0.4167 (0.6762)
<b>lnCar<sub>i,t</sub></b>			227.4016*** (57.4283)			0.7366 (0.6774)
<b>lnURoad<sub>i,t</sub></b>			22.9828 (26.5765)			-0.3879 (0.3335)
<b>lnFVH<sub>i,t</sub></b>			37.3149 (27.7563)			0.215 (0.2288)
<b>lnPVH<sub>i,t</sub></b>			-57.0696 (31.9788)			0.1579 (0.3724)
<b>lnPVU<sub>i,t</sub></b>			2.6891 (19.6725)			0.0941 (0.1346)
Year FE	No	Yes	Yes	No	Yes	Yes
City FE	No	Yes	Yes	No	Yes	Yes
Obs.	198	198	176	158	158	147
R-squared	0.0924	0.9491	0.9747	0.0283	0.6391	0.6533
F	3.52	21.28	85.47	1.146	0.958	1.115

Note. (1) Columns (1)–(3) are the results of equation (2) with different regression methods and control variables, and columns (4)–(6) are the corresponding results of equation (3); (2) all standard errors are clustered at the city level; (3) \*\*\* denotes  $p < 0.01$ , \*\* denotes  $p < 0.05$ , and \* denotes  $p < 0.10$ .

TABLE 6: The effect of renewal years and implementation years on traffic accidents.

	(1) ND <sub>i,t</sub>	(2) ND <sub>i,t</sub>	(3) ND <sub>i,t</sub>	(4) lnPL <sub>i,t</sub>	(5) lnPL <sub>i,t</sub>	(6) lnPL <sub>i,t</sub>
<b>Policy<sub>i,t</sub></b>		-130.8445** (52.4445)	-111.8730*** (31.3434)		0.1953 (0.3258)	0.1574 (0.2756)
<b>Policy2<sub>i,t</sub></b>	-64.5441 (40.6017)	-1.3176 (50.0523)		-0.0578 (0.1346)	-0.142 (0.2282)	
<b>Gap<sub>i,t</sub></b>			-15.0095*** (4.6574)			-0.0844 (0.0594)
<b>lnGDPP<sub>i,t</sub></b>	281.0779*** (74.4448)	265.7261*** (73.7577)	216.7671*** (57.9715)	0.187 (0.5456)	0.2038 (0.5535)	-0.0912 (0.6546)
<b>lnPop<sub>i,t</sub></b>	-127.5788 (134.1255)	-34.8656 (111.9098)	108.8926 (93.6053)	-0.3502 (1.8430)	-0.434 (1.9409)	0.3312 (1.5544)
<b>lnHighway<sub>i,t</sub></b>	21.0308 (56.9588)	-18.1351 (57.0968)	-57.2551 (39.9508)	0.367 (0.6011)	0.4332 (0.7004)	0.1895 (0.5001)
<b>lnCar<sub>i,t</sub></b>	216.4848*** (56.0718)	226.1850** (80.9098)	76.7828 (70.7397)	0.6321 (0.7461)	0.5781 (0.7737)	-0.2137 (0.9407)
<b>lnURoad<sub>i,t</sub></b>	26.5967 (37.5375)	22.9216 (28.6471)	2.1885 (20.6673)	-0.3927 (0.3327)	-0.4006 (0.3429)	-0.5439 (0.3933)
<b>lnFVH<sub>i,t</sub></b>	58.5326** (24.0273)	37.3814 (27.8033)	23.1232 (20.4322)	0.19 (0.1954)	0.2242 (0.2422)	0.1735 (0.1995)
<b>lnPVH<sub>i,t</sub></b>	-45.8735 (37.2978)	-56.9836 (31.5081)	-75.0113** (25.7593)	0.1402 (0.3467)	0.1649 (0.3828)	0.0133 (0.2561)
<b>lnPVU<sub>i,t</sub></b>	22.964 (22.2077)	2.4711 (17.0063)	-12.2346 (15.2524)	0.0501 (0.1523)	0.0721 (0.1386)	0.0106 (0.1808)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	176	176	176	147	147	147
R-squared	0.9681	0.9747	0.9815	0.653	0.6537	0.663
F	848.7	466.7	832.20	1.125	2.526	268.1

Note. (1) Columns (1)–(3) are the results of equation (2), including the renewal years and implementation years, and columns (4)–(6) are the corresponding results of equation (3); (2) all standard errors are clustered at the city level; (3) \*\*\* denotes  $p < 0.01$ , \*\* denotes  $p < 0.05$ , and \* denotes  $p < 0.10$ .

TABLE 7: The examination of the mechanism of motorcycle bans' effect.

	(1) $\ln R_{i,t}$	(2) $\ln U_{i,t}$	(3) $ND_{i,t}$	(4) $\ln PL_{i,t}$
<b>Policy<sub>i,t</sub></b>	-0.3916*** (0.0459)	0.1049 (0.1080)	-114.0098** (43.4911)	0.232 (0.2052)
<b><math>\ln R_{i,t}</math></b>			41.7701** (16.2710)	-0.2492 (0.4873)
<b><math>\ln U_{i,t}</math></b>			-35.5779 (30.3635)	-0.3010 (0.3102)
Control variables	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Obs.	165	165	165	137
R-squared	0.9186	0.9176	0.9765	0.689
F	74.63	29.61	.	.

Note. (1) Columns (1)–(4) are the results of equations (4)–(7); (2) the control variables are the same as those in Table 5; (3) all standard errors are clustered at the city level; (4) \*\*\* denotes  $p < 0.01$ , \*\* denotes  $p < 0.05$ , and \* denotes  $p < 0.10$ .

TABLE 8: The effect of policies on traffic accidents in cities with different amounts of motorcycles.

	(1) $ND_{i,t}$	(2) $\ln PL_{i,t}$
<b>Policy<sub>i,t</sub></b>	-0.2590*** (0.0646)	0.1794 (0.2840)
<b>MotorCar<sub>i,t</sub></b>	-0.1784 (0.1141)	0.0336 (0.3610)
<b>MotorCar<sub>i,t</sub> * Policy<sub>i,t</sub></b>	0.3166* (0.1623)	-0.2227 (0.6046)
Control variables	Yes	Yes
Year FE	Yes	Yes
City FE	Yes	Yes
Obs.	176	147
R-squared	0.9801	0.6537
F	.	.

Note. (1) Columns (1) and (2) show the results of equations (7) and (8); (2) the control variables are the same as those in Table 5; (3) all standard errors are clustered at the city level; (4) \*\*\* denotes  $p < 0.01$ , \*\* denotes  $p < 0.05$ , and \* denotes  $p < 0.10$ .

significant at the 1% level and  $Year3_{i,t}$  is significantly negative at the 5% level. However, the coefficient of  $Year1_{i,t}$  is not significant at the year of implementation of motorcycle bans, which maybe because these bans were enacted at the middle of the year, and therefore, the impact on the death number has not been fully reflected. In sum, changes in the death number do not precede the bans, which do have an effect on traffic accidents' deaths.

**5.5.2. Effect at Provincial Level.** To keep the results robust, this study applies the method to the motorcycle bans at the provincial level. However, provinces only put regulations on the provincial freeways, not on the urban roads in prefectural cities. Legally, the “Regulations on the Implementation of the Road Traffic Safety Law of the People’s Republic of China” does not explicitly prohibit motorcycles from driving on expressways, but there are provisions on the speed limit of all locomotives on expressways. In fact, local traffic regulations of some provinces and cities clearly stipulate that motorcycles are prohibited from driving on expressways, and those provinces set up “No Motorcycles Entering” signs at the entrance; however, the provinces with no signs prohibiting motorcycles

at the entrance of expressways allow motorcycles to get on the expressways. Here, this study constructs the policies with the provincial motorcycle bans on freeways, so as to analyze their effect on the traffic accidents. The results listed in Table 9 keep consistent with this study’s main results, i.e., policies do significantly decrease the death number of traffic accidents, while delivering no effect on property losses. And, the duration of the implementation of the motorcycle bans also has a significant negative effect on the death number.

**5.5.3. Adjusting the Sample Range.** As shown in Section 5.3, the sample covers 11 prefecture-level cities in Zhejiang Province from 2002 to 2019. The motorcycle ban in Shaoxing began in 2001, so its policy did not change during the whole sample period. Therefore, two control groups are explored in the previous analysis: (1) 7 prefectural cities which have never implemented motorcycle bans; (2) Shaoxing, where the policy has not changed over the sample period. Here, this study further removes Shaoxing from the sample and limits the control group to the cities that have never implemented motorcycle bans, so as to carry out robustness testing. All results listed in Table 10 keep consistent with Section 5.3;

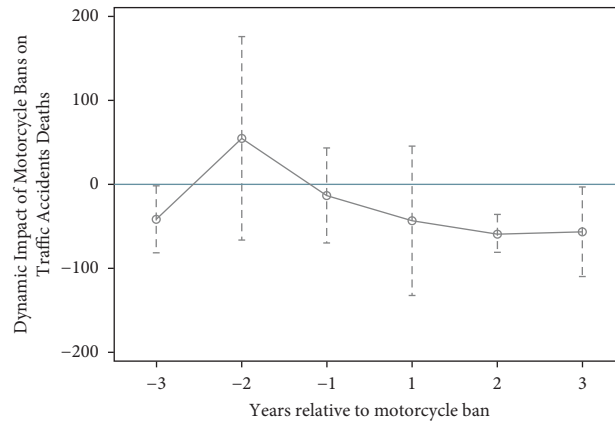


FIGURE 7: The dynamic impact of motorcycle bans on traffic accident deaths.

TABLE 9: The effect of provincial motorcycle bans on freeways on traffic accidents.

	(1) $ND_{i,t}$	(2) $\ln PL_{i,t}$	(3) $ND_{i,t}$	(4) $\ln PL_{i,t}$	(5) $RMotor_{i,t}$	(6) $UMotor_{i,t}$	(7) $ND_{i,t}$	(8) $\ln PL_{i,t}$
<b>Policy<sub>i,t</sub></b>	-716.8821*** (186.9944)	-0.3246*** (0.1151)	-684.8416*** (170.7719)	-0.3205*** (0.1075)	-10.3402*** (2.5857)	1.2193 (1.6112)	-432.5405* (226.2643)	-0.3021*** (0.0666)
<b>Gap<sub>i,t</sub></b>			-86.6197** (38.5853)	-0.0109 (0.0189)				
<b>RMotor<sub>i,t</sub></b>							374.5581* (195.7929)	0.0855 (0.0792)
Obs.	496	496	496	496	279	279	279	279
F	7.625	2.413	13	2.215	45.71	1.857	9.641	20.42

Note. (1) Columns (1)-(2) are the results of equation (2) at the provincial level, columns (3)-(4) are the results of equation (3) at the provincial level, columns (5)-(6) are the results of equations (4) and (5) at the provincial level, and columns (7)-(8) are the corresponding ones of equations (6) and (7); (2) all control variables, year fixed effect, and city fixed effect, are included; (3) all standard errors are clustered at the city level; (4) \*\*\* denotes  $p < 0.01$ , \*\* denotes  $p < 0.05$ , and \* denotes  $p < 0.10$ .

TABLE 10: The regression results of equations (2) and (3) (except for Shaoxing).

	(1) $ND_{i,t}$	(2) $ND_{i,t}$	(3) $ND_{i,t}$	(4) $ND_{i,t}$	(5) $\ln PL_{i,t}$	(6) $\ln PL_{i,t}$	(7) $\ln PL_{i,t}$	(8) $\ln PL_{i,t}$
<b>Policy<sub>i,t</sub></b>	-90.1799** (35.1041)		-144.9302** (48.8175)	-147.8498*** (28.7343)	0.2522 (0.3609)		0.1553 (0.3033)	0.079 (0.2258)
<b>Policy2<sub>i,t</sub></b>		-72.0655 (45.2899)	-6.9643 (50.7945)			-0.1084 (0.1612)	-0.1702 (0.2429)	
<b>Gap<sub>i,t</sub></b>				-20.0872** (7.7929)				-0.1091 (0.0784)
Obs.	161	161	161	161	134	134	134	134
F	.	6797	.	81.55	.	1275	.	14.14

Note. (1) Columns (1) and (5) are the corresponding ones of columns (3) and (6) in Table 5 excluding observations of Shaoxing, and columns (2)-(4) and (6)-(8) are the corresponding ones of Table 6 excluding observations of Shaoxing; (2) all control variables, year fixed effect, and city fixed effect, are included; (3) all standard errors are clustered at the city level; (4) \*\*\* denotes  $p < 0.01$ , \*\* denotes  $p < 0.05$ , and \* denotes  $p < 0.10$ .

motorcycle bans have reduced the deaths of traffic accidents, but not the property loss since the year they were released and the renewal points have no significant effect on traffic safety; as more motorcycles are scrapped mandatorily over time and no new ones are registered, the longer the duration from the implementation of bans, the more they will reduce the deaths of traffic accidents.

### 6. Conclusion

First, the overall effect of motorcycle ban on death numbers is significant negative. And, once the motorcycle ban begins to be implemented, its effect on traffic safety will remain the same during the whole covering period, whether it is renewed in the middle of the period or not. Furthermore,

due to more motorcycles subject to mandatory scrap, the death number will be more reduced for each additional year from the date of implementation, meaning that the ban would enhance its effect over time. This study's results can be referenced by policy makers for achieving the expected goal of their policies more effectively. For instance, if high speeds and poor performance of motorcycles are the main reasons for the high accident rate and fatality rate when they are driven in the same lanes with cars, a more reasonable and effective way to diminish such traffic accidents may be to design a special lane for motorcycles, instead of totally banning them.

Second, it is suggested that the motorcycle ban be capable of affecting traffic safety via two mechanisms: to cut the fatality rate of motorcycle-related accidents and to reduce the number of motorcycles. As revealed from the results, the impact of the dwindled number of motorcycles is more significant, and the role of the former mechanism is delivered mainly through mandatory retirement of the motorcycles with poor performance. Furthermore, the motorcycle ban and the mandatory retirement can complement each other to further suppress traffic accidents. In a word, diversified policies should be formulated to enhance their effectiveness (e.g., different limitations in lifetime and speed for different motorcycles).

### Data Availability

No data were used to support this study.

### Conflicts of Interest

The authors declare that they have no conflicts of interest.

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